LUMAT

General Issue
Vol 8 No 1 (2020)

In-service Zimbabwean teachers' views on the utility value of diagrams in the teaching and learning of geometry

Gladys Sunzuma, Cecilia Chando, Isaac Gwizangwe, Nicholas Zezekwa and Gracious Zinyeka

Bindura University of Science Education, Zimbabwe

Geometry is an essential component of mathematics which promotes the development of critical thinking and problem-solving skills. Geometry shapes are an integral part of our lives. This study focused on the teachers' practices, specifically on how teachers ought to be equipped with a good understanding of the effectiveness of the use of diagrams in geometry teaching and learning. A mixed-method approach comprising of questionnaires and interviews was used in this study. Ninety-one teachers participated in this study. The research findings were categorized using the four themes of utility, positive attitudes, negative attitudes, and teachers' use of diagrams in geometry class. The study showed that diagrams are effective in the teaching and learning of geometry concepts. It is recommended that teachers could do well if they make use of technology in designing diagrams to be used in the teaching and learning of geometry.

Keywords: geometry, diagrams, teaching, learning

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 1–18

Received 18 November 2019
Accepted 19 March 2020
Published 30 March 2020

Pages: 18
References: 44

Correspondence:
gsunzuma@gmail.com

https://doi.org/10.31129/LUMAT.8.1.1316

1 Introduction

Mathematics is one of the most important school subjects in the curriculum worldwide. It is a subject that has a direct relationship with other subjects, particularly in the technical and scientific areas. Mathematics also cuts across primary and secondary schools as a compulsory subject in Zimbabwe. In the Zimbabwean mathematics syllabus (2015- 2022), geometry is one of the major topics which covers almost three-quarters of the syllabus. Geometry is the main branch of mathematics, and its content is classified into four areas (Ndinda, 2016). Firstly, plane geometry is the component that deals with figures in the two-dimensional plane. Secondly, solid geometry focusing on figures in three-dimensional space. Thirdly, spherical geometry that focusses on figures on the surface of the sphere. Lastly, the Euclidean geometry that focusses on plane and solid based on Euclid's postulates and Analytical geometry that focusses on the connection between algebra and geometry, using graphs and equations of lines, curves, and surfaces to develop and prove relationships.

In the Zimbabwean mathematics syllabus (2015–2022), the common topics in geometry are plane geometry, solid geometry, transformation geometry, and analytical geometry. However, it is a challenge to note that with the wide coverage of geometry in the syllabus and the importance attached to it in Zimbabwe's education system, poor performance is recorded in geometry questions in the public examinations, which results in poor performance in mathematics. Since science and mathematics have turned out to be a crucial feature in social progress and national trade and industry, poor attainment in the mathematics subject is likely to impact negatively on scientific research, as well as trade and industry in developing nations such as Zimbabwe (Economic and Social Research Council, 2008). Mathematics and science education is perceived as a means of creating a critical mass of scientists and scientifically knowledgeable citizenry (Sjøberg & Schreiner, 2005) which is considered needed for an improved financial system and emancipation from social ills such as crime and disease, poor quality of life and poverty in general (Zinyeka, 2016).

There could be numerous causes why the majority of candidates who sit for public examinations in Zimbabwe do not achieve well in mathematics in the area of geometry. These reasons may be resulting from several sources. For example, those originating from the learners themselves such as absence of interest, poor language facility, poor motivation, the abstract nature of mathematics, learner worldviews that might be in clash with the ways of knowing in science and mathematics say (Zinyeka, 2016; Abrams, Taylor & Guo, 2013; Aikenhead, Calabrese & Chinn, 2006). Other causes may have to do with teacher factors, such as teachers' lack of effective ways of teaching, poor experience, qualifications and an insufficient knowledge base of teachers, as well as non-educational dynamics such as under-resourced large size classes (Mashingaidze, 2012; Telima, 2011; Chiwiye, 2013). This paper's research interest, however, is to contribute to the advocacy for use and full utilization of diagrams in the teaching and learning of as one way of supporting teachers to improve on learners' performance.

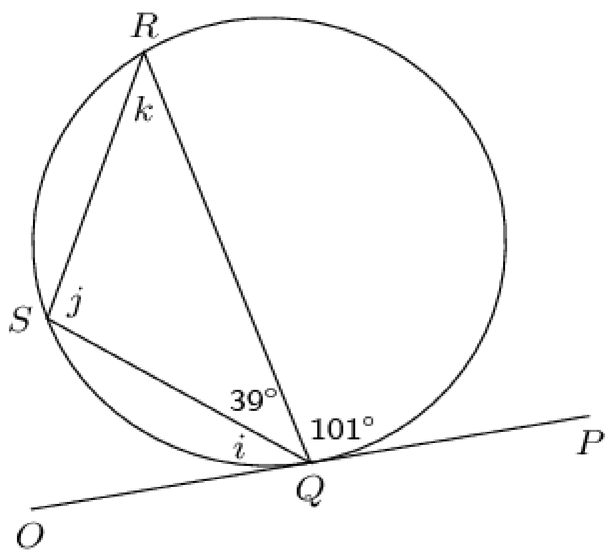
However, researchers have proposed various ways of improving the teaching and learning of geometry such as genetic approaches involving historical, logical and epistemological, psychological and socio-cultural aspects (Safuanov, 2007); ethno-mathematical and humanist approaches that value culture and scientific heritage (Gerdes, 2011); using artwork as an innovative instrument to teach geometry concepts (Pakang & Kongtaln, 2007), as well as the use of diagrams and examples (Zodik & Zaslavsky, 2007). Despite several suggestions by researchers, learners' performance remains poor in geometry. Zodik and Zaslavsky (2007) and Stylianou (2002), cited in Jones (2013) reported on the lack of evidence on the effective utilization of diagrams in the teaching and learning of geometry by teachers. However, the utilization of diagrams by teachers and more fundamentally, their knowledge with regards to the effectiveness of the use of diagrams in the teaching and learning of geometry remains unclear (Jones, 2013). This study focuses on teachers' views on the utility value of diagrams in the teaching and learning of geometry. In particular, the study seeks to address the following research questions and hypothesis:

1. What are the Zimbabwean teachers' views on the utility value of diagrams in the teaching and learning of geometry?
2. Is there a significant difference between rural and urban Zimbabwean teachers' views on the utility value of diagrams in the teaching and learning of geometry?
3. How are Zimbabwean teachers using diagrams to teach geometry?

2 Diagrams in geometry teaching and learning

Geometry continues to play a central role in modern mathematics applications; nonetheless, its concepts have become increasingly diagrammatic. It is one aspect of mathematics education that comprises the largest use of diagrams (Watson, Jones & Pratt, 2013). Purchase (2014, p. 59) defined a diagram as "taken to mean a composite set of marks (visual elements) on a two-dimensional plane that, when taken together, represent a concept or object in the mind of the viewer." Diagrams are 2D geometric figurative exemplification of data according to some visualization method, and at times, the method uses a 3D visualization that might be projected onto the 2D surface. Diagrams are visual illustrations of figures that are used to pass on information.

Gagatsis, Deliyianni, Elia, Monoyiou & Michael (2010) observed that geometry problems call for interaction with diagrams as well as making the use of picturing to identify the figures and their properties. The aptitude to use diagrammatic shapes to deduce appropriate geometry content knowledge in problem-solving is an indication of one's strong competency in geometry (Koedinger & Anderson, 1990). Jones (2001) was also of the view that diagrams contribute to problem-solving skills in geometry. Diagrams improve learners' reasoning skills in geometry (Herbst, 2004). They enhance the development of mathematical processes such as analytical, visual, and logical thinking (Jones, 2001). Diagrams also provide an opportunity for logical thought, critical thinking, elucidation, and explanation for solving geometric problems. In fact, diagrams enhance conceptual understanding and conception of geometry concepts, operations, and relations. For example, students may identify and appreciate the meaning of symbols, words, and relationships with a specific concept and use diagrams to build new geometry knowledge (Novick, 2004). Diagrams are a semiotic method of representation and communication that allows for the construction of geometrical meaning. Diagrams are a mode of communication in geometry. Diagrams play an important role in the construction of knowledge, argumentation, and understanding of geometry. Diagrams are employed as a method to visualize geometry concepts as well as in studying the meaning in geometry (Dimmel & Herbst, 2015). The following is an example of such a diagram that can be used to teach geometry concepts.



Find the angles *i*, *j*, and *k*.

Figure 1. Geometry diagram. Source: ZIMSEC (2016) past examination paper.

There are numerous benefits of using diagrams in the teaching and learning of geometry. Gagatsis et al. (2010) noted that geometrical diagrams are simultaneously concepts and spatial representations of abstract ideas. Diagrams in two-dimensional geometry may illustrate theoretical geometrical properties, or they might offer spatio-graphical properties, which may result in student's perceptual and critical thinking skills and activities if taught well. According to Herbst (2004), an interaction with diagrams creates possible chances of coming up with reasoned conjectures. Jones and Tzekaki (2016) thought that diagrams are tools to create examples that support conjectures; they are used to design and describe the domain and context of the task. Diagrams enable direct manipulations by providing feedback that reflects the process of inquiry. Diagrams bring some variety in clarifications of problems. Such a multiplicity of functions may give students opportunities to take part in fruitful inquiry as well as the aptitude to formulate and solve geometry problems (Butcher & Aleven, 2008). In addition, diagrams help directly in the cognitive process as well as engaging the students, thereby increasing their interest, which can translate into geometrical ability (Butcher & Aleven, 2008). Hence, teachers need to methodically incorporate diagrams in the teaching and learning of geometry so as to develop students' geometrical proficiency and critical thinking.

According to Jones (2013), diagrams are considered to be an essential element of doing and understanding mathematics in general and geometry in particular. Their application is not solely on the nature of geometrical objects, but also to improve the effective problem representation that enables complex geometric process and structures to be represented holistically. Diagrams offer the possibility of altering the approach in geometry teaching from the sequential, lingual to the visual-spatial presentation. All components of the display are presented concurrently, and analysis involves visual reasoning.

Diagrams allow both the teacher and the learner to view the problem in its totality as all parts of the problem are displayed on the diagram at the same time. Diagrams also offer teachers and learners an advantage of moving between diverse observations by viewing the complete diagram or some portions of it, which is crucial in arriving at alternative solutions to a problem. Diagrams are often a good starting point for solving geometry problems (Bishop, 1989; Jones, 2001).

Jones and Tzekaki (2016) noted that diagrams are worth a million in words, and reading from diagrams is helpful for students to understand geometry. In Zimbabwe, as in many other countries, the English language, which is the instructional language used for teaching and examinations, is a second language for both teachers and learners. As a result, in most cases, it is difficult to teach geometry concepts without diagrams. From this point of view, diagrams are useful in representing the information presented in the geometry images in ways that verbal language may not explain fully (O'Halloran, 1999 in Dimmel & Herbst, 2015). Diagrams act as a complementary language to written text and symbolic language of geometry.

One other important benefit of using diagrams in the teaching and learning of geometry is that it enhances conceptual understanding. Conceptual understanding, critical thinking, and effective problem-solving in geometry depend on students' understanding of the shape, size as well as on the properties of various figures (NCTM, 2000). Hence, using diagrams is crucial for effectively setting up as well as solving geometry problems (NCTM, 2000). These diagrams enable students to show and deduce the essential components of geometry problems throughout the problem-solving process (NCTM, 2000). Conceptual understanding is positively correlated with higher achievement in geometry (Bailey, 2013). Diagrams have a significant impact on students' geometry achievement; hence, there is a need to improve their conceptual knowledge through the use of diagrams (Bailey, 2013). Jones and Tzekaki (2016) were of the view that diagrams help in retaining of geometry knowledge and skills. The appropriate use of diagrams in the teaching and learning of geometry supports long-term knowledge retention of problem-solving skills (Butcher & Aleven, 2008). Yelland and Masters (2007) denoted the term cognitive scaffolding to the use of diagrams that helps in the development of conceptual and procedural understandings and encouraging students to work together with their partner. Diagrams support students in understanding the association of abstract concepts, such as transformation and its meaning.

As facilitators of student learning, teachers confess that diagrams are essential tools for solving problems and that diagrams aid in grounding the study of abstract geometric objects in specific realizations that are available to students (Dimmel & Herbst, 2015). Teachers depend on diagrams to communicate properties of order, incidence, and separation (Dimmel & Herbst, 2015) for the reason that an entirely overall treatment of such properties could make the previously challenging work of learning to write proofs even further demanding for students.

Jones (2013) views diagrams in geometry as based on the observation that generalizes facts. Students interact with the diagrams whilst investigating the situations under which the type of geometry problem can be answered (Herbst & Arbor, 2004). Matos and Rodrigues (2011) investigated how the construction of geometric proof related to the social practice developed in the classroom, and, in particular, the role of geometric diagrams. Further, they concluded that diagrams played "an important role in the process of sharing and increasing the ownership of the meaning of proof by highlighting the relevant properties" (p. 183). Diagrams in geometry are an example of a constructivism approach of learning which fosters critical thinking, and students make connections from concrete to abstract. According to Fosnot (1996), diagrams are grounded in the constructivism philosophy, where more emphasis is put on connecting learning content to the real world for the reason that knowledge is developed in the context of the student's surroundings.

Bieda (2011) reported on the aspects of proofs and non-proofs that were convincing to middle-grade students. The analysis found that the students "valued the explanatory power of a valid argument when evaluating a proof for a true geometry statement that provided a diagram" (p. 153). Teachers were of the view that diagrams can improve the teaching and learning of geometry as well as encouraging the students to reflect on the fundamental concept (Puphaiboon & Woodcock, 2005). Konyalioglu, Isik, Kaplan, Hizarci, and Durkaya's (2011) study revealed that the use of diagrams made lessons fascinating, motivating, thereby removing boredom from the learners. In addition, in the same study, most of the learners pointed out that they saw the necessity of visualization, specifically the use of diagrams, whether they were drawn or produced by technology. Üstün and Ubuz (2004) reported that the use of dynamic images improved the learning of geometry concepts. In addition, the same authors found that learners also developed strategies to form links between the geometry shapes and also formed hierarchical‖ connection between the shapes.

Diagrams are essential in geometrical thinking, whether they are produced using technological devices, imagined or drawn on papers, and they capture the utmost essential features of the geometrical problem as well as providing the possible solution (Alcock & Simpson, 2004). Diagrams are an important component of the concrete images and are vital to the cognitive process. According to Puphaiboon and Woodcock (2005), understanding a diagram is a component of the thinking process that joins design formation with the symbol aspects of geometry. Diagrams are synonymous with geometrical thinking and reasoning. Small (2012) states that:

> Diagrams either with or without accompanying words, can be extremely powerful tools for reasoning and explaining; they are powerful not only because they help us understand more quickly, but also because sometimes they lead us to be more general than when we use specific numerical examples. (p. 21)

From this statement, diagrams are likely to make mathematical explanations simpler as well as leading to generalities quickly. Diagrams have the potential of providing students with rapid visual access to the whole system of quantifiable relationships defined in the problem. Hence, the use of diagrams promotes a holistic vision of the problem for students.

The use of diagrams also promotes a deeper, abstract understanding of mathematic concepts (Limin Jao, 2013; Prusak, Hersckowitz & Schwarz, 2012). The benefits of diagrams are ascribed to the process of transforming a mathematics idea from one form into another, where learners are provided with alternative forms of illustrations of the same knowledge. They might turn out to be more motivated to make sense of it (Panasuk & Beyranevand, 2010). In addition, diagrams are useful in transforming word language of geometry concepts, definitions as well as proposition into geometrical symbol language (Ding, Jones & Zhang, 2013).

Despite the numerous benefits of using diagrams in the teaching and learning of geometry, researchers such as Jones and Tzekaki (2016) reported on obstacles on the use of diagrams in geometry both for students and teachers. They noted that in some situations, the diagrams might even distract students from their conceptual or appropriate hypothetical knowledge. Jones, Fujita, and Kunimune (2012) conducted a study involving secondary school students tackling a 3-D geometry problem that used a specific diagram as an image of a cube. The study findings showed that some of the students could "take the cube as an abstract geometrical object and reason about it beyond reference to the representation," while others needed to be offered "alternative representations to help them 'see' the proof" (p. 339). Haj-Yahya and Hershkowitz (2013) carried out a study with the aim of "linking visualization, students' construction of geometrical concepts and their definitions, and students' ability to prove" (p. 409). The study showed that many of the students knew the formal definitions of various shapes but could not use the definitions when given problems that required the use of diagrams. Diagrams provide an instantiation of a definition, not a universal and demanding proof that enables students to concentrate on the figural understanding that results in conceptual understanding (Jones, & Tzekaki, 2016).

If the diagrams are poorly designed, they are not effective in the teaching and learning of mathematics in general and geometry in particular (Jones & Mooney, 2003). Typical problems such as information not being structured to denote vital concepts or stages so as to point out the geometrical concepts involved, as well as the inability of diagrams to support spatial and pictorial reasoning (Jones & Mooney, 2003), makes the use of diagrams ineffective. The use of inappropriate and misleading diagrams may contribute to problems in the teaching and learning of geometry. For instance, if incorrect diagrams are used in the teaching and learning of geometry, they tend to confuse the students who will be struggling to learn new concepts (Puphaiboon & Woodcock, 2005). Superficial and diverted attention to information on diagrams might compromise the ability to solve problems (Butcher & Aleven, 2008). In addition, Leung and Park (2009) found that geometry language and daily language both support and inhibit students' understanding of shapes and their properties since the terms force students to focus on some exceptional features that are not in line with the definition of the shapes.

3 Research Methodology

3.1 Research design

Due to the nature of the problem under study, a mixed research paradigm was adopted, where both qualitative and quantitative research approaches were used. A mixed research paradigm was used in this study because it provides strengths that offset the weakness of both qualitative and quantitative. Mixed approaches also provide a more complete and comprehensive understanding of the research problem than either quantitative or qualitative only (Angell & Townsend, 2011).

3.2 Population and Sample

Ninety-one secondary school mathematics teachers who were attending a one-day in-service teacher training workshop on the use of latex in mathematics education completed the questionnaires before the commensuration of the workshop. The questionnaires were the first data source to gather data on teachers' views on the use of diagrams in the teaching and learning of geometry. The participating teachers were from a different school situated in rural and urban, where some schools are under-resourced whilst others are well-resourced. As a result, the participants and their schools were representatives of the schools in the province under study.

The second source of data consists of interviews with five teachers from different schools. The interviews allowed the teachers to spell out their views on the use of diagrams in the teaching and learning of geometry in secondary schools. One of the courses offered at the university is practicum teaching, which is done in some schools in the province. The five teachers interviewed were those where student teachers visited by the researchers during their appraisal and supervision. Hence, the interviewed teachers might be regarded as purposively selected for the reason that the teacher that was found at an attachment school on a particular day of the visit and that the school that was visited sent a teacher to take part in the workshop in which teachers completed the questionnaires for this study.

3.3 Data collection methods

In this study, data was collected using interviews and questionnaires. The questionnaires that were used to collect data were informed of closed-ended questions with two responses: Agree and disagree. Although it is generally agreed that a large number of response categories in Likert scale items improves the psychometric properties of a scale, a reduced number of response categories may possibly have a positive effect on the validity of gathered data by reducing the number of chances for incorrectly treating different views of response categories as if they were the same (Jones & Scott, 2013). Hence, fewer response categories are adequate, depending on the purpose and scope of the study (Jones & Scott, 2013). The participants were, therefore, asked to respond to the questionnaire with two categories, agree (A) and disagree (DA). Questionnaires were used because a large number of participants can be reached, they are easier to use, and they provide quantifiable answers that are relatively easy to analyse. Questionnaires were self-administered. Interviews helped the researchers to gather data that is detailed and rich to the topic under the study. The interviews were tap-recorded.

The validity and reliability of this research are strengthened by triangulation through using different data sources, for example, interviews and questionnaires. Pilot testing was conducted at a satellite school in the district with 5 participants in order to test suitability, problems, and barriers to the study area and feasibility of research instruments so as to improve the validity and reliability of the instruments used.

3.4 Data analysis

For statistical analysis, the data from the questionnaires were statistically analyzed using SPSS (Statistical Package for Social Sciences, version 20). A non-parametric test such as Mann-Whitney Test (U) was used to further analyse the data. A significance level of $p=0.05$ was used. The interview data were later transcribed in full and were also analysed.

4 Findings and discussion

The results of this study were presented according to the approaches used for data gathering. Results from the questionnaires were presented first, followed by those from interviews.

4.1 Data from questionnaires

Frequencies and percentages of the teachers' responses were arranged in descending order with the aim of determining the popularity of the teachers' responses on each category. Table 1 shows the responses of the teachers' views on the utility value of diagrams in the teaching and learning of geometry, which were categorised as utilitarian value and positive attitude.

Table 1. Teachers' responses on the utility value of diagrams in the teaching and learning geometry (n=91) (A=agree, DA=disagree).

Item	Narration	A	DA
Utilitarian value			
13	Geometry diagrams help students to acquire important information and skills	90 (98.9)	1 (1.1)
5	Diagrams develop students' procedural literacy in solving geometry problems and investigations in geometry	88 (96.7)	3 (3.3)
4	Geometric diagrams enhance the teaching and learning of geometry	86 (94.5)	5 (5.5)
9	Diagrams are used to analyse a problem logically and reach conclusions quickly	85 (93.4)	6 (6.6)
1	Diagrams can be used to help learners perform better in geometry	73 (80.2)	18 (19.7)
11	Geometry diagrams are used to build on already assumed geometry concepts	67 (73.6)	24 (26.4)
Positive attitude			
10	Students constantly connect mathematical ideas when using diagrams	88 (96.7)	3 (3.3)
8	Geometry diagrams usually display a variety of properties and strategies for problem-solving.	87 (95.6)	4 (4.4)
3	Diagrams have a higher impact on retention of geometry concepts	87 (95.6)	4 (4.3)
12	Geometric diagrams attach student s' prior experiences to his /her learning geometry topics	78 (85.7)	13 (14.3)
2	There is a greater achievement for learners who use diagrams in geometry	64 (70.3)	27 (26.9)
6	Diagrams make learners develop a good attitude towards geometry concepts	59 (64.8)	32 (31.2)
14	Geometric diagrams can effectively transfer the challenging work to new understandable situations	56 (61.5)	35 (38.5)
7	There is a relationship between geometry and diagrams	48 (53)	43 (47)

Teachers in this study held positive views about the utilitarian value of diagrams in the teaching and learning of geometry. The response percentages range from 73.6 (Item 11, Table 1) to 98.9 (Item 13, Table 1) for those who agreed. Those positive utilitarian values show how teachers regard the use of diagrams as useful in the teaching and learning of geometry. The views held by those teachers in this study are in line with (Jones, 2013; Jones & Tzekaki, 2016; Dimmel & Herbst, 2015) who were of the view that the integration of diagrams in geometry might be helpful for learners' conceptual understanding as well as improving their performance in geometry. The teachers showed positive opinions on the theme of positive attitudes on the use of diagrams in the teaching and learning of geometry. Their opinions ranged 53% (item 7, Table 1) to 96.7% (item 10, Table 1) for those who agreed and form 3.3% (item 10, Table 1) to 47% (item 7, Table 1) those who disagreed.

The study also sought to find out whether there was a significant difference between rural and urban Zimbabwean teachers' views on the utility value of diagrams in the teaching and learning of geometry. Table 2 displays the Mann-Whitney U test results.

Table 2. Results of Mann-Whitney U test on the utilitarian value of diagrams (n=91)

QSN	Teacher	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	P
Utilitarian value							
	Rural	41	46.61	1911.00	1000.000		
13	Urban	50	45.50	2275.00		-1.104	.269
	Total	91					
	Rural	41	46.72	1915.50	995.500		.447
5	Urban	50	45.41	2270.50		-.761	
	Total	91					
	Rural	41	44.61	1829.00	968.000		.249
4	Urban	50	47.14	2357.00		-1.152	
	Total	91					
	Rural	41	44.11	1808.50	947.500		.150
9	Urban	50	47.55	2377.50		-1.438	
	Total	91					
	Rural	41	49.21	2017.50	893.500		.128
1	Urban	50	43.37	2168.50		-1.520	
	Total	91					
	Rural	41	36.44	1494.00	633.000		.000
11	urban	50	53.84	2692.00		-3.911	
	Total	91					
Positive attitude							
	Rural	41	46.72	1915.50	995.500		.447
10	Urban	50	45.41	2270.50		-.761	
	Total	91					
	Rural	41	44.00	1804.00	943.000		.065
8	Urban	50	47.64	2382.00		-1.842	
	Total	91					
	Rural	41	44.00	1804.00	943.000		.065
3	Urban	50	47.64	2382.00		-1.842	
	Total	91					
12	Rural	41	42.83	1756.00	895.000		.087
	Urban	50	48.60	2430.00		-1.711	
	Total	91					

2	Rural	41	50.26	2060.50	850.500		.079
	Urban	50	42.51	2125.50		-1.759	
	Total	91					
6	Rural	41	53.30	2185.50	725.500		.004
	Urban	50	40.01	2000.50		-2.888	
	Total	91					
14	Rural	41	45.15	1851.00	990.000		.740
	Urban	50	46.70	2335.00		-.331	
	Total	91					
7	Rural	41	46.70	1914.50	996.500		.793
	Urban	50	45.43	2271.50		-.263	
	Total	91					

An examination of the results from the Mann-Whitney U test showed that rural and urban teachers' views on the utilitarian values diagrams in the teaching and learning of geometry on questions 13, 5, 4, 9, and 1 there was no significant difference. However, on question 11 the results showed that there was a significant difference (z=-3.911; p=.00 <0.05) on rural and urban teachers' views on teachers' views on the utilitarian values diagrams in the teaching and learning of geometry. The mean rank of rural was 36,44, while the urban teachers had a mean rank of 53.84, which indicates that the urban teachers had higher scores than the rural teachers implying that rural and urban teachers' views were different. Similarly, the results from the Mann-Whitney U test showed that rural and urban teachers' views on positive attitude towards the use of diagrams in the teaching and learning of geometry on question 10, 8, 3, 12, 2, 14 and 7 there was no significant difference. However, on question 6 the results showed that there was a significant difference (z=-2.888; p=.004<0.05) on rural and urban teachers' views on positive attitude towards the use of diagrams in the teaching and learning of geometry. The mean rank of rural was 53.30, while the urban teachers had a mean rank of 40.01, which indicates that the rural teachers had higher scores than the urban teachers implying that rural and urban teachers' views were different. With respect to questions 13, 5, 4, 9, 1, 10, 8, 3, 12, 2, 14 and 7, it can be concluded that there was no significant difference on rural and urban teachers' views on both utilitarian value and positive attitudes towards the use of diagrams in the teaching and learning of geometry.

4.2 Responses from interviews

The interview was guided by the following question; what are your views on the use of diagrams in geometry teaching and learning? In general, from this interview question, the teachers conveyed both positive views and negative views on the use of diagrams in the teaching and learning of geometry. The teachers held views such as diagrams that are easy to use for code-switching and for assessing students' understanding of geometry concepts and problem-solving skills. These views are exemplified by the following quotations:

> Diagrams convey meaning to geometry concepts; in other words, it helps in code-switching, although some of the students have difficulties in the English language used to teach geometry concepts. I mostly use geometric diagrams when assessing students whether they understand concepts and problem solving. T 1

> Geometric diagrams enable learners to notice geometrical properties, verifying logical deductions, representing ideas, and suggesting proofs. T 2

> Geometric diagrams illustrate a definition of a statement, making it easy for learners to draw conclusions and solve problems for geometry. T 3

> Diagrams in geometry are an aid to proof without words, where diagrams are drawn to illustrate what needs to be proved, and it is a learner-centered approach which makes learners active and problem solvers. T 4

> Diagrams are useful because they enable difficult geometric concepts and their processes to be arranged and represented comprehensively, making it easier for students to find solutions to a particular problem. T 5

Generally, the teachers held positive views about the use of diagrams in the teaching and learning of geometry. Diagrams are useful in assessing the students' understanding of geometry concepts as well as helping them with geometry proofs. The positive effect of diagrams on geometry proofs was also highlighted by Bieda (2011). The diagrams make it easier to examine the pertinent information and to notice connections and dependencies in a given problem.

Diagrams, if properly used, they make both teachers and learners actively involved during the teaching and learning process. Active learning is one of the key components learner-centered approaches that are advocated for by social constructivists such as Vygotsky (1978). The use of diagrams in illustrating definitions in geometry is in line with Ding, Jones & Zhang's (2013) 's word-symbol strategy in which definitions are translated into geometrical symbol language with diagrams that enhance students' understanding of geometry definitions.

However, the same teachers expressed negative views on the use of diagrams in the teaching and learning of geometry. Their negative views are exemplified by the following quotations:

> Geometric diagrams may result in students jumping into conclusions ignoring important information. T 1
>
> Students may rush through a problem and fail to read instructions and given information carefully when using diagrams in geometry. T 2
>
> If the diagrams are not well designed, students may not fully understand the problem that is required to be solved, and misrepresentation of geometry diagrams makes students not to notice the properties of the diagram. Some of the students may treat unnecessary data in the geometric diagram as important, resulting in failing to solve problems. T 4

The responses revealed that when using geometry diagrams to solve problems, students may jump to conclusions ignoring important information. This is in line with Butcher & Aleven (2008), who noted that if unfocussed attention compromised the performance of learners. One of the mathematics teachers at this school noted that if the diagram in geometry is misrepresented, the user may not be able to notice the properties of the diagram, which can make the user unable to solve problems in geometry, as noted by Jones & Mooney (2003).

The following question on the interview guide was on how the teachers use the diagrams in the teaching and learning of geometry. The findings showed that teachers' use of diagrams in the teaching of geometry was informed by social constructivist theories that encourage the use of the students' prior knowledge and their cultural environments. Their views are illustrated by the following quotations:

> I make use of mapping the relevant diagram features and properties to connect their prior knowledge. T 1
>
> I start from concrete to abstract, for example, using real-world situations like using where trees branches it gives angles, then use diagrams to represent angles. Geometry topics need field learning in order to connect learner's prior knowledge and diagrams. T 2
>
> I make use of the basic properties of the geometric diagram in order to connect the student's foregoing knowledge and diagrams in geometry. T 3.
>
> I normally use learners' everyday life materials and connect to geometry diagrams, for example, using an orange to represent a diagram of a circle, then cut an orange to get sectors of circles then draw to geometric diagrams. T 5

Most of the geometry teachers under this study have the same idea on how they connect geometry teaching and learning using diagrams to their prior knowledge. They start from concrete to abstract, simple to complex, known to unknown, which is a component of the learner-centered approaches. Those teachers connect prior knowledge of students to geometric diagrams, which enable problem-solving in geometry concepts. Those teachers' views of connecting geometry teaching and learning using diagrams are in line with Fosnot (1996), who was of the view that diagrams are rooted in the philosophy of constructivism as they connect geometry to the real world.

5 Conclusion

The results of this study showed that the participants regarded diagrams as useful in the teaching and learning of geometry concepts. Diagrams are important in the teaching and learning of geometry and can be connected to learners' prior knowledge in solving geometry problems. Geometric diagrams can help students acquire important information and critical thinking skills. Diagrams usually display a variety of properties and strategies for problem-solving. However, it was also reported that diagrams could be misleading, resulting in completely wrong solutions. It is recommended that teachers should make use of technology in designing diagrams that can be used in the teaching and learning of geometry. Further research should be carried out on a more extensive scale, including other districts in Zimbabwe, to find the effectiveness of using diagrams in the teaching and learning of geometry concepts and other areas of mathematics.

References

Abrams, E., Taylor, P.C. & Guo, C.J. (2013). Contextualizing culturally relevant science and mathematics teaching for indigenous learning. *International Journal of Science and Mathematics Education, 11,* 1–21.

Aikenhead, G., Calabrese, A. B. & Chinn, P. (2006). Towards a politics of place-based science education. *Cultural Studies of Science Education, 1*(2), 403–416.

Alcock, L., & Simpson, A. (2004). Convergence of sequences and series: Interactions between visual reasoning and the learner's beliefs about their own role. *Educational Studies in Mathematics, 57*(1), 1–32.

Bailey, M (2013). The Direct and Indirect Paths Impacting Geometry Student Achievement" (2013). *Dissertations, Theses and Capstone Projects*. Paper 587.

Bieda, K. N. (2011). Middle grades students' emerging beliefs about argumentation. *Proceedings of PME 35(2)*, 153–160.

Butcher, K. R. & Aleven, V. (2008). Diagram interaction during intelligent tutoring in geometry: support for knowledge retention and deep understanding. In: Love, B.C., McRae, K., Sloutsky, V.M. (eds.) *Proceedings of the 30th Annual Conference of the Cognitive Science Society*, pp. 1736–1741. Cognitive Science Society, Austin.

Chiwiye, T. (2013). Assessment of mathematics and science subjects in Zimbabwe: ZIMSEC Perspective, ZIMSEC.

Dimmel, J. K & Herbst. P. G. (2015). The Semiotic Structure of Geometry Diagrams: How Textbook Diagrams Convey Meaning. *Journal for Research in Mathematics Education, 46*(2), 147–195.

Ding, L., Jones, K, & Zhang, D. (2013). Teaching geometrical theorems in Grade 8 using the 'Shen Tou' method: a case study in Shanghai. In L. Fan et al. (Eds), *How Chinese Teach Mathematics*. Singapore: World Scientific.

Economic and Social Research Council (2008). Strategic Advisor for the undergraduate teaching quantitative methods (tender document). Swindon: ESRC.

Fosnot, C. (1996). Constructivism: A psychological theory of learning. In Fosnot (Ed), *Constructivism: Theory, perspectives and practice*. New York: Teachers College Press.

Gagatsis, A., Monoyiou, A, Deliyianni, E., Elia, I., Michael, P., Kalogirou, P., Panaoura, A. & Philippou, A. (2010). One Way of Assessing the Understanding of A Geometrical Figure. *Acta Didactica Universitatis Comenianae Mathematics*, *10*, 35–50.

Gerdes, P. (2011). African Basketry: Interweaving Art and Mathematics in Mozambique. In *Bridges Coimbra Mathematics, Music, Art, Architecture, Culture Conference Proceedings* (pp. 9–16).

Haj-Yahya, A., & Hershkowitz, R. (2013). When visual and verbal representations meet the case of geometrical figures. *Proceedings of PME 37(2)*, 409–416.

Herbst, P. (2004). Interactions with diagrams and the making of reasoned conjectures in geometry. *ZDM*, 36(5), 129–139.

Herbst, P., & Arbor, A. (2004). Interactions with diagrams and the making of reasoned conjectures in geometry. *ZDM*, *36*(5), 129–139.

Jones, K. and Mooney, C. (2003). *Making Space for Geometry in Primary Mathematics,* Open University Press, London.

Jones, K. (2013). Diagrams in the teaching and learning of geometry: some results and ideas for future research. *Proceedings of the British Society for Research into Learning Mathematics, 33*(2), 37–42.

Jones, W.P. & Scott, A.L. (2013). Optimal number of questionnaire response categories: More may not be better". *SAGE Open, 3*(2), 1–10.

Jones, K., & Tzekaki, M. (2016). Research on the teaching and learning of geometry. In A. Gutiérrez, G. Leder & P. Boero (Eds.), *The Second Handbook of Research on the Psychology of Mathematics Education: The Journey Continues* (pp. 109-149). Rotterdam: Sense. The published version is available at: http://dx.doi.org/10.1007/978-94-6300-561-6_

Jones, K. (2001). Spatial thinking and visualization. In K. Jones (Ed.). *Teaching and Learning Geometry* (pp. 55-56). London GB: Royal Society.

Jones, K., Fujita, T., & Kunimune, S. (2012). Representations and reasoning in 3-D geometry in lower secondary school. *Proceedings of PME 36*(2), 339–346.

Leung, F., & Park, K. (2009). The influence of language on the conception of geometric figures. *Proceedings of PME 33(1)*, 418.

Konyalioglu, A. C., Isik, A., Kaplan, A., Hizarci, S., & Durkaya, M. (2011). Visualization approach in teaching process of linear algebra. *Procedia-Social and Behavioral Sciences, 15*, 4040–4044.

Koedinger, K. R., & Anderson, J. R. (1990). Abstract planning and perceptual chunks: Elements of expertise in geometry. *Cognitive Science, 14*(4), 511–550. https://doi.org/10.1207/s15516709cog1404_2

Mashingaidze, S. (2012). The Teaching of Geometric (Isometric) Transformations at Secondary School Level: What Approach to Use and Why? *Asian Social Science, 8* (15), 197–210. https://doi.org/10.5539/ass.v8n15p197

Matos, J. F., & Rodrigues, M. (2011). Proof in classroom social practice. *Proceedings of PME 35(3),* 177–184.

National Council of Teachers of Mathematics. (2000). Principles and standards for school mathematics. Reston, VA: Author.

Ndinda, M. D (2016). An analysis of the factors influencing achievement in mathematics geometry among secondary school students in Makadara Sub-County, Nairobi County. http://ir-library.ku.ac.ke/handle/123456789/15293

Novick, L. R. (2004). Diagram literacy in preservice math teachers, computer science majors, and typical undergraduates: The case of matrices, networks, and hierarchies. *Mathematical thinking and learning, 6*(3), 307–342.

Pakang, J., & Kongtaln, P. (2007). Creative thinking and mathematics learning about circle of ninth-grade students through art work. *Proceedings of PME 31*(1), 271.

Prusak, N., Hershkowitz, R., & Schwarz, B. B. (2012). From Visual Reasoning to Logical Necessity through Argumentative Design. *Educational Studies in Mathematics, 79*(1), 19–40.

Puphaiboon, K., & Woodcock, A. (2005). Diagram design method to enhance mathematical learning. In Contemporary Ergonomics 2005. *Proceedings of the International Conference on Contemporary Ergonomics (CE2005).* Hatfield, UK: Taylor & Francis.

Purchase, H. (2014). Twelve years of diagrams research. Journal of Visual Languages & Computing, 25(2), 57–75. https:doi.org/10.1016/j.jvlc.2013.11.004

Safuanov, I. S. (2007). Genetic approach to teaching geometry. *Proceedings of PME, 3*(4), 145–152.

Sjøberg, S., & Schreiner, C. (2005). How do learners in different cultures relate to science and technology? *Asia-Pacific Forum on Science Learning and Teaching*, *6*(2), 1–16.

Small, M. (2012). Visual reasoning K-12. *Ontario Mathematics Gazette, 51*(1), 21–24.

Telima, A. (2011). Problems of teaching and learning geometry in secondary schools in Rivers State, Nigeria. *International Journal of Emerging Science*, *1*(2), 143–152. http://hdl.handle.net/1893/26189

Üstün, I., & Ubuz, B. (2004). *Student's development of geometrical concepts through a dynamic learning environment*. Paper presented at the The 10th International Congress on Mathematics Education. http://www.icme-10.dk/index.html

Watson, A., Jones, K., & Pratt, D. (2013). *Key ideas in teaching mathematics: Research-based guidance for ages 9–19*. Oxford, UK: Oxford University Press.

Yelland, N & Masters, J. (2007). Rethinking scaffolding in the information age, *Computers & Education 48*, (2007), 362–382

Zodik, I. & Zaslavsky, O. (2007). Is visual example in geometry always helpful? In Woo, J. H., Lew, H. C., Park, K. S. & Seo, D. Y. (Eds.). *Proceedings of the 31st Conference of the International Group for the Psychology of Mathematics Education, 4, 265–272.*

Zimbabwe Ministry of Primary and Secondary Education New Curriculum Framework (2016). *2015–2022 Handbook*. Harare. Government Printers.

Zinyeka, G. (2016). The epistemological basis of indigenous knowledge systems in science education. University of Pretoria. URI: http://hdl.handle.net/2263/52979

Understanding of learning styles and teaching strategies towards improving the teaching and learning of mathematics

Jose M. Cardino Jr.[1] and Ruth A. Ortega-Dela Cruz[2]

[1] Department of Education, Division of Los Baños, Laguna, Philippines
[2] University of the Philippines Los Baños, Laguna, Philippines

This study was conducted to analyse the influence of learning styles and teaching strategies on academic performance in mathematics. Surveys were conducted to 277 randomly selected grade 9 students and five purposively sample mathematics teachers. Findings reveal that most of the student-respondents have a combination of dependent, collaborative and independent learning styles. Multiple regression analysis indicates that among the learning styles, only the independent style has a significant influence on the academic performance of grade 9 students. Four teaching strategies including cooperative learning, deductive approach, inductive approach, and integrative approach, were found to have a significant influence on academic performance. By understanding the learning styles of students, teachers will be guided in designing different strategies to help students enhance learning for their improved performance in mathematics.

Keywords: learning styles, mathematics, performance, secondary, teaching strategies

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 19–43

Received 10 February 2020
Accepted 4 May 2020
Published 25 May 2020

Pages: 25
References: 47

Correspondence:
raortegadelacruz@up.edu.ph

https://doi.org/10.31129/LUMAT.8.1.1348

1 Introduction

Mathematics plays a predominant role in everyday life. Learning mathematics helps students think analytically and have better reasoning abilities. It helps them develop their lifelong learning skills to solve problems in life. Academically speaking, mathematics is a subject that many students either love or hate. It is hated by learners who do not find figures interesting, especially those students who are more into social sciences (Prayoga & Abraham, 2017). Most students perceive mathematics subjects negatively (Zakaria, Solfitri, Daud & Abidin, 2013; Fonseca, 2007). Because of the formula and rules involved in a mathematics lesson, students tend to develop negative attitudes and concern towards the subject (Altintas & Ilgün, 2017). Many students struggle with learning mathematics at some point. For this reason, they have to experiment with different learning styles in learning mathematics. The learning styles of the students define how they respond to stimuli in the context of learning.

According to Keefe (1979 in Ariola, 2012), "learning style is the composite of characteristics of cognitive, affective and psychological factors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment." According to Stewart and Felicetti (1992), learning is influenced by the educational conditions under which a student learns. Therefore, learning style is not just concerned about what students need to learn but rather how they want to learn in the most effective way.

One of the most significant challenges in learning is for individuals to take responsibility for their own learning. When learners take responsibility for their own learning, they attribute meaning to the process of learning, leading to effective learning (Nzesei, 2015). Teachers need to understand the process of individual learning. In the learning process, individuals are interacting with the environment, i.e., uniquely processing the information and requiring a unique environment for learning. Thus, addressing the challenge in facilitating learning conditions while organizing such interactions should be taken into consideration to help individuals to optimize their learning (Sighn, 2017).

To bring a fundamental change in the learner is the primary purpose of teaching at any level of education (Tebabal & Kahssay, 2011). Teachers should apply appropriate teaching strategies that best suit specific objectives and competencies to secure and facilitate the process of knowledge transmission.

In the past decades, many educators widely applied teacher-centred strategies to impart knowledge to learners' comparative to student-centred strategies. Until today, questions about the effectiveness of teaching strategies on student learning have consistently raised considerable interest in the thematic field of educational research (Hightower, Delgado, Lloyd, Wittenstein, Sellers & Swanson, 2011). Moreover, researches on teaching and learning constantly endeavour to examine the extent to which different teaching strategies enhance growth in student learning.

Effective teaching requires flexibility, creativity, and responsibility in order to provide an instructional environment able to respond to the learner's individual needs. Tomlinson (2001 in Tulbure, 2012) puts it beyond the experiential evidence that pervasive uniformity in teaching fails many learners. There is a reason in both theory and research to support a movement towards an instruction attentive to students' variance manifested in at least three areas: the student's readiness, interest, and learning profile. Nowadays, one of the challenges in teaching-learning process is knowing the most effective teaching approach and strategies that are also in line with the learning styles of the students. Recent researches indicate the following teaching strategies are common and effective in teaching mathematics: cooperative learning (Javed, Saif & Kundi, 2013), lecture type, deductive approach (Baig, 2015), inductive approach (Atta, Ayaz & Nawaz, 2015; Padmavathy & Mareesh, 2013), demonstrative approach (Ramadhan & Surya, 2017), repetitive exercises (Warthen, 2017), and integrative approach (Panicker, 2014).

Aside from learning styles and teaching strategies, academic achievement is also considered as the centre of interest in educational research. Studying the issue of achievement has extended beyond simple to complex issues of intelligence and prior academic achievement into how learners interact with the learning material and teaching strategies.

This issue on academic achievement is particularly true in the case of the Philippine basic education, as reflected in the overall performance of the high school students. Results of the National Achievement Test (NAT) among public high schools all over the country had been declining since 2010 (Valdez, 2016). NAT is just one of the country's criteria for measuring students' academic achievement in mathematics. The Philippine NAT results provide continuous documentation of the need to put greater emphasis on improving the teaching and learning of mathematics in the country. The question is: what more must be done and taken into greater account to be able to improve the academic performance of high school students in mathematics?

This study sought answers to this major concern. The researchers believe that by understanding the influence of learning styles and teaching strategies, educators will find effective ways to improve academic performance in mathematics. This also tried to fill in the gap in terms of the researches that look closely into the contribution of these key variables on the students' performance in mathematics.

The study presented in this paper specifically (i) determined the profile of the students in terms of sex, the average grade in mathematics and learning styles (ii) determined teaching strategies applied by the teachers in teaching mathematics; and (iii) analysed the influence of learning styles and teaching strategies on the academic performance in mathematics.

1.1 Theoretical framework

According to Samadi (2011), studies about the learning styles started in the 1950s and in the early 1960s due to interest in the effect of the individual differences in the learning process. One of the famous learning styles models is Grasha-Riechmann Learning Styles Model. This model integrates individual teaching and learning styles and demonstrates how the stylistic qualities of teachers and students can enhance the nature and quality of the learning experience (Grasha, 1996). It is based on the notion that to maximize learning; one must truly understand individual learning styles. To do this, differences in student attitudes must be taken into account. Grasha (1996) identified six distinct learning styles based on the individual student's attitude towards learning. These proposed six styles can be changed by the consistent use of one teaching method. Grasha also proposed that students naturally select the most productive style. Avoidant students tend to be at the lower end of the grade distribution. They tend to have high absenteeism, they organize their work poorly, and they take little responsibility for their learning. Participative students are characterized by their willingness to accept responsibility for self-learning and relate well to their peers. Competitive students are described as suspicious of their peers leading to competition for rewards and recognition. Collaborative students enjoy working harmoniously with their peers. Dependent students typically become frustrated when facing new challenges not directly addressed in the classroom. Independent students prefer to work alone and require little direction from the teacher.

However, Grasha and Hicks (2000 in Shaari, Yusoff, Ghazali, Osman & Dzahir, 2014) argue that to ensure the effectiveness of a teaching and learning process, teaching strategies also need to be considered as an important element in the success of a lesson. These teaching strategies are the pattern of belief, knowledge, performance, and behavior of teachers when they are teaching (Grasha, 1996).

According to Hamzeh (2014), there are several teaching strategies that can be used by teachers to improve the academic performance of the students in mathematics. Those teaching strategies are accounted for in different time periods and applied inside the classroom. The most common one is **lecture type**. It is an instructional method where the teacher who possesses the knowledge on a given topic delivers all relevant information to students verbally. The person presenting the lecture was called a reader because the information in the book was read to students who would then copy the information all down (Goffe & Kauper, 2014). **Cooperative learning** is a simple strategy that allows students to work and solve a problem with a pair or a group (Razak, 2016). When a teacher has provided the basic instruction, s/he will then split the class into pairs or groups to work on problems (Chan & Idris, 2017). Since the pairs are working as a team, the students can discuss the problems and work together to solve them. The goal of cooperative learning is to teach students critical thinking skills that are necessary for future math problems and real life (Sari, Mulyono, & Asih, 2019; Zakaria, Solfitri, Daud & Abidin, 2013). A simple strategy teacher can use to improve math skills is **repetition or repetitive exercise**. By repeating and reviewing previous formulas, lessons, and information, students are better able to comprehend concepts at a faster rate (Bates, 2020). According to Wilson (1999), the core concepts of basic math must be mastered before students are able to move into a more advanced study. Repetition is a simple tool that makes it easier for students to master concepts without wasting time. A strategy which connects other subject matter in other subject area is called **integrative approach**. This is another way of organizing those learnings that came from another subject area and making an instructional design be interesting and integrative (Panicker, 2014). In this strategy, all the factors that can contribute to the teaching-learning process are considered (Adunola, 2011). Demonstration method of teaching is another form of traditional classroom strategy that requires step by step process of solving math problems (Ramadhan & Surya, 2017). It focuses on achieving psychomotor and cognitive objectives. Another approach that teaches the students to learn how to learn rather than what to learn is induction. This is an effective approach for helping students to understand concepts and generalizations and for developing their higher-order-thinking skills (Rahmah, 2017). The inductive approach is a much more student-centred approach that makes use of a strategy known as 'noticing.' Here, various facts and examples are presented to the learners from where they have to find out rules or establish a general formula. Therefore, it is a method of constructing a formula with the help of an adequate number of concrete examples (Singh & Yadav, 2017). Meanwhile, the **deductive approach** is the opposite of the inductive approach, where the teacher conducts lessons by introducing and explaining concepts to students and then expecting students to complete tasks to practice the concepts. In this approach, all the general ideas or information are given to the students and the specific ideas or information are discussed later (Singh & Yadav, 2017; Adunola, 2011).

The researchers used the Grasha-Riechmann Learning Styles Model because it is an approach that focuses on how personal attributes (e.g., belief, knowledge, performance, behavior and even motivation) influence strategies, approaches and concepts associated with effective teaching and learning (Coffield, Moseley, Hall & Ecclestone, 2004). The model has been studied and has been found practical across a variety of educational settings. For instance, using Grasha-Riechmann Learning Styles Model, Azarkhordad and Mehdinezhad (2016) found that teaching methods based on cooperation could create opportunities to achieve educational goals and provide access to higher mental activity. Thus, they concluded that by strengthening cooperative and participative learning styles, teachers could improve levels of student learning. Ford, Robinson, and Wise (2016) adapted the Grasha-Riechman Student Learning Style Survey and Teaching Style Inventory to assess individual teaching and learning styles in a quality improvement collaborative. They found that individual learners and coaches utilize multiple approaches in the teaching and practice-based learning of quality improvement (QI) processes. They suggested that to improve the organizational processes and outcomes, efforts to accommodate learning styles need to be taken into consideration. Baneshi, Tezerjani, and Mokhtarpour (2014) investigated the psychometric properties of the Grasha-Riechmann Student Learning Styles Scale and found that the Participative Styles Scale to be an instrument qualifying validity and reliability for measuring interactive learning styles. Baneshi, Karamdoust, and Hakimzadeh (2013) investigated the male and female students' learning styles of classroom participation and these styles' differences between Humanities and Science majors. They concluded that female students tend to collaborate with other students of the same sex and participate in their activities. In terms of their major, science students are more participative and collaborative than humanities students because they need more collaboration in their projects and course work. Gujjar and Tabassum (2011) used the Grasha-Riechmann learning style survey to determine the learning styles of student teachers at the Federal College of Education in order to develop teaching strategies in them. Their findings showed a significant difference in all the dimensions of learning styles among the classes and that dependent learning style was found to be the best learning style for the student-teachers.

2 Materials and methods

2.1 Research design

The descriptive-correlational research design was used in the study. Descriptive research simply describes the characteristics and/or behaviour of the sample population. (Dudovskiy, 2016).

2.2 Subjects of the study

The subjects of the study were composed of a randomly selected sample of 277 Grade 9 students in a public high school in Laguna, Philippines. They were drawn from a population of 910 regular students from 18 classes with varied types of students. The study employed proportional allocation of student-respondents using the fishbowl method to get the representatives from each class.

For the selection of teachers, purposive sampling was done since there were only five Grade 9 mathematics teachers who handled the 277 students for the School Year (S.Y.) 2017- 2018.

2.3 Instrumentation

The data utilized for the study were the survey scores of Grasha-Riechmann Learning Styles Scales (GRLSS) (1996). The reliability coefficient numbers of the 6 sub-dimensions pointed in the theory of the inventory was found to be medium and the validity coefficient numbers of the 6 learning styles mentioned in the inventory were found to be good (Grasha,1996). The Teaching Strategies Questionnaire was adapted in the study of Hamzeh (2014). The adapted teaching strategies survey tool was undergone with a test of validity and a test of reliability. For the test of validity, the tool was presented to the five (5) faculty members of Education Sciences College, Jordan. The researcher conducted a test of reliability with a test-retest and Cronbach-Alpha method, and the result got a total degree (0.89) with a reliability factor of 'good.' Moreover, the researchers conducted a similar test of reliability and got the same result. Cronbach's Alpha for the total scale was obtained as 83 percent while its subscales were obtained from 45 percent to 73 percent. The GRLSS is a pre-designed 60-item questionnaire, each with a 1 to 5-point Likert Scale, which is as follows: 1 – strongly disagree, 2 – disagree, 3 – moderately agree, 4 – agree and 5 – strongly agree. While in teaching strategies, there are 49 situations that were evaluated according to the 1 to 5-point Likert scale as follows: 1 – Never, 2 – Seldom, 3 – Sometimes, 4 – often and 5 – always (see Appendix 1).

Looking at the GRLSS and teaching strategies, it can be seen that each style or strategy is described by different characteristics. Based on the description, the questions and situations in both survey tools were manually grouped according to learning style and teaching strategies. For learning styles, the Avoidant is related to items 2, 8, 14, 20, 26, 32, 38, 44, 50, 56; the Collaborative is under 3, 9,15, 16, 22, 28, 34, 40, 46, 52, 58; Competitive can be seen on 5, 11, 17, 23, 29, 35, 41, 47, 53, 59; Dependent assigned to numbers 4, 10, 16, 22, 28, 34, 40, 46, 52 , 58; next to it is Independent in numbers 1, 7, 13, 19, 25, 31, 37, 43, 49, 55; and lastly Participant is reflected in numbers 6, 12, 18, 24, 30, 36, 42, 48, 54, 60. The Teaching Strategies Questionnaire has corresponding situations for each strategy. These are as follow:

Cooperative learning assigned numbers include 16, 21, 29, 37, 38, 39, 43; Demonstration includes 4, 11, 19, 27, 28, 35, 49; Deductive approach includes 5, 12, 14, 18, 26, 34, 36; Inductive approach includes 1, 7, 13, 17, 20, 42, 48; Integrative approach includes 2, 8, 10, 23, 30, 33, 41; Lecture type includes 3, 22, 25, 32, 40, 44, 46 and lastly those remaining statements are for Repetitive exercise including 6, 9, 15, 24, 31, 45, 47.

On the other hand, the scoring key was provided where the ratings assigned for each test item were indicated. The sum of each learning style statements and strategy statements determined the learning style of the students and teaching strategies applied by their teachers.

2.4 Data collection

The items of the questionnaires assessed students' and teachers' profiles, learning styles, and teaching strategies. After seeking permission, the researcher personally administered the questionnaires in a paper-and-pencil format. The survey administration was done after the classes. Two sets of survey questionnaires were adapted. The first set was a five-point Likert scale that determined the learning styles of the students. While the other set of survey-questionnaire was used to identify the teaching strategies applied by their teachers. In addition to primary data, secondary data such as the students' final grades in mathematics for the S.Y. 2017-2018 were requested from their respective teachers.

2.5 Data analysis

Descriptive statistics such as means, frequencies, and percentages were used to describe the basic features of data in the study. The students' grades in mathematics were analysed following the descriptors prescribed by the Philippine Department of Education (DepEd) (Table 1).

Table 1. Descriptors, grading scale and remarks

Descriptor	Grading Scale	Remark
Outstanding	90-100	Passed
Very Satisfactory	85-89	Passed
Satisfactory	80-84	Passed
Fairly Satisfactory	75-79	Passed
Did Not Meet Expectations	Below 75	Failed

Source: 2019 DepEd K to 12 Grading System. Retrieved, 3 April 2020, from https://www.teacherph.com/deped-grading-system.

Inferential analysis, such as the multiple linear regression was used to determine the influence of learning style and teaching strategies on academic performance. It specifically determines which among the learning styles and teaching strategies significantly influence the academic performance of Grade 9 students. Multiple linear regression (MLR) is the most common form of linear regression analysis. As a predictive analysis, the multiple linear regression is used to explain the influence between one continuous dependent variable and two or more independent variables (Kenton, 2019). The independent variables were categorical with dummy codes. In the study, the dependent variable was the average or final grade of the student respondents for the S.Y. 2017-2018, while the independent variables were learning styles and teaching strategies. In MLR analysis, the values of the intercept indicate the grade that a student will get if the learning styles and teaching strategies are zero or not available while the value of the slope determines the change in the value of the student academic performance for every change in the value of learning styles and teaching strategies.

3 Results and discussion

3.1 Profile of the student respondents

The students were composed of 133 (48 percent) male and 144 (52 percent) female. The majority or 95 percent of them were between 13-16 years old. Their average age is 15 (SD=0.89). In terms of their average or final grade in mathematics for the S.Y. 2017-2018, out of 277 student-respondents, 141 (51 percent) have the grade of 80 and below, 76 (27 percent) were in between 81-86 and those who have a grade of 87-92 are 53 (19 percent). Meanwhile, only 7 of them have a grade ranging 93 and above. This indicates that the majority of the student-respondents were performing between satisfactory and fairly satisfactory in mathematics.

3.2 Learning styles of student respondents

Table 2 shows that most of the student-respondents have a combination of dependent, collaborative, and participant learning styles. According to Samadi (2011), they are the students who enjoy working harmoniously with their peers. Meanwhile, 17 percent of the students have independent learning styles. Such students are more likely to prefer working alone (Fenrich, 2014).

Table 2. Students' learning styles

Students' Learning Styles	f	%
Dependent	83	30
Collaborative	64	23
Independent	48	17
Participant	45	16
Competitive	24	9
Avoidant	13	5
Total	277	100

3.3 Teaching strategies observed by student respondents to their teachers

With regard to teaching strategies, most of the student-respondents agreed that demonstration and cooperative learning were commonly applied teaching strategies by their mathematics teachers (Table 3). Which is true, in teaching math subject there must be a demonstration before letting the students to do their own. Such demonstrations are so-called examples. According to Ramadhan and Surya (2017), the use of demonstration methods is effective in increasing students' mathematical ability, especially in mastering mathematical concepts on the matter of multiplication operations. The demonstration method increases the students' activeness and helps them in understanding the material, thus enhances their overall learning outcomes in mathematics.

Table 3. Observed teaching strategies by the student respondents

Teaching Strategies	f	%
Demonstration	105	38
Cooperative Learning	43	16
Inductive Approach	39	14
Lecture Type	39	14
Repetitive Exercise	18	6
Integrative Approach	17	6
Deductive Approach	16	6
Total	277	100

3.4 Profile of the teacher respondents

Table 4 presents the profile of the teacher respondents. Mathematics teachers were composed of three males and two females. From five teacher respondents, two were aged 20-29, another two were in between 30-39 years old and one of them was in between 40-49 years old. Most of them were teaching mathematics for more than five years and only one with 1-3 years of teaching experience.

Table 4. Profile of the teacher respondents

Demographic Profile	f	%
Age		
20 – 29 years old	2	40
30 – 39 years old	2	40
40 – 49 years old	1	20
n	5	100
Sex		
Male	3	60
Female	2	40
n	5	100
Civil Status		
Single	3	60
Married	2	40
n	5	100
Number of years as a Math Teacher		
Less than a year	0	0
1 – 3 years	1	20
more than 5 years	4	80
n	5	100

3.5 Teaching strategies applied by the teacher respondents

Three teachers applied cooperative learning, only one applied demonstration, and the other one applied repetitive exercise. This validates the students' response regarding demonstration and cooperative learning as the most observed teaching strategies by their mathematics teachers.

3.6 Regression analysis

This section presents multiple regression analyses between the dependent variable and independent variables.

The result of regression analysis (see Table 5 below) explicitly shows that among the learning styles, only the independent style has a significant influence on the academic performance of grade 9 students (b = 3.638, p = 0.029). While those learning styles do not necessarily contribute to the level of their performance in Math subject are collaborative (b = 1.487, p = 0.356), competitive (b = 2.638 p = 0.148), dependent (b = 1.786 p = 0.285), and participant (b = -2.043, p = 0.221). Although other styles have something to do with their learning, but there is no effect on academic performance. In fact, it contributed 24 percent (R^2 = 0.236) to the variance in academic performance.

Table 5. The summary output of regression statistics of academic performance, learning style and teaching strategies

	Unstandardized Coefficients			
Learning style	**b**	**Std. Error**	**t**	**Sig**
Constant	80.154	1.466	54.690	1.970E-148
Collaborative	1.487	1.608	0.925	0.356
Competitive	2.638	1.820	1.450	0.148
Dependent	1.786	1.576	1.133	0.258
Independent	3.638	1.652	2.202	0.029*
Participant	-2.043	1.664	-1.228	0.221
Teaching strategies				
Constant	79.952	0.519	154.151	3.272E-265
Cooperative	2.722	0.962	2.829	0.005*
Deductive	3.298	1.426	2.312	0.022*
Inductive	3.253	0.997	3.264	0.001**
Integrative	5.283	1.389	3.802	0.000**
Lecture	0.304	0.997	0.305	0.761
Repetitive Exercise	2.603	1.356	1.920	0.056

**significant at the 0.01 level; *significant at the 0.05 level

On the other hand, four (4) teaching strategies have significant influence on the academic performance of Grade 9 students. These were cooperative learning, deductive approach, inductive approach and integrative approach with (b = 2.722, p = 0.005), (b = 3.298, p = 0.022), (b = 0.001), (b = 5.283, p = 0.000), respectively. However, teaching strategies that did not contribute to increase the performance in

Math subject were lecture type (b = 0.304, p = 0.761) and repetitive exercise (b = 2.603, p = 0.056). Overall, teaching strategies have significant impact on the academic performance of the students, F (6, 277) = 5.160, $p < 0.05$). These contributed 51 per cent ($R^2 = 0.508$) to the variance in the academic performance.

This supports the findings of Akiri and Ugborugbo (2017), who showed that effective teachers produced better-performing students. However, due to the limitations of the study, the observed differences in students' performance were found not statistically significant. Thus, the study concluded that teachers' effectiveness is not the only determinant of students' academic achievement. But based on the study of Fayombo (2015), the teaching strategies and learning styles contributed 20 percent ($R^2 = 0.20$) to the variance in academic achievement, and this was statistically significant (F (2,168), (21.04, $p < .05$)). These findings revealed the importance of utilizing different teaching strategies to accommodate different learning styles and improve students' academic performance in mathematics. To support the result, according to Khan and Javed (n.d.), teachers should understand learning styles and relate them to their own context. Analysing learning styles can be beneficial to students and might help them focus on learning, thus increasing educational outcomes and satisfaction.

Looking back to the response of the teacher respondents, most of them apply cooperative learning, which is being revealed in the regression analysis with a high significance level of influence in the performance of the grade 9 students. According to the study of Ganyaupfu (2013), the results demonstrate that teacher-student interactive method was the most effective teaching strategy, which is one of the features of cooperative learning, followed by student-centred method while the teacher-centred approach was the least effective teaching strategy which is shown in the lecture-type strategy. On the other hand, repetitive exercise has no influence on the performance of the students, but it gives the teacher another way of teaching mathematics.

4 Synthesis of the Findings

This study was conducted to understand the influence of learning styles and teaching strategies on the academic performance of grade 9 students. There were 277 student-respondents from 991 population and five teacher-respondents who are teaching grade 9 Mathematics. In terms of the teaching strategy, mathematics teachers mostly applied cooperative learning. This was followed by a demonstration and repetitive exercise. This result had been validated by the students who agreed that cooperative learning and demonstration were applied by their teachers in teaching mathematics. In terms of the learning style, most of the students were collaborative.

Of all the learning styles, only an independent learning style has a significant influence on improving the academic performance of the students, whereas teaching strategies that have a significant influence on the academic performance of the students were cooperative learning, deductive approach, inductive approach, and integrative approach.

5 Conclusions and implications

The study provides discussions about the influence of student learning styles and teaching strategies on academic performance in mathematics. This adds to what the existing literature claims that to improve the academic performance of the students in mathematics, we must begin in knowing the students' learning style. Determining their learning styles will be a great help to teachers in designing and implementing a particular strategy that suits them. The following are some of the suggested strategies and techniques to improve the teaching and learning of mathematics:

For ***cooperative learning***, mathematics teacher may explore the following techniques:

Think-Pair-Share as it allows students to engage in individual and small-group thinking before asking the questions in front of the class (Razak, 2016).

Round table or rally table. This is a simple cooperative learning strategy that covers those content-based topics, and it builds a spirit of cooperation and participation (Sari et al., 2019). This strategy has three steps. These include firstly; the teacher poses a question that has multiple answers. Secondly, the first student in each group writes one response on a paper and passes the paper counterclockwise/clockwise to the next student. And finally, the group with the greatest number of correct answers will gain some type of recognition.

Jigsaw. In this strategy, each member of the group is responsible for learning a specific part of the topic. Each member is called 'expert' because of what s/he knows in the given topic to him/her. Each expert discusses his/her findings and learnings to the group. By this strategy, the whole topic is discussed, and each student has mastery in the process of learning (Zakaria, et al., 2013).

For **deductive**, there should be a (i) clear recognition of the problem; (ii) search for a tentative hypothesis; (iii) formulation of a tentative hypothesis; and (iv) verification of the hypothesis. This is appropriate for giving practice to the student in applying the formula or principle or generalization which has already been arrived at. This method is very useful for the retention of facts and rules as at provides adequate drill and practice (Adunola, 2011).

For ***inductive***, math teachers should incorporate the following techniques:

Presentation of Examples. Where math teachers present many examples of same type and provide solutions for those specific examples with the help of the students.

Observation. Using the examples and solutions, the students are engaged to make some conclusions.

Generalization. The teacher and students share their common observations and make a conclusion or a generalization about the principle and concept bound by logical explanations.

Testing and Verification. To check if the arrived conclusion is correct and acceptable, the students are to test and verify the principle and concept using the examples given. Through this method, the students attain the knowledge and logical explanations (Rahmah, 2017).

For ***integrative teaching***, math teachers are encouraged to:

Incorporate the thematic and integrated curriculum in the daily schedule or weekly lesson plan. Adapt lesson plans for diversity, which means a lot to the different kinds of learners inside the classroom. Provide new interdisciplinary ways of presenting old topics like video presentations, project making, and hands-on.

Foster an atmosphere that welcomes and encourages creativity in the classroom. Design activities that require students to discover, manipulate, combine, and transform knowledge into useful creation.

Use age-appropriate materials and techniques in teaching mathematics. Interrelating the cognitive, affective, and psychomotor must be considered in preparing materials and activities that are appropriate to the age and maturity of the students (Adunola, 2011).

These are some of the practical ways by which mathematics teachers can make a difference in the academic life of students who find no intrinsic motivation in mathematics. This is something more that must be done and taken into greater account to be able to improve the academic performance of high school students in mathematics. If teaching and learning processes are working effectively, a unique kind of relationship must exist between those two separate parties-some kind of a connection, link or bridge between the teacher and the learner. By understanding the diversity of students, realizing their different learning styles, teachers will be guided in designing different strategies. These will help students learn the easier way and, thus, achieve better academic performance in mathematics.

References

Adunola, O. (2011). The Impact of Teachers' Teaching Strategies on the Academic Performance of Primary School Pupils in Ijebu-Ode Local Cut Area of Ogun State. *Ego Booster Books*, Ogun State, Nigeria.

Akiri, A. A., & Ugborugbo, N. M. (2009). Teachers' Effectiveness and Students' Academic Performance in Public Secondary Schools in Delta State, Nigeria. *Studies on Home and Community Science, 3*(2), 107–113.

Altintas, E., & Ilgün, S. (2017). Exploring the Opinions about the Concepts of" Formula" and" Rule" in Mathematics. *Educational Research and Reviews, 12*(19), 956–966.

Ariola A. (2012), Learner's Learning Preferences and Teaching Strategies in Mathematics of Fourth Year High School at Mabitac Laguna.

Atta, M. A., Ayaz, M., & Nawaz, Q. (2015). Comparative study of inductive & deductive methods of teaching mathematics at elementary level. *Gomal University Journal of Research, 31*(1), 20–28.

Azarkhordad, F., & Mehdinezhad, V. (2016). Explaining the students' learning styles based on Grasha-Riechmann's student learning styles. *J Admin Manage Train, 12*(6), 241–247.

Baig, F. (2015). Application of Teaching Methods in Mathematics at Secondary Level in Pakistan. *Pakistan Journal of Social Sciences (PJSS), 35*(2).

Baneshi, A. R., Karamdoust, N. A., & Hakimzadeh, R. (2013). Validity & reliability of the Persian version of Grasha-Richmann student learning styles scale. *Journal of Advances in Medical Education & Professionalism, 1*(4), 119–124.

Baneshi, A. R., Tezerjani, M. D., & Mokhtarpour, H. (2014). Grasha-Riechmann college students' learning styles of classroom participation: Role of gender and major. *Journal of Advances in Medical Education & Professionalism, 2*(3), p. 103.

Bates, A. (2020). Basic Math Teaching Strategies. Retrieved 03 April 2020 from https://resilienteducator.com/classroom-resources/basic-math-teaching-strategies/

Chan, L. L., & Idris, N. (2017). Cooperative learning in mathematics education. *International Journal of Academic Research in Business and Social Sciences, 7*(3), 539–553.

Coffield, F., Moseley, D., Hall, E., Ecclestone, K. (2004). Learning styles and pedagogy in post-16 learning: A systematic and critical review.

Department of Education (DepEd) (2019). DepEd K to 12 Grading System. Retrieved, 3 April 2020, from https://www.teacherph.com/deped-grading-system/

Dudovskiy, J. (2016). The ultimate guide to writing a dissertation in business studies: A step-by-step assistance. Pittsburgh, USA.

Fayombo, G. (2015). Learning Styles, Teaching Strategies and Academic Achievement among Some Psychology Undergraduates in Barbados. *Caribbean Educational Research Journal, 3*(2), 46–61.

Fonseca, J. R. (2007). Can We Reduce Students' Negative Attitude Towards Math? In SITE 2007: Informing Science+ IT Education Conference (Vol. 7).

Ford, J. H., Robinson, J. M., & Wise, M. E. (2016). Adaptation of the Grasha Riechman Student Learning Style Survey and Teaching Style Inventory to assess individual teaching and learning styles in a quality improvement collaborative. *BMC Medical Education, 16*(1), p. 252.

Ganyaupfu M. E. (2013). Teaching Strategies and Students' Academic Performance. *International Journal of Humanities and Social Science Invention, 2*(9), 29–35

Goffe, W. L., & Kauper, D. (2014). A survey of principles instructors: Why lecture prevails. *The Journal of Economic Education, 45*(4), 360–375.

Grasha, A. F. (1996). An Integrated Model of Teaching and Learning Style. *Teaching with Style: A Practical Guide to Enhancing Learning by Understanding Teaching and Learning Styles.* Alliance Publishers.

Grasha, A. F., & Yangarber-Hicks, N. (2000). Integrating teaching styles and learning styles with instructional technology. *College teaching, 48*(1), 2–10.

Gujjar, A. A., & Tabassum, R. (2011). Assessing learning styles of student teachers at federal college of education. *Procedia-Social and Behavioral Sciences, 30*, 267–271.

Hamzeh, M. A. W. (2014). Teaching Strategies Used by Mathematics Teachers in the Jordan Public Schools and Their Relationship with Some Variables. *American Journal of Educational Research, 2*(6), 331–340.

Hightower, A. M., Delgado, R. C., Lloyd, S. C., Wittenstein, R., Sellers, K., & Swanson, C. B. (2011). *Improving Student Learning by Supporting Quality Teaching*.

Javed, A., Saif, N., & Kundi, G. M. (2013). The Study of Effectiveness of Cooperative Learning Approach in Teaching of Mathematics at Secondary Levels in Pakistan. *Mathematical Theory and Modeling, 3*(10), 24–33.

Kenton, W. (2019). Multiple Linear Regression – MLR Definition. Retrieved 4th November 2019 from https://www.Investopedia.Com/Terms/M/Mlr.Asp

Khan, J., & Iqbal, M.J. (2016). Effects of Learning Style on Achievement of Distance Learners.

Nzesei, M. M. (2015). A Correlation Study between Learning Styles and Academic Achievement among Secondary School Students in Kenya. University of Nairobi.

Padmavathy, R. D., & Mareesh, K. (2013). Effectiveness of problem based learning in mathematics. *International Multidisciplinary e-Journal, 2*(1), 45–51.

Panicker, V. M. (2014). Teaching of Mathematics through Integrated Approach at Secondary Level for Value Inculcation.

Prayoga, T., & Abraham, J. (2017). A psychological model explaining why we love or hate statistics. *Kasetsart Journal of Social Sciences, 38*(1), 1–8.

Rahmah, M. A. (2017). Inductive-Deductive Approach to Improve Mathematical Problem Solving for Junior High School. *Journal of Physics: Conference Series, 812*(1), IOP Publishing.

Ramadhan, N., & Surya, E. (2017). The Implementation of Demonstration Method to Increase Students' Ability in Operating Multiple Numbers by Using Concrete Object. International Journal of Sciences: *Basic and Applied Research (IJSBAR), 34*(02), 62–68.

Razak, F. (2016). The Effect of Cooperative Learning on Mathematics Learning Outcomes Viewed from Students' Learning Motivation. *JRAMathEdu (Journal of Research and Advances in Mathematics Education), 1*(1), 49–55.

Samadi, M. (2011). Evaluation of the Psychometric Properties of the Questionnaire of Learning Style of Felder Solomanin Pre-High Schoolgirls. *Educational Modern Approaches of Educational and Psychological Sciences, 13*(1), 39–60.

Sari, D., Mulyono, M., & Sri Noor Asih, T. (2019). Mathematical Problem Solving Ability Viewed from Extrovert Introvert Personality Types on Cooperative Learning Models Type Rally Coach. *Unnes Journal of Mathematics Education Research*, *8*(2), 141–146. Retrieved from https://journal.unnes.ac.id/sju/index.php/ujmer/article/view/28019

Shaari, A. S., Yusoff, N. M., Ghazali, I. M., Osman, R. H., & Dzahir, N. F. M. (2014). The Relationship between Lecturers' Teaching Style and Students' Academic Engagement. *Procedia-Social and Behavioral Sciences, 118*, 10–20.

Singh, N. K., & Yadav, A. K. (2017). Inductive and Deductive Methods in Mathematics Teaching. *South East Asian Journal of Mathematics and Mathematical Sciences, 14*(1), pp. 151–158.

Singh, V. (2017). Exploring the relationship between cognitive style and learning style with academic achievement of elementary school learners. *Educational Quest-An International Journal of Education and Applied Social Sciences*, *8*(spl), 413–419.

Stewart, K. L., & Felicetti, L. A. (1992). Learning Styles of Marketing Majors. *Educational Research Quarterly, 15*(2), 15–23.

Tebabal, A. & Kahssay, G. (2011), The Effects of Student-Centred Approach in Improving Students' Graphical Interpretation Skills and Conceptual Understanding of Kinematical Motion. *Latin-American Journal of Physics Education, 5*(2), 374–381.

Tomlinson, C. (2001). *How to differentiate instruction in mixed-ability classrooms*. Alexandria, VA: Association for Supervision and Curriculum Development.

Tulbure, C. (2012). Learning styles, teaching strategies and academic achievement in higher education: A cross-sectional investigation. *Procedia-Social and Behavioral Sciences, 33*.

Valdez, D. B. (2016). Investigative Approach in Teaching System of Linear Equation and Inequalities to Grade 8 Students of Los Banos National High School – Batong Malake, Los Banos, Laguna.

Warthen, S. (2017). Instructional Strategies of Effective Mathematics Teachers of African American Upper Elementary Students.

Wilson, E. O. (1999). Consilience: *The Unity of Knowledge* (Vol. 31). Vintage.

Zakaria, E., Solfitri, T., Daud, Y., & Abidin, Z. Z. (2013). Effect of cooperative learning on secondary school students' mathematics achievement. *Creative Education, 4*(2), 98–100.

Appendix 1

A. Students' Learning Styles' Questionnaire

The following questionnaire has been designed to help you clarify your attitudes and feelings toward the mathematics. There is no right or wrong answers to each question. However, as you answer each question, form your answers with regard to your general attitudes and feelings toward mathematics.

Respond to the items listed below:

5 – Strongly Agree (SA)
4 – Agree (A)
3 – Moderately Agree (MA)
2 – Disagree (D)
1 – Strongly Disagree (SD)

Attitudes and Feelings toward Mathematics	SA 5	A 4	MA 3	D 2	SD 1
1. I am confident of my ability to learn important information in the subject.					
2. I often daydream during class.					
3. Working with other students on class projects is something I enjoy.					
Attitudes and Feelings toward Mathematics	**SA 5**	**A 4**	**MA 3**	**D 2**	**SD 1**
4. Facts presented in textbooks and lectures usually are correct.					
5. To do well, it is necessary to compete with other students for the teacher's attention.					
6. I am usually eager to learn about the content areas covered in class.					
7. My ideas about content are often as good as those in the textbook.					
8. Classroom activities generally are boring.					
9. I enjoy discussing my ideas about the content of the subject with other students.					
10. Teachers are the best judges of what is important for me to learn in the subject.					
11. It is necessary to compete with other students to get a high grade.					
12. Class sessions typically are worthwhile.					
13. I study what is important to me and not always what the instructor says is important.					
14. Sometimes, I do become excited about the materials covered in the subject.					
15. I enjoy hearing what other students think about issues raised in class.					
16. I like the way teachers state exactly what they expect from students.					
17. During class discussions, I must compete with other students to get my ideas across.					
18. I get more out of going to class than staying at home.					
19. Most of what I know, I learned on my own.					
20. I generally feel like I have to attend class rather than like I want to attend.					
21. I can learn more by sharing ideas with one another.					

22. I try to do assignments exactly the way my teachers say they should be completed.					
23. Students have to become aggressive to do well in school.					
24. Everyone has a responsibility to learn more in the subject as much as possible.					
25. I can determine for myself the important content issues in the subject.					
26. Paying attention during class sessions is difficult for me to do.					
27. I like to study for tests with other students.					
Attitudes and Feelings toward Mathematics	**SA 5**	**A 4**	**MA 3**	**D 2**	**SD 1**
28. Teachers who let students do whatever they want are not doing their jobs.					
29. I like to get the answers to problems or questions before anybody else can.					
30. Classroom activities generally are interesting.					
31. I like to develop my own ideas about subject matter.					
32. I have given up trying to learn anything from going to class.					
33. The ideas of other students help me to understand the subject matter.					
34. Students need to be closely supervised by teachers on all subject projects.					
35. To get ahead in class, it is necessary to step on the toes of other students.					
36. I try to participate as much as I can in all aspects of the subject.					
37. I have my own ideas about how classes should be run.					
38. In most of my class, I study just hard enough to get by.					
39. An important part of the class is learning to get along with other people.					
40. My notes contain almost everything the teacher said in class.					
41. Students hurt their chances for a good grade when they share their notes and ideas.					
42. Assignments are completed whether or not I think they are interesting.					
43. If I like the topic, I usually find out more about it on my own.					
44. I typically cram for exams.					
45. Learning should be cooperative effort between students and teachers.					
46. I prefer class sessions that are highly organized.					
47. To stand out in my classes, I try to do assignments better than other students.					
48. I complete my assignments soon after they are given.					
49. I prefer to work on class related projects (e.g. studying for exams, papers) by myself.					
50. I would like teachers to ignore me in class.					

Attitudes and Feelings toward Mathematics	SA 5	A 4	MA 3	D 2	SD 1
51. I let other students borrow my notes when they ask for them.					
52. Teachers should tell students exactly what material is going to be covered on a test.					
53. I like to know how well other students are doing on exams and assignments.					
54. I complete required reading requirements as well as those that are optional.					
55. When I don't understand something, I try to figure it out for myself before seeking help.					
56. During class, I tend to talk or joke around with people sitting next to me.					
57. Participating in small group activities in class is something I enjoy.					
58. I find teacher outlines or notes on the board very helpful.					
59. I ask other students in class what grades they received on tests and assignments					
60. In my classes, I often sit towards the front of the room.					

B. Teaching Strategies Questionnaire

The following statements are the ways how your teacher teaches mathematics.

Respond to the items listed below:

5 – Always (AL)
4 – Often (O)
3 – Sometimes (ST)
2 – Seldom (SD)
1 – Never (N)

Teaching Strategies Applied by the Teacher	AL 5	O 4	ST 3	SL 2	N 1
1. Teacher uses specific questions to discuss the whole topic.					
2. Teacher awards students for their right answer.					
3. Teacher provides students feedbacks regarding their answer at all times.					
4. Teacher uses direct presentation to provide students with information.					
5. Teacher trains students to determine the whole idea of the topic.					
6. Teacher makes advantage of providing different activities to secure the teaching – learning process.					

Teaching Strategies Applied by the Teacher	AL 5	O 4	ST 3	SL 2	N 1
7. Teacher dissembles the teaching – learning material into specific tasks that need specific responses.					
8. Teacher depends on criteria in evaluating his students.					
9. Teacher cares about correcting students by providing many worksheets.					
10. Teacher neglects undesired behaviors in the teaching – learning situations.					
11. Teacher helps his students imitate desired models by showing it.					
12. Teacher provides students with a chance to apply new knowledge in new real life situations.					
13. Teacher trains his students on distinguishing between different characteristics of the same concept.					
14. Teacher trains students on learning the whole concept before the specific idea.					
15. Teacher gives similar examples during the discussion to secure the mastery of the topic.					
16. Teacher encourages students to work with others to generate as many alternatives as they can for the problem discussed.					
17. Teacher begins with presenting main ideas of the topic at the beginning of the class.					
18. Teacher ends teaching – learning situation with connecting the lesson parts together.					
19. Teacher begins the teaching – learning situation with presenting a problem to students.					
20. Teacher uses specific problem solving strategy in the teaching process.					
21. Teacher gives students enough time to think and to investigate with others to achieve desirable					

Teaching Strategies Applied by the Teacher	AL 5	O 4	ST 3	SL 2	N 1
objective.					
22. Teacher ends teaching – learning situation with clarifying and discussing diagrams suitable for students.					
23. Teacher makes use of concept maps during the teaching – learning process.					
24. Teacher takes part in training students by providing different learning activities.					
25. Teacher trains students on generating specific answers for the questions raised to them.					
26. Students tend to generate new information through making comparison between their previous knowledge and new one.					

Teaching Strategies Applied by the Teacher	AL 5	O 4	ST 3	SL 2	N 1
27. Teacher trains students to plan, observe, and evaluate their teaching activities.					
28. Teacher shows students how to verify information and facts before giving judgments.					
29. Teacher gives students a chance to generate new concepts.					
30. Teacher facilitates students to make use of the procedures that organizes memory potentials (symbolizing information).					
31. Teacher helps students identify their own mistakes by doing similar worksheets.					
32. Teacher's cognitive teaching strategies harmonize with students' learning strategies.					
33. Teacher guides students to references such as dictionaries, encyclopedias, internet sites, etc.					
34. Teacher moves from the abstract to the concrete examples.					
35. Teacher begins with examples up to the concept in the teaching – learning situation.					
36. Teacher asks students to do written or verbal summaries of the information they get.					
37. Teacher applies group work in the class to serve desired objectives.					
38. Teacher distributes different teaching – learning tasks on students.					
39. Teacher lets students have their own conversations positively.					
40. Teacher allows students to have more clarifications and explanations on a certain topic.					
41. Teacher supports students in using different learning tools for the purpose of teaching – learning process.					
42. Teacher assigns students in a specific task into a general task.					
43. Teacher encourages students to interact positively amongst themselves.					
44. Teacher trains students to solve their problems in a comfortable way.					
45. Teacher gives students the chance to correct their mistakes by answering similar question.					
46. Teacher makes students take part in different roles					

in the teaching – learning situation.

Teaching Strategies Applied by the Teacher	**AL 5**	**O 4**	**ST 3**	**SL 2**	**N 1**
47. Teachers trains students by providing different sets of worksheets.					
48. Teacher helps students to analyze the main idea to be used in discussing the topic as a whole.					
49. Teacher teaches students the way to identify those simple tricks to understand the lesson.					

Scoring Key of Learning Styles and Teaching Strategies

Instruction: The numbers below represent the items in the questionnaire that correspond to each of the learning style and teaching strategy dimensions on the questionnaire.

A. To self-score this questionnaire, place the ratings you assigned to each item in the space provided. Get the sum of each column to determine your learning styles.

Independent	Avoidant	Collaborative	Dependent	Competitive	Participant
1 _____	2 _____	3 _____	4 _____	5 _____	6 _____
7 _____	8 _____	9 _____	10 _____	11 _____	12 _____
13 _____	14 _____	15 _____	16 _____	17 _____	18 _____
19 _____	20 _____	21 _____	22 _____	23 _____	24 _____
25 _____	26 _____	27 _____	28 _____	29 _____	30 _____
31 _____	32 _____	33 _____	34 _____	35 _____	36 _____
37 _____	38 _____	39 _____	40 _____	41 _____	42 _____
43 _____	44 _____	45 _____	46 _____	47 _____	48 _____
49 _____	50 _____	51 _____	52 _____	53 _____	54 _____
55 _____	56 _____	57 _____	58 _____	59 _____	60 _____
_____	_____	_____	_____	_____	_____

B. To self-score this questionnaire, place the ratings you assigned to each item in the space provided. Get the sum of each column to determine which teaching is most applied by your teacher.

Cooperative Learning	Lecture Type	Deductive Approach	Inductive Approach	Demons-tration	Repetitive Exercise	Integrative Approach
16 _____	3 ____	5 _____	1 _____	4 _____	6 _____	2 _____
21 _____	22 ____	12 _____	7 _____	11 _____	9 _____	8 _____
29 _____	25 ____	14 _____	13 _____	19 _____	15 _____	10 _____
37 _____	32 ____	38 _____	17 _____	27 _____	24 _____	23 _____
38 _____	40 ____	26 _____	20 _____	28 _____	31 _____	30 _____
39 _____	44 ____	34 _____	42 _____	35 _____	45 _____	33 _____
43 _____	46 ____	36 _____	48 _____	49 _____	47 _____	41 _____
_____	_____	_____	_____	_____	_____	_____

Educators' perceptions of mathematically gifted students and a socially supportive learning environment – A case study of a Finnish upper secondary school

Eeva Haataja, Anu Laine and Markku S. Hannula

Department of Education, University of Helsinki, Finland

This article explores five educators' conceptions of the characteristics of mathematically gifted students and a social learning environment that supports their development in a school for mathematically gifted adolescents in Finland. We conducted this qualitative study through semi-structured interviews and participant observations in a Finnish upper secondary school with a special mathematics program. The research shows that gifted students and their educators form a tight community, the social learning environment of which supports shared motivation, healthy perfectionism, and practicing social skills. The results deepen the understanding of gifted education in the Finnish context and the significance of educators' shared understanding of social activities as a basis for successful gifted education.

Keywords: mathematical giftedness, qualitative case study, social learning environment, secondary education

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 44–66

Received 7 October 2019
Accepted 24 April 2020
Published 1 June 2020

Pages: 23
References: 43

Correspondence:
eeva.haataja@helsinki.fi

https://doi.org/10.31129/LUMAT.8.1.1368

1 Introduction

A gifted adolescent's school environment is a complex and continuously changing network of several actors and different forms of relationships (Ziegler & Stoeger, 2017). In their research review, Thapa, Cohen, Guffey, and Higgins-D'Alessandro (2013) define five dimensions of beneficial school climate: safety, relationships, teaching and learning, institutional environment, and improvement process. By improving these dimensions, educators can create a positive environment in their schools and significantly influence their students' social-emotional wellbeing, motivation, and learning outcomes (Thapa et al., 2013). To examine the educators' conceptions of the social aspects of school in Finnish gifted education, this research focuses on social relationships, which Thapa et al. (2013) describe as connectedness between people in the school community.

The significance of relationships is also apparent in Gagné's (2015) definition of talent development as a process of advancing natural abilities to high competence. This development is influenced by two types of catalysts: the student's intrapersonal characteristics (e.g., motivation, perfectionism) and the surrounding environment

 | CC BY 4.0

(e.g., peer relationships) (Gagné, 2015), which are in continuous interaction (Ziegler & Stoeger, 2017).

Previous research has highlighted the significance of a sensitive and dedicated teacher for the collective learning of gifted students and the need for charting pedagogical practices that can support a community of gifted students (Kuusisto & Tirri, 2015). To investigate what makes a beneficial social learning environment for gifted education in a Finnish school community of mathematically gifted adolescents, this study examines educators' conceptions of the characteristics of gifted students and the practical implications of the social learning environment in gifted education. We collected the data by interviewing five educators (three teachers, the school social worker, and the principal) who work with students of a special mathematics program.

2 Mathematically gifted students

Mathematical giftedness means the ability to master abstract numbers, variables and functions, and the relations between them. For a mathematically gifted person, talent development also requires courage, persistence, and intrinsic motivation to go further and deeper into such modes of comprehension (Reis & McCoach, 2002; Movshovitz-Hadar & Kleiner, 2009; Subotnik et al., 2009). A mathematically gifted and well-performing upper secondary school student is well on her way to becoming a member of the domain of mathematics (Cross & Coleman, 2014). She has developed an in-depth understanding of the mathematical concepts studied at school, and is committed to studying hard (Subotnik et al., 2009) and, with the support of her surroundings, is able to play an active role in her own learning (Cross & Coleman, 2014; Usiskin, 2000).

A gifted person is only able to fulfill her whole potential if her intrinsic characteristics and surrounding environment are in balance (Subotnik, Pillmeier, & Jarvin 2009; Usiskin, 2000). Mathematically gifted adolescents need intrinsic motivation to study and adequate social skills to be part of a peer group, express their mathematical insights and seek guidance when needed (Mann, 2006; Subotnik et al., 2009). Sharing the learning environment with other gifted students affects their motivation and social relationships (Plucker & Dilley, 2016). The following sections of this paper investigate these aspects and combine the viewpoints of gifted education and social learning environment.

2.1 Supporting the motivation of gifted students

Teachers' conceptions affect the development of gifted students (McNabb, 2003). Therefore, these conceptions play a significant role in helping young gifted students advance their talent (Mann, 2006; Pettersson, 2008). Several studies have shown that teachers relate giftedness to motivation to learn quickly, intelligently, and creatively (Kaya, 2015; Laine, Kuusisto, & Tirri, 2016; Mattsson, 2010; Moon & Brighton, 2008). One study of Swedish teachers saw motivation as including persistence and enjoyment of mathematics (Mattsson, 2010). However, the participants found it difficult to motivate mathematically gifted students if they were not used to persistent studying (Mattsson, 2013).

High-level learning is fundamental for talent development (Gagné, 2015) and requires a proper motivational structure that enhances the beneficial attributes of failure and success (Heller, 2013). Some gifted people possess perfectionistic traits, which can either enhance or restrict positive talent development. Healthy, adaptive perfectionism offers satisfaction from high-level learning and sustains motivation to learn more, whereas unhealthy, maladaptive perfectionism has the opposite effect (Basirion, Majid, & Jelas, 2014). The orientation of perfectionism can vary from positive pursuit of excellent learning to unhealthy comparison to surrounding peers (Speirs Neumeister, 2016; Stoeber, 2014).

Teachers can support healthy perfectionism in their school community (Basirion et al., 2014). According to teachers' perceptions, collaborative learning, and shared goals positively influence students' relationships by enhancing connectedness and trust (Thapa et al., 2013). Together with adequately challenging instruction (Brigandi, Weiner, Siegle, Gubbins, & Little, 2018; Speirs Neumeister, 2016), this feeling of connectedness helps gifted students focus their perfectionism on positive striving (Basirion et al., 2014; Stoeber, 2014). Informal learning and out-of-school activities such as summer schools may provide opportunities for collaborative learning with congenial peers and thus support the wellbeing of gifted adolescents (Koichu & Andzans, 2009; McHugh, 2006; Winkler, Stephenson, & Jolly, 2012).

According to Ziegler and Phillipson's (2012) systemic theory of gifted education, the social, emotional, and structural context of a gifted student affects their talent development. As the development of individual talent takes unique paths (Cross & Coleman, 2014), it is important to investigate the values, relationships, and practices of the whole school community (Ziegler & Phillipson, 2012).

2.2 Supporting relationships of gifted students

Positive relationships between individuals in the school community can be seen in, for example, the sense of connectedness and respect for different personalities (Thapa et al., 2013). According to Finnish teachers, the most determining characteristic of gifted students in the school context is their specific difference from others (Laine et al., 2016). Several studies in different cultures show that dissimilarity and even unpopularity may be challenges for gifted adolescents among their age group (Cross, 2016; Cross & Cross, 2015; Mönks & van Boxtel, 1985), especially when one is gifted in mathematics (Pettersson, 2008).

To prevent possible isolation of gifted adolescents, and to encourage them to develop their giftedness, the school community should receive guidance in creating supportive peer relationships (Cross, 2016; Cross & Cross, 2015). Support of congenial peers is essential for talent development (Brigandi et al., 2018; Muratori et al., 2006). Learning social skills in a beneficial learning environment constructs a basis for creating egalitarian friendships (Cross, 2016), but also for development towards successful professional mathematical performance (Cross & Coleman, 2014). Highly mathematically gifted girls, in particular, seem to benefit from a supportive school environment (Heller, 2013).

It is interesting to note that Nordic teachers mainly associate positive social-emotional characteristics such as enthusiasm, sensitivity, and curiosity with giftedness (Kaya, 2015; Laine et al., 2016; Mattsson, 2010). In general, gifted students are seen as well-behaving, well-managing independent learners (Kaya, 2015; Mattsson, 2010; Moon & Brighton, 2008).

3 Conceptions of giftedness among educators in Finland

Public and personal conceptions of giftedness (Speirs Neumeister, 2016), as well as the needs of the gifted students themselves (Pfeiffer & Burko, 2016), vary across cultures. In Finland, special education of the gifted is still rare and focuses mainly on academic achievement, although the Ministry of Education of Finland acknowledged the need for the social-emotional education of gifted students already in 2010 (Tirri & Kuusisto, 2013). In the Nordic countries, the purpose of the school system is to enhance egalitarianism in society (Mattsson, 2013). These egalitarian objectives emphasize a shared assumption of similarity and coherence in society and the avoidance of embracing extremes in people's achievements and goals (Persson, 2014).

As a result, Nordic public discourse (Laine, 2010; Persson, 2011) and educators' conceptions of giftedness (Mattsson, 2013) lack coherent definitions and interest in intellectual giftedness (Laine, 2010; Mattsson, 2013; Persson, 2011). As an example, Finland's normative National Core Curriculum for General Upper Secondary Schools (Finnish National Agency for Education, 2015) offers no guidance on gifted education, and the current Core Curriculum for Basic Education (Finnish National Agency for Education, 2014) is the first to even mention talented students.

Laine, Kuusisto, and Tirri (2016) investigated Finnish teachers' conceptions of giftedness and noticed superficiality and inconsistency among them. According to the study, many teachers still define giftedness as a fixed, natural characteristic of a person. Some teachers even believe that gifted students do not need training or instruction. The research also shows a gap between teachers' conceptions and the practices of gifted education (Laine et al., 2016).

4 Research question

The purpose of this study was to examine educators' conceptions of a social learning environment that can support the social-emotional needs of mathematically gifted adolescents. Our research question is:

How do the educators of a Finnish upper secondary school with a special mathematics program describe their students' giftedness and the school's practices to promote a positive social learning environment?

5 Method

Only five of Finland's 342 upper secondary schools (optional general education grades 10–12 after compulsory basic education, for adolescents aged 16–18) offer an official special mathematics program. One of these was the case in this study. The conceptions of gifted education held by the educators of the school were explored through semi-structured interviews.

5.1 School context

The school's special program was founded in 1995, whereas the history of the school dates back to the 1920s. The school is a private upper secondary school in a large city. In Finland, even private schools are government-funded, with no fees for the students.

However, as a private school, this school has its own administration and curriculum, which has to be aligned with the National Core Curriculum for Upper Secondary Schools (Finnish National Board of Education, 2003, at the time of the study). According to the school's current 2016 curriculum, the purpose of the school is to enhance the mathematical skills of Finnish adolescents.

The special mathematics program students belong to the larger school community of approximately 800 lower and upper secondary school students and approximately 30 upper secondary school teachers. Approximately 100 students of both genders study the special mathematics program, divided into three classes according to their initial year. The selection of students for the mathematical program is based on an entrance examination and their final grades in the academic subjects of basic education. According to the principal's interview (Interview 2, February 9, 2012), the school wishes to find students who possess a good knowledge of mathematical content taught in basic school but also a strong motivation to learn more. As is common in Finland, measurements of giftedness or intelligence are not in use in this school.

The school offers a wide range of instruction in mathematics. In addition to the fourteen national compulsory courses, students can study up to twenty extra courses, ranging from the history of mathematics to the results of recent mathematical research. Furthermore, the school offers diverse learning environments through a variety of informal teaching methods. For example, the Night of Mathematics is an overnight activity at the school's premises every January and September, and the Lapland summer school is an annual summer camp in Northern Finland, which combines informal mathematics learning and experiential biology education in nature. The school also arranges courses in cooperation with a university as well as practice camps for the International Mathematical Olympiad. The biology teacher (Interview 4, February 14, 2012) estimated that after the matriculation examination, 80% of the students of the special mathematics program proceed to studies in mathematical domains.

5.2 Participants

We collected the data by interviewing three teachers, the principal, and the school social worker, and by observing an overnight school activity. The researcher first contacted Mathematics Teacher 1 (Interview 1, February 9, 2012), who responded by expressing interest in this research. With the principal's permission, five educators volunteered for an interview. The students were informed of the researcher's observation in advance. All research participants (educators and students) gave their consent for the study.

These particular interviewees were selected to provide a comprehensive and diverse picture of the education of the gifted in this school from a specific viewpoint. The mathematics teachers were able to offer insights into mathematical giftedness and the mathematics education of the school. Mathematics Teacher 1 was the headteacher of the special program and assisted the principal in administrative work. He was also a former student of the school and had worked in the school as a part-time teacher during his university studies since 2003 and in a full-time position for five years. With his help, the researcher chose the rest of the interviewees. Mathematics Teacher 2 (Interview 3, February 14, 2012) had taught both lower and upper secondary school students for six years at the school. At the time of the data collection, Mathematics Teacher 2 had participated in the Lapland summer school twice. Mathematics Teacher 1 recommended interviewing the biology teacher (Interview 4, February 14, 2012) due to her experience in teaching the students of the special program: She had worked at the school for 27 years, attended 15 summer camps, and been involved in the establishment process of the special mathematics program in the 1990s.

The school social worker (Interview 5, February 28, 2012) and principal (Interview 2, February 9, 2012) were interviewed to gain a comprehensive picture of the topic. The school social worker had worked as an elementary school teacher prior to starting in this position in 2002. She worked as a counselor for the students and helped them with challenges related to their studies and general wellbeing. Her clients mostly consisted of basic education students, but she also worked with the students in the special mathematics program. The principal was the head of the whole school community. She was a qualified Finnish language teacher and had worked in the school for over 20 years as a teacher and for three years as the principal. She had also contributed to the establishment of the special mathematics program.

5.3 Procedure

Table 1 presents the study's data collection process and inductive content analysis.

Table 1. Procedural phases of data collection

1	Getting acquainted with the research case: Observations in overnight school and mathematics lessons and informal discussion with Mathematics Teacher 1
2	Creating research questions according to observation perceptions and literature: How do the educators of a Finnish upper secondary school with a special mathematics program describe their students' giftedness and the school's practices to promote a positive social learning environment?
3	Creating the interview frame (for whole frame, see Appendix): Question categories: Mathematical giftedness, Students of the school, Teaching, Practices An example question from the Practices category: What are the objectives of the Lapland summer school? What do you do there?

The first author attended the overnight school (January 20, 2012) and engaged in the social and mathematics activities of the event. The researcher also followed two mathematics lessons during the fall semester of 2011. The observations were in the form of video-recordings and note-taking. As Gillham (2010) argues, participant observation through descriptive notes can be used for getting acquainted with a case. Our purpose was to provide background information for the interviews and to improve the trustworthiness of the interpretations of the interview material through the researcher's personal experience of the school environment and social activities.

To cover our research questions, we selected semi-structured interviews as our main data source. The interview frame was formulated on the basis of the observations in the school and the cited literature on the social-emotional development of gifted students. Interviewing the authorities of the case can offer both wide and profound context evidence (Gillham, 2010). The researcher interviewed each respondent individually in the school building once. The duration of the interviews varied from 40 to 80 minutes. A qualitative semi-structured interview technique was used in order to give the interviewees the possibility to conceptualize and describe the topic in the way they preferred (Newby, 2010; Bodgan & Biklen, 2007).

First, the interviewees were asked briefly about their professional background. Second, the questions concerned the interviewees' conceptions of mathematics and mathematical giftedness. Third, the researcher asked the informants to describe their students' social and emotional skills, issues, and relationships. The fourth topic of the interviews included conceptions of education and teaching. The final topic was concerned with this particular school's education in practice, especially informal and experiential learning methods, such as the summer school in Lapland and the overnight school. The complete English translation of the interview framework is in the Appendix.

5.4 Analysis

The first author recorded and transcribed the interviews and analyzed them using inductive content analysis. We chose the inductive approach, as we wanted to cover both the individual characteristics and social practices of the needs and support of gifted students. Table 2 presents an example of the qualitative analysis: an excerpt from the interview of the biology teacher regarding the summer school.

Table 2. Example of the analysis process

The analysis of the biology teacher's reply to the example question: What are the objectives of the Lapland summer school? What do you do there? A whole statement: *"But we are pretty silly there. Hey, let's try this. Okay, let's do it."* ➔A code: *in Lapland the atmosphere allows teachers and students to act silly* ➔A subcategory: *the teacher-student relationships in the Lapland summer school* ➔A category: *the summer school supports the social-emotional development of the students* ➔The main category: *experiential education and informal learning supports social-emotional development of the students*.

We chose a whole statement as the unit of the analysis. We identified the whole statements by searching for all the replies to the research questions from the transcripts. Each whole statement included one thought, conception, or opinion, which varied from a couple of words to several sentences. First, we summarized these units into codes. After this, as is typical in inductive content analysis (Bodgan & Biklen, 2007; Elo & Kyngäs, 2008), we connected the codes concerning the same topics into subcategories and then categories. The two research questions directed the categorization of the categories into main categories and the interpretation of the findings in light of the theoretical background of the study. In this phase, we compared the words the participants used in the original data to the concepts in the literature. To increase the trustworthiness of this study, the authors reflected on the chosen categories and peer debriefing during all the phases of the analysis process.

The names in this paper have been anonymized. However, because of the uniqueness of this research context in the Finnish school system, it is not possible to ensure the anonymity of the school or its teachers. The respondents granted their permission for this publication and were offered the opportunity to comment on its content. A preliminary analysis has been published in the proceedings of The Tenth Congress of the European Society for Research in Mathematics Education CERME10 (Haataja & Laine, 2017).

6 Results

First, we discuss how the educators described their students' mathematical giftedness. In the interviews, the conceptions of giftedness and gifted students were somewhat intermingled. The main categories responding to this research question were the conception of mathematical giftedness, high motivation, perfectionism, and variation of social skills. Second, we examine the conceptions of the school's social learning environment and the practices to support it. The main categories responding to this research question were appreciation of uniqueness, shared motivation, healthy perfectionism, and supportive environment for learning social skills.

6.1 Educators' conceptions of mathematically gifted students

Identification of giftedness is not common in Finland, and the interviewees approached the giftedness of their students descriptively. The educators interviewed in this study generally described their students as gifted despite the absence of the concept in the school's curriculum or official objectives during the time of the interviews (Curriculum of the School, 2005).

The conception of mathematical giftedness. The educators defined mathematical giftedness as the ability to picture, learn, and remember mathematical structures rapidly and with clarity. The interviewees saw mathematical giftedness as innate, but as invariably changing and developing through motivated practice.

> "Of course, they need some kind of giftedness. If someone is totally ungifted, he can't learn no matter how motivated he is. But with some kind of basic giftedness, you can go quite far." (Interview 3)

They described two types of giftedness apparent in the school: students with multiple talents and those with a single mathematically focused talent. Students with multiple talents were often interested in influencing societal matters and participating in students' social activities. Other students focused on one talent with a deep commitment to studying mathematical reasoning skills.

> "Roughly speaking, there are those Renaissance talents who are widely gifted. And then those with a special talent, who could be gifted in any field but focus on the area of their deepest interest." (Interview 2)

High motivation. The mathematics teachers interviewed in this study emphasized the significance of motivation in talent development. The educators described that motivation and enjoyment of learning mathematics was an essential characteristic of gifted students.

> "They [students] are very motivated. [...] And that is more determining than giftedness." (Interview 3)

> "They [mathematics teachers and students] enjoy digging into mathematics." (Interview 2)

Perfectionism. A high level of motivation sometimes relates to unhealthy perfectionism. The interviewees described students at risk of unhealthy perfectionism either as those with multiple interests and the will to learn several subjects to high standards or as those with extreme interest and overly serious relationship with learning mathematics. The biology teacher and the school social worker had seen how achieving high objectives or failing to do so could cause stress and feelings of exhaustion.

> "It [exhaustion] does not occur often, but someone every year [is affected]." (Interview 2)

> "If studies don't go as planned, it can cause terrible stress." (Interview 4)

> "Often, great giftedness and striving for perfection and achievements are a part of the personality. There is a risk of stress and fatigue and exhaustion." (Interview 5)

> "Upper secondary school is quite a tough thing if one wants to do it properly. [If, for the student,] properly means that one studies four languages [...] and a hundred courses. [...] Many find that only that is the proper way." (Interview 1)

Variation of social skills. According to the interviews, the students with a narrow focus on mathematical talent faced more challenges in terms of social skills than those talented in various domains. According to Mathematics Teacher 1, both "social sharks" with an excellent level of social skills and those who had "obvious problems in that respect" could be found among the students of the school.

> "Some of them have very poor social skills. [...] It's often the case in this narrow domain of talent." (Interview 4)

> "We have many who are fundamentally reserved as individuals, but most of them open up during upper secondary school." (Interview 1)

6.2 Educators' descriptions of the school's social learning environment

The educators shared a strong vision of the tight community of their school. This was seen to arise from "the spirit of the school" (Interview 2) and from "basic human values" (Interview 5). The tight community was described as consisting of (a) the appreciation of uniqueness and (b) a meeting place for congenial adolescents.

> "I think that it's built into the ideology of our school. I don't believe that we've written any socialization objectives for the students of the special mathematics program. It's built into the spirit of the school." (Interview 2)

> "And the kind of basic human values that teachers have here. [...] When you have the courage to use your abilities, then you also have the courage to fail and hurl yourself into difficult subjects." (Interview 5)

Appreciation of uniqueness. The interviewees underlined the appreciation of the uniqueness of their students instead of characterizing them as a homogenous group. They described the students' personalities, interests, social skills, and profiles of talent as being very individual. The uniqueness of these individuals formed the basis of the school community.

> "I don't want to give any stereotyped answer here. I don't want to say that they are like this or like that." (Interview 2)

> "We have a wide variety of personalities and a tight community, which means that it becomes a broad-minded community." (Interview 1)

The interviewees described their school community as a meeting place for mathematically gifted students who are, in some way, different from other adolescents. According to educators, many of the students had experiences and memories of feeling different and isolated during lower secondary school. Sometimes a change of school was essential for a gifted adolescent.

> "And we offer a community where you can discuss the Schrödinger equation during a break without being sneered at." (Interview 3)

> "I just received a message in which the parents were grateful because it's been so important [for their child] to be encouraged, accepted in the group, and let himself be himself [in this school]." (Interview 4)

The interviews indicate that the opportunity to study and associate with other gifted students was considered one reason for the distinctive solidarity in the school. Even though the students varied in terms of their social skills, common interests made social interaction easier.

> "To find congenial people. And I know how the teachers describe how they [the students] do experiments in, for example, physics lessons, the burning enthusiasm they show." (Interview 5)

The mathematics teachers found it important to create a safe, beneficial, social learning environment for their students, but their ultimate goal was to offer high-quality mathematics education.

> "I'm not a social skills coach. Essentially, I teach mathematics." (Interview 1)

> "Of course, if someone misbehaves, I have to do something. But I think that we teach the subject [mathematics] to students of this age." (Interview 3)

The interviewees described that the social support of gifted students was based on a shared vision of appreciation of unique, mathematically gifted personalities. The following sections present the characteristics of the social learning environment, which were also seen as beneficial for the development of mathematical talent.

Shared motivation to learn mathematics. The interviewees highlighted the significance of peer support for maintaining motivation. The shared motivation and interest in mathematics was visible in the overnight school, where groups of students solved mathematical problems together and demonstrated amazing enthusiasm.

> "The passion for [mathematics] creates good common things in the class [...] and among the students." (Interview 5)

> "And also, the point that the other members of the group are diversely gifted as well; no one is the best at everything. That makes everyone seriously try." (Interview 1)

The tight community of the school focused on studying, which contributed to learning at an advanced level. The mathematics teachers believed that learning could also be negatively influenced by strong solidarity between the students if the group identified with anti-school opinions. In these circumstances, success at school might become a social burden to a motivated student. However, a tight community with a positive attitude towards school can encourage even an unmotivated student to study harder. Thus, motivation is not merely the characteristic of a single student but also of a school community that develops through shared support and goals.

> "Social pressure can affect them one way or the other. In this school, it has more positive effects. [Here] someone may feel shame for not succeeding, but in some schools, it's shameful to succeed. [...] [Here] they encourage each other very much to study." (Interview 3)

> "If the group focuses on knowing and studying hard, it supports those who in some other environment would lag behind and laze around." (Interview 1)

The teachers also underlined persistence and courage to address mathematical challenges. The mathematics teachers considered the teaching of study techniques and the importance of constant studying one of their most important tasks.

> "Teaching how to study is the duty of all teachers. [...] The emphasis on the significance of [persistent] work is very important." (Interview 3)

> "And it's excellent if I can say that the practice exam didn't go so well, and let's practice now." (Interview 1)

> "Because after lower secondary school, many of them lack the culture of working hard. [...] But on the other hand, it's very important to experience success right at the beginning." (Interview 1)

Healthy perfectionism. The informal learning environments of the school enabled open discussions on social matters. The observations of the overnight school showed that the students were able to discuss their perfectionism. The conversation was humorous, and the participants laughed at their perfectionistic traits. According to the interviews, studying with other gifted students in a supportive school environment helped the adolescents construct their perfectionism in a realistic self-image, as both people and mathematicians.

> "It's easy to get perspective, [because] some students really are incredibly good. [...] It combats thoughts of whether I am the very best. Well, everyone knows that they're not. Nobody is the very best." (Interview 1)

The interviewees tended to see unhealthy perfectionism as a practical problem of the educational system rather than a problem of the gifted. Summing up the perceptions of the interviewees, the school social worker told us that educators could prevent and address unhealthy perfectionism by guiding the students being adaptive and offering them constant care.

> "Flexibility and a flexible education system protect the path of the adolescents somehow. And also caring in particular, daily care." (Interview 5)

Supportive environment to practice social skills. According to the interviews, one important goal of the school was to teach acceptance of all kinds of personalities. To elaborate, one participant at the overnight school had brought his own computer with him and spent the whole evening playing alone, but in the same room with others.

> "Of course, one can choose to enjoy small groups or solitude." (Interview 1)

The practice of social skills in upper secondary mathematics education was seen to occur through group work and conversation, which were commonly used as teaching methods. The interviewees saw that encouraging the students to discuss the studied contents together was a crucial method of teaching social skills in their school.

> "But when we work with [mathematical] problems that take several hours to solve, brainstorming is very good. And I try to encourage that." (Interview 1)

> "It starts in the classroom. [...] To make everyone communicate and work with others at least sometimes." (Interview 4)

According to the interviewees, the students of the school were able to form close relationships with each other. The class-based structure and diverse range of informal activities formed the basis for the development of friendships at the school. The biology teacher had noticed that collaborative learning helps students also create relationships beyond mental boundaries between age groups. The educators were proud of the school's practices, such as the overnight school, which supported the connectedness of different age groups and "conveyed traditions" (Interview 1) from previous students to freshmen. Overnight school was seen to offer an opportunity to associate with like-minded peers, make new friends and informally learn interesting mathematics.

> "And then across the groups of each grade, because they spend time together on Mondays [when extra courses in mathematics are taught] and at overnight schools, there are no [age] boundaries." (Interview 4)

> "They go to the Olympics training in [another upper secondary school], so they are interwoven with them, too." (Interview 4)

> "It [the overnight school] is a really great way to informally give good role models when you can say that these ten buddies [former students] were once in the finals of a mathematics competition." (Interview 1)

When asked about the practice of the annual Lapland summer school, Mathematics Teacher 1 described its objectives as "fifty-fifty" academic and social. The summer school offered informal, experiential education in mathematics and biology and practiced social skills with other gifted students.

> "These summer camps are, of course, about spending time together in [...] a beautiful environment with instructive tasks." (Interview 2)

The summer school affected the students as individuals and the relationships both among themselves and between the students and the teachers. According to the biology teacher, this influence was built through collaboration, connectedness, and outdoor experiences. The students had the opportunity to experience nature together, and the teachers directed them less than in the school environment. During the summer school, even the most introverted students tended to open up socially and get to know others.

> "There, the students need each other's support and they have to work as a team. And at the same time, they share experiences with each other." (Interview 4)

> "And sometimes those kinds of [introverted] students come there with us. [...] Then, when they are together long enough, they start to communicate more with others." (Interview 3)

> "It's amazing to notice how they somehow gain self-confidence." (Interview 5)

According to the Biology Teacher and Mathematics Teacher 2, the summer school made it possible to break out of the roles of teacher and student by changing the forms of interaction, which led to relaxing and having fun.

> "But we are pretty silly there. Like hey, let's try this? Okay, let's do it." (Interview 4)

> "I think they are somehow more relaxed. At least they seem to like it a lot." (Interview 3)

7 Discussion

The semi-structured interviews enabled the educators to freely describe their school according to their own conceptions. The analysis of these interviews offered two main findings. First, the educators' descriptions of mathematical giftedness reflected the Finnish educational context and public discourse. Secondly, the interviews underlined the significance of a positive school community.

This qualitative case study deepens our understanding of the relatively unexplored field of gifted education in Finland. The Finnish context explains the conceptual incoherence in the educators' descriptions of giftedness (Laine, 2010). Approximately half of the Finnish teachers see giftedness as something innate and fixed (Tirri & Kuusisto, 2013; Laine et al., 2016). The interviewees of this study described giftedness as an innate characteristic of a student, but as malleable rather than fixed, and as developing in the school community. Finnish teachers also tend to associate gifted students with positive social-emotional characteristics (Laine et al., 2016). These educators had also noticed issues of unhealthy perfectionism and isolation among the gifted students. Still, the positive attitude towards giftedness, as well as the educators' enthusiasm and pride in their students, were easily discerned in the interviews. The amount and especially the quality of cooperation with gifted students have also previously been found to determine teachers' conceptions of and approaches to giftedness (Kaya, 2015), which is congruent with the results of this research.

Finnish public discourse sometimes discourages separating groups of gifted students from other students (Laine, 2010). Whereas the identification of gifted individuals is often the first step of formal gifted education (Ziegler & Phillipson, 2012), in this school, it seemed to occur during studies at the school, as giftedness per se was not the eligibility requirement of applying. Instead, giftedness was seen to be present in the social learning environment and in the interaction between the members of the school community. This finding was aligned with the theory of systemic gifted education, according to which talent development occurs in the nexus of an individual and the environment (Ziegler & Stoeger, 2017).

At the time of the data collection of this study, the social objectives of gifted education were not explicit in the school curriculum nor in the National Core Curriculum for Upper Secondary Schools (Finnish National Board of Education, 2003). Instead, social learning was embedded in the teaching methods of mathematics education. Throughout the interviews, the educators referred to the school's unique character, which guided their practices. The practices supporting talent development included three significant aspects: maintaining a high level of shared motivation, supporting healthy perfectionism, and providing a supportive environment in which to practice social skills. These aspects of support shared the factor of relationships as a catalyst for talent development (Gagné, 2015). The interviewed educators emphasized that the social learning environment is formed by motivating, caring for, and supporting the relationships between unique personalities in school.

The concept of dissimilarity is frequently included in the definitions of giftedness and in the conceptions of giftedness commonly held by Finnish teachers (Laine et al., 2016). The gifted are seen as somehow, although often positively, differing from others (Shani-Zinovich & Zeidner, 2009). Therefore, it is important to understand the difference between the conception of dissimilarity in the theoretical definitions on the one hand and the subjective experience of a gifted adolescent in relation to their peers on the other. Teachers who work with gifted students can, at least to a certain extent, grasp what it is like for the students to feel different. According to this research, these feelings may cause isolation, which can, however, be prevented by supporting connectedness in school.

The social learning environment was found to support connectedness if the strong motivation for high-level learning was appreciated, challenges of unhealthy perfectionism were confronted openly and flexibly, and opportunities to practice social skills were offered. The pedagogical practices presented in this study could also be applied in other educational contexts. We suggest broad pedagogical reflection when planning and conducting informal, out-of-school learning activities, to reach a shared vision of the values behind and objectives of these methods.

7.1 Limitations and future recommendations

The authors used both observation and interviews to obtain a comprehensive picture of the school's social learning environment. The observation of the school's overnight activity and mathematics lessons provided first-hand information to the researchers, who had been unfamiliar with the school community before the study. With these perceptions, the interviews became easier to analyze and interpret. Nevertheless, a longer period of participatory observation could have offered more profound information on the social interactions of the students. In the future, student or parent interviews would help construct a more systemic picture of the school's gifted students and social learning environment. The selection of the interviewees was based on the recommendation of the headteacher of the special program, Mathematics Teacher 1 in this report. We asked him to recommend colleagues who had the most experience in the mathematical education of the students of the special program. Choosing teachers of humanistic subjects or arts might have led to somewhat different research results and could serve as an enlightening topic for future research.

Comparing these results with similar results in other cultural contexts either in Finland (e.g., cultural minorities or other fields of giftedness) or in other countries would provide a more profound picture of the role of social practices in gifted education. The Finnish education system offers a research context in which gifted education is planned and conducted by individual school communities without the explicit regulation of the National Board of Education. This highlights the importance of the shared vision of gifted education among the educators of schools. Comparison of the conceptions of the social learning environment and gifted education with school communities in more standardized gifted education contexts might serve as a relevant topic for future research.

7.2 Conclusion

The preceding discussion directs back to the implications of the school context. The organization and the curriculum of national school systems should meet the needs of every student, including the gifted (Cross & Coleman, 2014; Kaya, 2015). This study shows that opportunities to build close relationships with educators and other gifted people create a social learning environment that is supportive and motivating for all kinds of gifted individuals. Finnish teachers are highly qualified and skilled at differentiating learning content for both fast and slow learners (Laine et al., 2016). However, this research shows that even the most devoted and competent teacher cannot replace the need to meet, study with, and make friends with congenial peers.

Although the Finnish national core curriculum (Finnish National Agency for Education, 2015) does not provide schools with tools for arranging gifted education, the school community plays a role in defining the shared attitude towards gifted students' special needs. In this school, the community enabled academic and social everyday support for gifted individuals. The results of this study afford both ideas for practical implications for educators and evidence of the need to organize and reflect on gifted education on a national level in Finland.

References

Basirion, Z., Majid, R., & Jelas, Z. (2014). Big Five personality factors, perceived parenting styles, and perfectionism among academically gifted students. *Asian Social Science, 10*(4), 8–15. doi:10.5539/ass.v10n4p8

Brigandi, C. B., Weiner, J. M., Siegle, D., Gubbins, E. J., & Little, C. A. (2018). Environmental Perceptions of Gifted Secondary School Students Engaged in an Evidence-Based Enrichment Practice. *Gifted Child Quarterly, 62*(3), 289–305. doi:10.1177/0016986218758441

Cross, J. R. (2016). Gifted children and peer relationships. In M. Neihart, S. I. Pfeiffer, & T. L. Cross (Eds.), *The social and emotional development of gifted children: What do we know*? (2nd ed.), (pp. 41–54). Waco, TX: Prufrock.

Cross, J. R., & Cross, T. L. (2015). Clinical and mental health issues in counseling the gifted individual. *Journal of Counseling & Development, 93*(2), 163–172. doi:10.1002/j.1556-6676.2015.00192.x

Cross, T., & Coleman, L. (2014). School-based conception of giftedness. *Journal for the Education of the Gifted, 37*(1), 94–103. doi:10.1177/0162353214521522

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing, 62*(1), 107–115. doi:10.1111/j.1365-2648.2007.04569.x

Finnish National Board of Education (2003). *National core curriculum for upper secondary schools*. Helsinki, Finland: Board of Education.

Finnish National Agency for Education (2015). *National core curriculum for general upper secondary schools*. Helsinki, Finland: Agency for Education.

Gagné, F. (2015). Academic talent development programs: A best practices model. *Asia Pacific Education Review, 16*(2), 281–295. doi:10.1007/s12564-015-9366-9

Gillham, B. (2010). Case study research methods. London, England: Bloomsbury.

Haataja, E., & Laine, A. (2017). Finnish educators' conceptions of the social-emotional needs of mathematically gifted high school students. In Dooley, T. & Gueudet, G. (Eds.), *Proceedings of the Tenth Congress of the European Society for Research in Mathematics Education* (CERME10, February 1-5, 2017), (pp. 1082–1089) Dublin, Ireland: DCU Institute of Education and ERME.

Heller, K. (2013). Findings from the Munich Longitudinal Study of Giftedness and their impact on identification, gifted education and counseling. *Talent Development & Excellence, 5*(1), 51–64.

Kaya, F. (2015): Teachers' conceptions of giftedness and special needs of gifted students. *Ted egitim ve bilim, 40*(177), 59–74. doi:10.15390/EB.2015.2885

Koichu, B., & Andzans, A. (2009). Mathematical creativity and giftedness in out-of-school activities. In R. Leikin, A. Berman, & B. Koichu (Eds.), *Creativity in mathematics and the education of gifted students* (pp. 285–308). Rotterdam, The Netherlands: Sense.

Kuusisto, E. & Tirri, K. (2015). Disagreements in working as a team: A case study of gifted science students. *Revista de Educación, 368,* 279-305. doi: 10.4438/1988-592X-RE-2015-368-287

Laine, S. (2010). The Finnish public discussion of giftedness and gifted children. *High Ability Studies, 21*(1), 63–76. doi:10.1080/13598139.2010.488092

Laine, S., Kuusisto, E., & Tirri, K. (2016). Finnish teachers' conceptions of giftedness. Journal for the Education of the Gifted, 39(2), 151–167. doi:10.1177/0162353216640936

Mann, E. (2006) Creativity: The essence of mathematics. *Journal for the Education of the Gifted, 30(*2), 236–262. doi:10.4219/jeg-2006-264

Mattsson, L. (2010). Head teachers' conception of gifted students in mathematics in Swedish upper secondary school. *Nordic Studies in Mathematics Education, 15*(3), 3–22.

Mattsson, L. (2013). *Tracking mathematical giftedness in an egalitarian context* (Doctoral thesis, University of Gothenburg, Sweden). Retrieved from http://hdl.handle.net/2077/34120

McHugh, M. (2006). Governor's Schools: Fostering the social and emotional wellbeing of gifted and talented students. *Journal of Secondary Gifted Education, 17*(3), 50–58.

McNabb, T. (2003). Motivational issues: Potential to performance. In N. Colangelo & G. Davis (Eds.), *Handbook of gifted education* (3rd ed.), (pp. 417–423). Boston, MA: Allyn and Bacon.

Moon, T., & Brighton, C. (2008). Primary teachers' conceptions of giftedness. *Journal for the Education of the Gifted, 31*(4), 447–480.

Movshovitz-Hadar, N., & Kleiner, I. (2009). Intellectual courage and mathematical creativity. In R. Leikin, A. Berman, & B. Koichu (Eds.), *Creativity in mathematics and the education of gifted students* (pp. 31–50). Rotterdam, The Netherlands: Sense.

Muratori, M., Stanley, J., Ng, L., Ng, J., Gross, M., Tao, T. & Tao, B. (2006). Insights from SMPY's greatest former child prodigies: Drs. Terence ("Terry") Tao and Lenhard ("Lenny") Ng reflect on their talent development. *Gifted Child Quarterly, 50*(4), 307–32. doi:10.1177/001698620605000404

Mönks, F., & van Boxtel, H. (1985). Dyssynchrony: Uneven development. In J. Freeman (Ed.), *The psychology of gifted children* (pp. 275–296). New York, NY: Wiley.

Newby, P. (2010). *Research methods for education*. Harlow, England: Pearson Education Limited.

Persson, R. (2011). Ability climates in Europe as socially represented notability. *High Ability Studies, 22*(1), 79–101. doi:10.1080/13598139.2011.576086

Persson, R. (2014). The needs of the highly able and the needs of society: A multidisciplinary analysis of talent differentiation and its significance to gifted education and issues of societal inequality. *Roeper Review, 36*(1), 43–59. doi:10.1080/02783193.2013.856830

Pettersson, E. (2008). *Hur matematiska förmågor uttrycks och tas om hand i en pedagogisk praktik* [How mathematical abilities are expressed and taken care of in an educational practice]. (Licentiate's dissertation). Available from Reports from MSI. (Record No. 08030)

Plucker, J. A., & Dilley, A. (2016). Ability Grouping and the Socioemotional Development of Gifted Students. In M. Neihart, S. I. Pfeiffer, & T. L. Cross (Eds.), *The social and emotional development of gifted children: What do we know?* (2nd ed.), (pp. 231–242). Waco, TX: Prufrock.

Pfeiffer, S. I., & Burko, J. (2016). Counseling the gifted. In M. Neihart, S. I. Pfeiffer, & T. L. Cross (Eds.), *The social and emotional development of gifted children: What do we know?* (2nd ed.), (pp. 243–258). Waco, TX: Prufrock.

Reis, S., & McCoach, D. (2002). Underachievement in gifted students. In M. Neihart, S. Reis, N. Robinson, & S. Moon (Eds.), *The social and emotional development of gifted children* (pp. 81–92). Washington: The National Association for Gifted Children.

Shani-Zinovich, I., & Zeidner, M. (2009) On being a gifted adolescent: Developmental, affective and social issues. In R. Leikin, A. Berman, & B. Koichu (Eds.), *Creativity in mathematics and the education of gifted students* (pp. 195–220). Rotterdam, The Netherlands: Sense.

Speirs Neumeister, K. (2016). Perfectionism in gifted students. In M. Neihart, S. I. Pfeiffer, & T. L. Cross (Eds.), *The social and emotional development of gifted children: What do we know?* (2nd ed.), (pp. 29–40). Waco, TX: Prufrock.

Stoeber, J. (2014). How other-oriented perfectionism differs from self-oriented and socially prescribed perfectionism. *Journal of Psychopathology and Behavioral Assessment, 36*(2), 329–338. doi:10.1007/s10862-013-9397-7

Subotnik, R., Pillmeier, E. & Jarvin, L. (2009) The psychosocial dimensions of creativity in mathematics: Implications for gifted education policy. In R. Leikin, A. Berman, & B. Koichu (Eds.), Creativity in mathematics and the education of gifted students (pp. 165–180). Rotterdam, The Netherlands: Sense.

Thapa, A., Cohen, J., Guffey, S., & Higgins-D'Alessandro, A. (2013). A review of school climate research. *Review of Educational Research, 83*(3), 357–385. doi:10.3102/0034654313483907

Tirri, K., & Kuusisto, E. (2013). How Finland serves gifted and talented pupils. *Journal for the Education of Gifted, 36*(1), 84–96. doi:10.1177/0162353212468066

Usiskin, Z. (2000). Development into the mathematically talented. *Journal of Secondary Gifted Education, 11*(3), 152–162.

Winkler, D., Stephenson, S., & Jolly, J. (2012). Governor's schools: an alternative for gifted children. *Gifted Child Today, 35*(4), 292–295. doi:10.1177/1076217512455483

Ziegler, A., & Phillipson, S. (2012). Towards a systemic theory of gifted education. *High Ability Studies, 23*(1), 3–30. doi:10.1080/13598139.2012.679085

Ziegler, A., & Stoeger, H. (2017). Systemic Gifted Education: A Theoretical Introduction. *Gifted Child Quarterly, 61*(3), 183-193. doi:10.1177/0016986217705713

Appendix

Interview Framework

•Participants' professional background

•Mathematical giftedness
-What is mathematical giftedness?
-How does mathematical giftedness develop?
-Is the development of the gifted similar to the development of others?
-Why does this special program exist?

•Students of the school
-How would you describe the students of this special program? How are they different from students of other upper secondary schools?
-How would you describe your students' social skills?
-How would you describe their emotional skills?
-Do they feel pressure because they are gifted? (Underachievement, perfectionism…)
-What are the pros and cons of associating with other mathematically oriented adolescents? Why?
-How would you describe the friendships between the students of the special mathematics program?

•Teaching
-What kind of role does an upper secondary school teacher play in the development of students' social skills?
-Does your curriculum help you support adolescents' social-emotional development? Would you like to see any changes to the curriculum?
-How would you describe encouraging and supporting students?
-To what extent do you see your (or the teachers') job as an instructor of contents or as a personal development guide [kasvatus in Finnish]?
-How central do you feel your role is as a moral educator?

•Practices
-What are the objectives of the overnight school activity? What do you do there? How does it support the social-emotional development of the students?
-What are the objectives of the Lapland summer school? What do you do there? How does it support the social-emotional development of the students?
-What are the objectives of the extra mathematics courses? What do you do there? How do they support the social-emotional development of the students?
-How does participating in mathematics competitions affect students' social-emotional development?

Planning in mathematics teaching – a varied, emotional process influenced by others

Helena Grundén

Linnaeus University and Dalarna University, Sweden

Planning is an essential part of teachers' work that has consequences for students' learning. However, previous research shows that what it means to plan vary. To explore the meaning of planning from teachers' point of view, and to open up for planning as a situated and emotional process, an interview study with Swedish mathematics teachers was conducted. In the analysis, the theoretical concepts, meaning, and emotions were used as analytical tools to fill the gap identified in the review of previous research about planning. Findings reveal planning as a varied process in which teachers draw on different resources. Actors other than teachers influence both how planning is done and the mathematics teaching that is planned for. Findings also reveal that feelings, such as joy, shame, and insufficiency, are present in the process of planning. These feelings sometimes have consequences for decisions teachers make about their mathematics teaching.

Keywords: emotions, mathematics teaching, meaning, planning

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 67–88

Received 7 April 2020
Accepted 20 May 2020
Published 1 June 2020

Pages: 22
References: 29

Correspondence: hgn@du.se

https://doi.org/10.31129/LUMAT.8.1.1326

1 Introduction

Teachers make decisions about their teaching that have consequences for students' possibilities to learn mathematics. In mathematics education research, there is an increasing interest in those decisions (Potari, Figueiras, Mosvold, Sakonidis, & Skott, 2015) and there has been a shift of emphasis from research on teachers and their characteristics to an emphasis on acts of teaching (Skott, Mosvold, & Sakonidis, 2018). Teaching, in turn, involves not only teachers' actions in the classroom, but also some parts of teachers' work outside the classrooms, including planning.

Planning differs both within and between cultures and between teachers (e.g., Roche, Clarke, Clarke, & Sullivan, 2014), and one reason is to what extent curriculum materials influence and govern the teaching. Influence and government can, on the one hand, vary depending on how detailed the curriculum materials are. On the other, they can vary depending on how teachers interact with the materials. In Sweden, for example, teachers have, at least in theory, a high degree of freedom to plan their teaching (Utbildningsdepartementet, 2009), and the national curriculum does not provide detailed instructions. Despite differences, there is a common feature between descriptions that planning includes the choice of mathematical content and activities

 | CC BY 4.0

in relation to specific students. Attempts have been made to grasp this common feature in models and templates (e.g., Goméz, 2002). The rationale behind these models and templates can, for example, be to use them in teacher education or to support teachers (John, 2006). However, some studies show that teachers do not plan in line with the models and templates (e.g., Zazkis, Liljedahl, & Sinclair, 2009), and one reason is according to Hargreaves (1998) that planning models take no account of, for example, emotions, which in turn might indicate that planning is more complex and inadequate to simplify and fit into a model where the complexity is getting lost. Emotions in mathematics education are emphasized by Evans (2001), which can support the importance of emotions also in the planning process.

Existing planning processes have been described in various ways, such as a psychological process (Clark & Yinger, 1987), as curriculum implementation (Superfine, 2008), as interaction with curriculum materials (Remillard, 2005), or as a process where the choice of activities is emphasized (Roche et al., 2014; Superfine, 2008). Hence, there is a diversity in meaning when researchers talk about planning, and it seems reasonable to believe that planning also is understood in various ways on various levels in school organizations, for example, among teachers and school leaders.

Acknowledging planning as an essential part of teaching makes a lack of recognition of the diverse meanings of planning problematic, for example, in expectations of teachers, in discussions between teachers and school management, in teacher education, and in supporting material for teachers. Since teachers are the ones responsible for planning, their perspective on the meaning of planning may be particularly interesting, especially since results from an Australian study suggest that initiatives to support teachers in the planning process should start in what they already do (Sullivan, Clarke, Clarke, Gould, et al., 2012; Sullivan, Clarke, Clarke, Farrell, & Gerrard, 2013). Hence, insights into mathematics teachers' own processes and meaning-making are essential.

This article aims to contribute with such insights by presenting results from an interview study exploring what I choose to understand as planning, i.e., an on-going process of considerations, decisions, and reflections about future teaching. In the preliminary analysis of the interviews, it turned out that feelings[1] are a significant part of the meaning of planning, much in line with Alvesson and Karreman (2000) and

[1] In this article, emotions, and feelings are used interchangeably.

Hargreaves (1998). Based on the interviews with six mathematics teachers, two questions will be answered in the article: What meaning do teachers ascribe to planning? And also, what emotional aspects emerge when teachers ascribe meaning to planning? The answers will open up for a discussion about the complex processes involved in planning and what we can learn from these processes concerning teachers' decisions and actions.

2 Previous research on planning

Most studies on planning in mathematics teaching focus on learning studies, lesson studies, or on teachers' mathematical knowledge in relation to planning. Few articles focus on planning as a recurring everyday activity, which is at the scope of this article, but the few found were of two kinds. In some of the articles, the intention seems to be prescriptive, i.e., by giving suggestions on how to do it, authors aim to improve/support/develop planning in mathematics planning (e.g., Gomez, 2002, Zazkis et al., 2009). Other articles focus on describing and understanding the process of planning in mathematics teaching through for example case studies in the USA (Superfine, 2009) and Spain (Muñoz-Catalán, Yánez, & Rodríguez, 2010), and a larger study with focus groups and a survey made in Australia (e.g., Roche et al., 2014). Although the articles were different and could be sorted into prescriptive articles versus descriptive articles, three themes were spanning over them: *models and templates*, *supporting, changing, and improving teachers' planning*, *everyday work*.

Some studies acknowledge the social aspects of planning. However, ”social” often means interactions with colleagues and social life in classrooms, which means that research about planning for mathematics teaching where ”social” is seen in a wider sense seems to be missing. Consequently, the previous studies can contribute with insights into some aspects of planning, but address the complex processes of planning with a focus on meaning, methodological tools other than those used in previous studies about planning in mathematics teaching are necessary.

2.1 Models and templates for planning

Studies focusing on models and templates often build on linear ideas about planning where the models have much in common (John, 2006). In the models, planning is equated with choosing content, linking to curriculum, specifying learning objectives, goals, and teaching methods, choosing activities, and thinking of assessment (e.g., John, 2006). Models for planning are frequently used in teacher education, but practicing teachers rarely use them (Zazkis et al., 2009). Reasons for using models in teacher education include students need to learn how to plan rationally before being able to grasp the whole process. Reasons for wanting in-service teachers to use models can, for example, be a wish to control teachers (John, 2006). However, Hargreaves (1998) argues that models used for planning are flawed because they do not take emotional aspects into account.

Another critique on using linear models is that reflections and "the negotiated nature of learning" (John, 2006, p. 487) is getting lost, and that important factors that influence teachers' planning are omitted (Superfine, 2008). In line with this critique, alternative models for planning are described. An organic model that recognizes different kinds of decisions and the decision-making of experienced teachers has been developed by John (2006). In another alternative model, relations between curriculum, teachers' experiences, and teachers' conceptions are used to understand planning problems. This model is however used to understand the process of planning rather than to support teachers in the planning process (Superfine, 2008). In yet another model, which, although based on linear models, Gomez (2002) tried to include some social aspects that influence planning. In the model, planning is acknowledged as a social activity where teachers have to face both individual and social [on a classroom level] problems in collaboration with colleagues.

2.2 Supporting, changing, and improving planning

Advice on how to support, change, and improve teachers' planning is common in the research literature. For in-service teachers, collegial work and support from colleagues are important when developing planning skills (Muñoz-Catalán et al., 2010; Sullivan et al., 2013). For example, in Muñoz-Catalán et al. (2010), a novice teacher developed her flexibility in the planning process by working with more experienced colleagues.

Somewhat contradictory to the increased flexibility when planning that is described as desired by Muñoz-Catalán, some researchers suggest that support and improvement in the process of planning could be provided through specific templates or models (e.g., Gomez, 2002; Zazkis et al., 2009). Such suggestions seem to indicate a wish for more rigid planning. In addition to templates and models, curriculum materials, such as teacher guides, are produced and used to implement reforms and to support teachers in their planning process (Superfine, 2008), and for the support to be as effective as possible teacher guides should be clear and prescriptive (Smith & Sendelbach, 1979 in Clark & Yinger, 1987). Clear and prescriptive teacher guides include, for example, "summaries of the mathematical content, specific questions to ask students throughout a lesson, and examples of student errors" (Superfine, 2008, p. 12). However, Sullivan et al. (2012) conclude that "attempts to be overly prescriptive or to provide a 'teacher-proof' lesson will be counterproductive" (p. 702). Instead, they argue, education and developmental work that concerns planning should be based on processes that teachers already use.

Despite teachers' different processes, there are aspects identified as important for developing teachers' ability to plan. One such aspect is developing a "Plan B- ability" (Martin & Mironchuk, 2010) to handle situations where plans are "challenged by the realities of classroom life" (p. 23). In an attempt to handle this unpredictability of teaching situations, Zazkis et al. (2009) suggest an activity, "lesson play," in which student teachers are encouraged to engage in planning and imagine potential interactions, different possibilities, and possible student responses. A lesson play focuses on a mathematical concept and takes difficulties or misconceptions that students often have into account. In the play, there is close attention to mathematical language and various forms of mathematical reasoning that might emerge.

Sullivan et al. (2012), Martin & Mironchuk (2010), and Zazkis et al. (2009) all emphasize the importance of seeing planning as closely related to teachers' and students' everyday life.

2.3 Everyday work of planning

The everyday work of planning involves many simultaneous considerations, where aspects such as tacit knowledge and intuition, and conceptions of teaching and learning are of importance (Superfine, 2008). When planning, teachers often start with activities and nature of content rather than starting with objectives and goals (John, 2006), as emphasized in the models building on linear thinking.

A critical aspect of planning is working with curriculum materials (e.g., Remillard, 2005), and there are different views of how this is done. Teachers are sometimes described as curriculum implementers (Superfine, 2008), which indicates that there is a direct link between curriculum documents, teachers' plans, and what is enacted in classrooms. Another way of describing teachers' work with curriculum materials is "transforming curriculum ideas, captured in the form of mathematical tasks, lesson plans, and pedagogical recommendations into real classroom events" (Remillard, Herbel-Eisenmann, & Lloyd, 2009, p. 1), which means that teachers interact with curriculum materials, and hence, both the material and the teacher influence what is planned (Remillard, 2005). In these interactions, formal curriculum, e.g., policy documents, textbooks, and teacher guides, are transformed into the planned curriculum, which in turn is transformed into the enacted curriculum in the meeting with the students (Remillard, 2005). The complexity of planning and the interaction with curriculum materials is also described by Sullivan et al. (2013), who states that teachers need to interpret the curriculum and match the interpretation with mathematical ideas and tasks. Hence, teachers need to extract mathematical ideas and anticipate the potential of tasks, which, according to Sullivan et al. (2013), is a challenge for the Australian teachers that participated in their study.

When planning, teachers are influenced, for example, by assessments they made (Sullivan et al., 2013); official documents; materials developed by themselves and their peers; and web-based curriculum materials (Clarke, Clarke, & Sullivan, 2012). The context in which the planning is done is also of importance (e.g., Roche et al., 2014). Planning in the USA is often described as teachers taking given tasks from instructional material and based on those tasks plan implementation and assessment of the mathematical content. In Australia, teachers seem to exercise autonomy (Sullivan et al., 2013) and are expected to plan at the year and the unit level as well as at the level of the lesson (Sullivan et al., 2012). In contrast to, for example, Japan and China, unit and lesson plans are, to a large extent, personal and made to respond to the needs of particular students and individual teachers' styles (Roche et al., 2014). Teachers may draw on various resources such as national, state, and school-level curriculum documents when they plan. Other resources might be web-based material, commercial material, information about students provided by assessment, and colleagues.

2.4 Conclusions from the literature review

To summarize, in previous research, there is a common view that planning is an essential part of mathematics teaching. Planning is mainly described as an activity where teachers make different decisions about their teaching. However, the degree to which researchers see planning as a complex and situated process varies, but not even those who recognize the complexity and situatedness emphasize emotional aspects of planning. Hence, there seems to be a lack of research that, in line with recommendations from Hargreaves (1998), approach planning as an emotional practice. Roche et al. (2014) argue that traditions, expectations, and assumptions underlying teachers' planning are of importance for further research, and hence, exploring planning in mathematics teaching based on what meaning teachers ascribe to it is relevant. Besides, such focus opens up for insights into what the "social" and emotions mean in relation to planning. However, since there is a lack of research in the mathematics education field that acknowledges the complexity, the situatedness, and the emotional aspects of planning, there is, as mentioned in the above, a need to search for methodological tools other than those found in previous research.

3 Theoretical concepts

In this article, two essential theoretical concepts that are common in studies focusing on the wider social context of teachers' work will function as analytical tools: meaning and emotions. In the following sections, I present the understanding of these concepts that underpins this article.

3.1 Meaning

Meaning, in Cambridge Dictionary, stated as "what something represents or expresses" ("meaning," n.d.). According to Alvesson and Karreman (2000), meaning should be understood beyond what is stated in a glossary, namely as situated and produced in social practices, such as mathematics teaching, for example, when people talk. In their production of meaning, i.e., their meaning-making, people represent parts of the world in different ways, and those who listen interpret in turn what they hear. Hence, the meaning is made through an interplay between the one who produces what is said, what is said, and the one who interprets what is said (Fairclough, 2003). People make meaning in interactions with others, influenced by power, ideologies, and history (Cherryholmes, 1999). When people make meaning, there is a meeting between the individual dimension with previous experiences, the social dimension in relation with others, and the cultural dimension (Quennerstedt, Öhman, & Öhman, 2011). Hence, meaning in this article is seen as consisting of both what Alvesson and Karreman (2000) calls durable meaning, including cultural and individual ideas, and what they call transient meaning that is situated and tightly connected to language use in interactions. The meaning that is produced includes, according to Alvesson and Karreman (2000), the ways people make sense of specific issues and also how they interpret, value, think, and feel about them. Based on this, meaning in this study implies teachers making sense of, interpreting, valuing, thinking, and feeling about planning in mathematics, which means that meaning includes emotional dimensions, and hence, this definition of meaning can contribute to describing planning as the emotional practice Hargreaves (1998) suggests.

3.2 Emotions

In this article, emotions are seen as significant in the process of meaning-making (Alvesson & Karreman, 2000). Emotions are seen as both individual psychological phenomena and socio-cultural situated "cultural artefacts that convey socio-cultural messages" (Zembylas, 2007, p. 61) in line with what Zembylas calls the interactionist perspective. Expressions of emotion are seen as discursive, which means that what is possible to feel and say about feelings differs between discourses (Zembylas, 2005). However, in this study, the focus is not on discursive aspects, but on what emotions are expressed. Evans (2001) argues that it is possible to study emotions in all kinds of texts by looking for "indicators for the experiencing of emotions, such as verbal expressions of feeling, body language, emphasis or repetition of certain terms, and metaphors" (pp. 90–91), which means that it is possible to use texts, such as transcripts from interviews, to access the emotional parts of meaning-making.

4 Method

To explore the meaning of planning that emerge in teachers' stories, I needed to learn about their world, and a useful way to do this is interviewing (Qu & Duman, 2011). To find participants for the interviews, eight mathematics teachers and seven principals were contacted. In the end, six teachers from five different schools agreed to participate. All of them were teaching mathematics as one of several subjects (which is common in Sweden), four of them taught mathematics and science in compulsory school year 7-9, and two of them were class teachers teaching almost all subjects in compulsory school year 1-3. They were all experienced mathematics teachers (>10 years of teaching).

When doing interviews, there is a risk that words of the interviewer and words of the interviewees have different meanings (Qu & Dumay, 2011). Since previous studies indicate that there is no unambiguous way to talk about planning and this study aims to explore the meaning that teachers ascribe to the concept, I decided not to provide my definition or explanation of planning in contact with the teachers before and during the interviews.

Focusing on teaching in research implies challenges when it comes to grasping aspects of teaching not easily observable. This includes planning. In this study, I handled the challenges by giving each participant a notebook a few weeks before the interviews in which the teachers were asked to make notes, draw pictures, or add material that for them were related to planning. My intention with the notebooks was to study planning from teachers' perspectives. The teachers used the notebooks to prepare for the interview and brought the notebooks to the interview so that the notes reminded the teachers of previous thoughts. In that way, the notebooks served as stimuli during the interviews, which opened up for the conversation not only to touch on things the teachers came to think of in the interview situation but also what they thought and reflected on earlier. Hence, the design opened up for the possibility to grasp the durable as well as the transient meaning (Alvesson & Karreman, 2000). Interviews lasted between 24 and 60 minutes and were recorded and transcribed. Since the aim was not to explore individual teachers' meaning, all the interviews were gathered in one transcript. For this article, quotations are translated from Swedish to English.

5 Analysis

Conducting interviews with notebooks as stimuli was one way of foregrounding teachers' experiences and meaning, and throughout the analysis, attempts were made to stay close to teachers' utterances. In order to grasp the complex process of planning, the analysis was made based on the idea that using language to express, reflect, and inform are ways of acting (Fairclough, 2003) and that semiosis is meaning-making as an element in social processes (Fairclough, 2016). This means that teachers in their utterances do semiotic actions that are involved in meaning-making about planning for mathematics teaching. According to Alvesson and Karreman (2000), meaning implies "a (collectivity of) subjects' way of relating to—making sense of, interpreting, valuing, thinking, and feeling about—a specific issue" (p. 1147). Thus, meaning-making involves what teachers do, value, think, and feel, inspired by Alvesson and Karreman's (2000).

The analysis was made in three steps: 1) extraction of important passages in the transcript, 2) thematic analysis, and 3) focus on feelings. I the first step, the transcript was sieved through the abovementioned categories of do, i.e., semiotic actions about what teachers say they do when planning, and how planning is practically done; value and think, semiotic actions answering the questions "How do teachers value planning?" respectively "What do teachers think of planning?"; and feel semiotic actions where feelings are expressed. In this way, the parts of the material that concerned meaning about planning were deductively categorized for further thematic analysis (step 1 in figure 1).

The analysis so far involves getting familiar with the data, which is described as the first phase in a thematic analysis (Braun and Clarke, 2006), but also involves the extraction of passages in the transcript where meaning was ascribed to planning. Then all extracts were coded with respect to what each utterance was about; see Table 1, for example.

Table 1. Examples from generating initial codes

Data extract	Coded for
I need to have them |the students] on my side	Relations
I asked them [the students]: What do we do now?	Student participation

After that, extracts were "collected together within each code" (Braun & Clarke, 2006, p. 89). The different codes were then sorted into sub-themes, for example, the codes: student participation, relations, different needs, and students' attitude, were sorted into the sub-theme ”students"; and the codes: assessment, grade, and examination were sorted into the theme ”assessment." At this stage, relations between codes and sub-themes were considered, and four main themes were formed: Mathematics and students, Resources, Work of planning, and Impact of others (step 2 in figure 1). These themes represent the core content of the meaning the teachers ascribe to planning. All teachers are represented within each theme, although not all teachers are represented within each code. For example, there are extracts from all teachers in the sub-code assessment in which five of the teachers talked directly about assessment, while the sixth teacher talked about grades.

In this article, there is a special interest in emotions as significant in the process of meaning-making. Hence, semiotic actions found in the first filtering of the transcript through the category feel were analyzed separately (step 3 in figure 1) based on the questions: What does the teacher feel something about? What feelings are explicitly expressed? What is a reasonable interpretation of implicitly expressed feelings? In table 2, examples from the analysis are shown.

Table 2. Examples from analysis of emotional aspects

Extract	What are your feelings about?	What feelings are explicitly expressed?	Interpretation of implicitly expressed feelings?
"planning in mathematics teaching is really fun."	Planning	Joy	
"I am a little embarrassed because that [the teaching she had planned for] is not what I stand for."	Teaching Herself	Embarrassment	Shame

In the second example in the table, "I am a little embarrassed because that [the teaching she had planned for] is not what I stand for," I interpret the combination of embarrassment and "is not what I stand for" as an implicitly expressed feeling of shame. Expressions of emotion go across all of the four themes and were expressed by all achers but one.

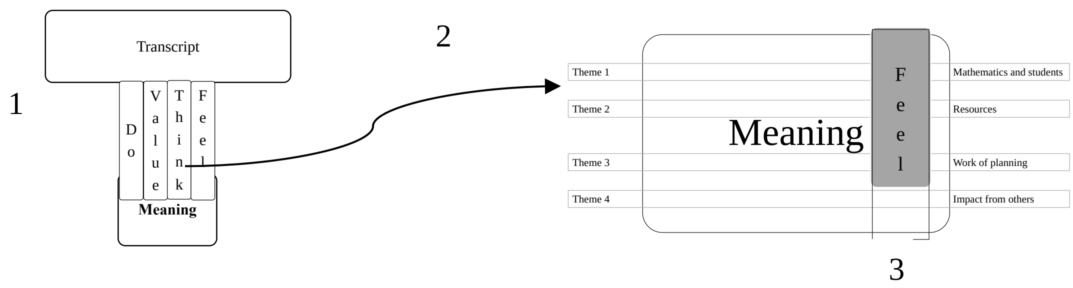


Figure 1. Overview of analysis

6 Results

The results are presented in two sections. In the first, the meaning the teachers ascribed to planning is presented, and in the second, emotional aspects of meaning are presented.

6.1 Meaning of planning

In this section, the core content of the meaning the teachers ascribed to planning is presented. It is not the meaning each teacher expressed, but a synthesized meaning of planning to which all six teachers have contributed. The intention is not to give a picture of all teachers' meaning of planning, but to give insights into meaning some Swedish teachers ascribe to planning. The result is organized around the four themes Reflections on mathematics and students, Resources for planning, Work of planning, and Impact of others.

Reflections on mathematics and students

Despite no common view on what planning includes, there is a common feature: making decisions about the mathematical content in relation to specific students. These decisions are made for a longer period, such as a semester, or a lesson or a series of lessons. In relation to long-term planning, distributing the mathematical content over one semester or one school year is one example of such work. One teacher describes how this is done: "I make a plan for one semester based on the textbook." Even if planning is not based directly on a textbook, there are several examples in the interviews where headlines in the book (e.g., Numbers and Geometry) also become headlines in the long-term plans. Short-term planning includes analyzing tasks to see what mathematical ideas students will meet and also to make detailed descriptions of what to talk about and what examples to use in a whole-class presentation.

To make decisions about the mathematical content in the planning process, teachers reflect and have considerations in relation to students and their prior knowledge, which is expressed, for example, as: "[We had] a test with simple equations [...]. And that was because I wanted a starting point to know how to continue." Another teacher gives an example of how the planning fails due to lack of insights: "some things surprised me, for example locating points in a coordinate plane. Suddenly many students did not know how to do it, and everything was delayed." In this example, the teacher had misjudged students' prior knowledge and therefore chosen too difficult examples, which is an example of when plans are made based on expected scenarios and needs to be adjusted when meeting with the students.

Although it seems implied that planning is done in relation to specific students and groups of students, teachers sometimes use the same plans for several groups, expressed, for example: “now one group regulates the others.” One teacher describes how “there are some things in common for all groups, and then there also is planning for each class or group,” which also is an example of using the same planning as the starting point for several groups. However, plans made by others have to be adjusted by each teacher, partly because students and groups are different, but also because teachers choose to teach differently. When planning, teachers often think of a ‘middle group’ of students, which is visible in utterances such as “then some students already know this” and means that students in need of more challenges are overlooked.

Teachers value planning as beneficial for students’ learning, which one teacher express as: “the biggest advantage is when you plan well. Then you have a chance to think things through, for example, which students you want to push.” Planning also contributes to teachers’ possibilities to see students’ knowledge in the classroom: Well-planned lessons with clear aims make it easier to make assessments on the go, and, as one teacher says, “move around during the lesson and catch sight of what they [the students] know.” Being well-planned is also a possibility to individualize teaching, e.g., to think through which students should answer which questions. Planning and assessment are thought of as tightly linked together, although time invested in planning is expressed as more valuable for students’ learning than time invested in assessment.

Other issues that need reflection from teachers are the choice of activities and the division of mathematical content. One teacher expresses that some activities are chosen habitually instead of consciously reflecting on which activities best benefit students’ learning. Another teacher said: “working so divided have the consequence when all parts are brought together, for example at national tests it is harder for the students,” which indicate that dividing mathematical content in the same way textbooks do might have consequences for students’ possibilities to deal with complex tasks.

Resources for planning

When planning, teachers draw on different resources. Often mentioned in the interviews are textbooks and colleagues. Textbooks seem to frequently form the base for planning in various ways, including as a template for how to divide the mathematical content. Teachers seem to use textbooks differently based on how experienced they are, which one teacher express as: “Honestly, I have used the textbook so many years, so I do not have to make so much effort to know what parts to focus or what exercises students shall work with.” Her story indicates that using the same textbook many years saves time in the planning process.

Although textbooks often are used as a base when planning, teachers often complement tasks in the textbook with activities that are in line with aims for the period. These activities can, for example, be found in other books or on the Internet, and often materials such as worksheets or cards with numbers or pictures have to be produced beforehand. One teacher problematizes this administrative work being part of the planning process: “it takes much time to laminate and make cards [...] it is expensive working time that we spend on making the material”.

Another resource mentioned in the interviews is colleagues. Most work in the short-term planning seems to be done alone, while work in the long-term planning more often is done in collaboration, which one of the teachers expresses frustration with:

> “When will I be able to plan with my colleagues? The work turns into working alone, although I don’t want it. It is a lot... We make these big, long-term plans, but we never have time to see each other once we have started.”

The quotation is an example of teachers thinking of planning as something that is preferably done in collaboration also in short-term planning.

Work of planning

Planning is seen as an essential part of teachers’ work that has consequences for students learning as well as teachers’ work situation – planning can cause stress as well as be a way to reduce stress. When planning, frames for teaching are made. However, these frames often need to be adjusted in the teaching situation, although modifications also can be made before meeting with the students, for example, when spontaneous ideas replace prior planning.

The work of planning varies for several reasons; for example, what time of the school year the planning is done. At the beginning of a school year, teachers, as well as students, have more energy to be creative and put more effort into the planning so that they can plan for teaching that demands more of students. One teacher expresses the variation: “it depends on what time of the year it is if you have the energy or not.” In semesters where national tests take place, planning seems to focus on repetition.

Students’ age is another aspect that makes the work on planning vary. For example, teachers who meet younger students have to think about what more complex processes such as reasoning might be for the youngest students or think about how to translate aims and goals so that they are understandable for the students. Teachers who teach older students need to consider their right to participate in planning.

Decisions are made in advance and at the moment. Sometimes the decisions are hasty, and sometimes they are well thought through, and previous experiences are used to make them. Sometimes detailed plans are made at the moment, which one teacher calls spontaneous planning:

> “Spontaneous last-minute planning often turns out well [...], but you often dis it because it was spontaneous. Instead, you should take the time afterward and write down or memorize that this was good. I can use this in my planning another time”.

The spontaneous planning might, according to the same teacher, be more influenced by students, and lead to valuable experiences, especially if reflections are made afterward.

Impact from others

Planning is influenced by the material as well as by people. For example, national curriculum influence planning and planning can be seen as a way to ensure that content from the national curriculum is covered. Another result pointing to influence on planning is that decisions made by other actors, such as school leaders, influence teachers’ planning. Their organizational decisions have consequences for teachers’ possibilities to, for example, plan for letting students work in smaller groups and work thematically in cooperation with other teachers. Their decisions also influence to what degree teachers can be creative. For example, requirements to plan in a specific template can change the process of planning from creative to instrumental, and from doing planning for yourself to doing it for others – written plans often should be available to school leaders and parents – and the purpose of that is sometimes perceived as a way to control teachers.

When planning, teachers seem to evaluate their thoughts on mathematics teaching and activities they want to do against the thoughts of others, and also against some general idea of what mathematics teaching is and how it should be done. One example of this is when one teacher wants to change her teaching and asks herself: “Do I dare? Do I have the energy [to argue for her choices with parents]?”

6.2 Emotional aspects

Emotional aspects seem to be a key to new insights about the meaning of planning in mathematics teaching; they emerge on several levels and span the aspects presented above. Planning itself raises feelings explicitly expressed by the teachers. In addition, feelings are also implicitly expressed, for example, when describing imagined or real consequences of decisions made in the planning process, or as consequences of decisions made by others that influence the planning. There is a multitude of feelings that emerge: joy, creativity, shame, and control are some examples.

When teachers say: “It is a freedom to feel that I can do differently with different students” and “I have been at schools where teachers are trusted [to plan and organize their teaching by themselves],” they express feelings of freedom and trust. These feelings were emphasized as important, and part of the joy teachers feel when planning.

In contrast to freedom, there are examples of teachers feeling constrained in the process of planning, expressed by one teacher who has been obliged to use a specific template for planning:

> “I have had exactly that content, but it has not been as formal. That formality… Everything must look the same. That makes me feel locked in, or I feel that I am not as free in my thinking as before.”

In this quotation, the teacher turns against the template and talks about her decrease in creativity. In another part of the interview, the same teacher emphasizes creativity as necessary for planning fruitful mathematics teaching. Creativity, which in the interviews is talked about as related to feelings, is also raised by another teacher when she refers to administrative work and says that this “takes away a lot of the creativity [in planning process]” which made her feel more constrained and planning became more boring. Hence, creativity seems to be related to joy, which is prominent in the example when one teacher says: “The fun part is to think about how to explain this in the best way.” Fun is a term that also comes up in utterances as: “Planning in mathematics is really fun,” where the teacher describes a feeling of joy related to this specific part of the work, especially when it is done in cooperation with other teachers.

Planning can also raise frustration: “Neither the students nor I get the help we need” That makes me angry, and then I get… [teacher cries]”. In this situation, the teacher describes how she thinks it is impossible to do the planning she wants due to a lack of resources. She has to plan and organize her teaching in ways she knows will not benefit students’ learning. Her expression of anger and sadness seems to reveal a feeling that both she and her students are abandoned.

Feelings of insecurity also emerge in the interviews. One teacher expresses it as “a fear that I will go to low” which indicates that the teacher is worried about not being able to challenge all students, or as when a teacher talks about how she has planned her teaching without textbooks for some time: “I have always been afraid not to have a textbook.” In the first example, insecurity is related to students, not giving them what they need, and the second example is insecurity related to the teacher herself, a textbook is safe – without it, the teacher has to rely on herself. Common for expressions of insecurity is that teachers worry about not planning a mathematics teaching that benefits students’ learning optimally and also is accepted by students, parents, and other actors.

Another example relating to other actors is the teacher who refers to herself as “bounded to textbooks” and express how they make her feel safe, although she “knows that it [being bounded to textbooks] does not sound good.” Here she expresses that other actors have opinions and implies a feeling of shame for relying on the textbooks in her planning. Shame is also present in an example where one teacher describes how she met students’ desires and changed her teaching. In the interview, she recalls a conversation with her students: “I am getting a little embarrassed because this is not what I stand for. So, there are tensions. You know, now I am as old-fashioned as I was before. Five years ago.” In this quotation, she implies that abandoning her ideas about mathematics teaching and organizing her teaching in line with students’ desires makes her feel ashamed since she does not teach the way she wants to.

Feelings related to students are common when planning. Thinking of how to explain a specific content to students is described as fun, while feelings of insufficiency or sadness are visible, for example, when one teacher talked about a test situation: “It was a fiasco. I felt despair […], and I just felt that I had turned myself inside out. I didn´t know what to do!” In this situation, the teacher did not know how to plan her teaching to give students opportunities to learn, which seems to cause a feeling of powerlessness.

7 Discussion and conclusions

Results from this study indicate that meaning Swedish teachers ascribe to planning in many respects are in line with the previous research from other contexts presented earlier in the article, for example, that planning is done in long-term and short-term, that textbooks are frequently used, and that colleagues are seen as resources. Hence, it seems as although planning is a cultural, contextual phenomenon; there are similarities so that conclusions drawn in one context might be valuable for other contexts as well. This means that findings from this Swedish context in this study, which reveal planning for mathematics teaching as an even more complex process than previously shown, might be worth taking into consideration also in other contexts. This study contributes with new insights by showing that others' opinions and ideas highly influence teachers' planning, both when it comes to how the planning is done and when it comes to the mathematics teaching planned for. This study also shows how feelings are important, but previously often neglected, part of the planning for mathematics teaching.

Planning for mathematics teaching gives rise to a series of feelings, such as joy and shame. Feelings of joy are expressed in relation to being creative in the planning process. These results can be compared to research showing that one way to implement reforms and to support teachers in the planning process is to make teacher guides with detailed instructions (e.g., Superfine, 2008). Such teacher guides might correspond with indications that teachers need support in extracting important mathematical ideas (Sullivan et al., 2013). However, the results in this study indicate that there might be a risk that such teacher guides reduce creative work and, consequently, also the joy with planning, which might have unwanted consequences.

Another recurring theme in the interviews that influences teachers' work is templates and models for planning. Previous research indicates that templates and models are not used by in-service teachers but frequently used in teacher education (Zazkis et al., 2009). However, findings in this study indicate that some teachers are obliged to use templates, which affects their planning as well as their feelings concerning planning negatively. Whether the purpose is to facilitate planning or to, as John (2006) suggests, control teachers, making templates mandatory might, as findings from this study indicate, have negative consequences. Hence, initiatives intended to support teachers' planning processes may not automatically do so, and more information is needed about how supportive initiatives should be designed to contribute in a fruitful way to teachers' planning and ultimately to students' learning.

Several examples in previous research emphasize planning as a task for the teacher without acknowledging that the teacher does the planning in social settings influenced by values, opinions, and decisions from others. Although some studies (e.g., Gómez, 2002; Sullivan et al., 2013) widen the view and recognize planning as a social activity that can be made with colleagues, research most often positions the teacher as someone who can make decisions regarding teaching independently. Teachers as independent and free to plan their teaching as they want to correspond well with writing that preceded the Swedish national curriculum (Utbildningsdepartementet, 2009). However, results from this study show that planning is situated and influenced by opinions, ideas, and decisions from others, which means that even if teachers are the ones responsible for planning, planning is not something teachers can do in isolation from context, from governing, and from other actors, such as colleagues, school-leaders, students, and parents. Hence, teachers, as independent actors in the planning process, can be questioned.

Feelings of shame are expressed when teachers make decisions and organize teaching in a way that is not consistent with their own ideas about how mathematics teaching should be done. It seems like some teachers refer to an unspoken common idea about how mathematics teaching should be done, an idea that students, parents, school leaders, and others can hold against them if they teach in another way. Hence, teachers sometimes act against their own ideas to teach in line with the ideas of others. This means that not only teachers' traditions, expectations, and assumptions are of importance when planning in mathematics teaching, but also several other actors. Hence, it is not enough that teachers are well-educated and informed about how to organize teaching to support students' learning if there are other actors with different views of good mathematics teaching that have the power to influence decisions on teaching.

How decision-makers at an organizational level look at planning and mathematics teaching also have consequences for teachers' planning, for example, if teachers have allocated time with their colleagues, how long lessons are and when they are scheduled, and if school leaders have opinions about what and how the teacher teaches.

Results from this study build on interviews with six teachers, and hence, it is not possible to generalize findings to what meaning all teachers ascribe to planning. Nevertheless, findings give insights into some teachers' meaning and thereby contribute with new insights about the complexity of being a teacher and also shed light on the gap between what meaning teachers ascribe to planning and the ways decision-makers may deal with planning in mathematics teaching. Feelings as an important part of planning in mathematics raise questions about what lies behind them and what can be done for the positive feelings to outweigh, at the same time as planning is done so that the students are given the best opportunities to learn mathematics. The results might also be of value for teachers who, by reflecting on a specific part of their work that they may often take for granted, may come to new insights that benefit them in their professional practice. For example, being aware of that the views of other actors, such as school-leaders, influence the planning, might open up for discussions between teachers and school leaders about what mathematics teaching should be. In addition, results need to be considered in discussions about how to support teachers and student teachers in their planning, so that initiatives, on the one hand, are based on what teachers already do, and on the other hand, function as a way to make research in mathematics education influence the planning of and thus the teaching of mathematics.

References

Alvesson, M., & Karreman, D. (2000). Varieties of discourse: On the study of organizations through discourse analysis. *Human Relations, 53*(9), 1125–1149. doi:10.1177/0018726700539002

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. doi:10.1191/1478088706qp063oa

Cherryholmes, C. H. (1999). *Reading pragmatism*. New York, NY: Teachers College Press.

Clark, C. M., & Yinger, R. J. (1987). Teacher planning. In J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 84–103). London, England: Cassell Educational.

Clarke, D. J., Clarke, D. M., & Sullivan, P. (2012). How do mathematics teachers decide what to teach? *Australian Primary Mathematics Classroom, 17*(3), 9–12.

Evans, J. (2001). Developing the ideas of affect and emotion among adult learners. In L. Östergaard Johansen & T. Wedege (Eds.), *Numeracy for Empowerment and Democracy? Proceedings of the 8th International Conference of Adults Learning Mathematics (ALM8)* (pp. 88–96). Roskilde, Denmark: Roskilde University.

Fairclough, N. (2003). *Analyzing discourse: textual analysis for social research*. New York, NY: Routledge.

Fairclough, N. (2016). A dialectical-relational approach to critical discourse analysis in social research. In R. Wodak & M. Meyer (Eds.), *Methods of critical discourse studies* (3rd ed., pp. 86–108). Los Angeles, CA: Sage.

Gómez, P. (2002). Theory and practice in pre-service mathematics teacher education from a social perspective. In P. Valero & O. Skovsmose (Eds.), *Proceedings of the 3rd International MES Conference* (pp. 1–13). Copenhagen: Centre for Research in Learning Mathematics.

Hargreaves, A. (1998). The emotional practice of teaching. *Teaching and Teacher Education, 14*(8), 835–854. doi:10.1016/S0742-051X(98)00025-0

John, P. D. (2006). Lesson planning and the student teacher: re-thinking the dominant model. Journal of Curriculum Studies, 38(4), 483–498. doi:10.1080/00220270500363620

Martin, D. B., & Mironchuk, A. (2010). Plan B: If I knew then what I know now. New England *Mathematics Journal*, *42*, 20–29.

Meaning. (n.d.). In *Cambridge Dictionary*. Retrieved from https://dictionary.cambridge.org/dictionary/english/meaning

Muñoz-Catalán, C. M., Yánez, J. C., & Rodríguez, N. C. (2010). Mathematics teacher change in a collaborative environment: to what extent and how. *Journal of Mathematics Teacher Education*, *13*, 425–439. doi:10.1007/s10857-010-9157-5

Potari, D., Figueiras, L., Mosvold, R., Sakonidis, C., & Skott, J. (2015). Introduction to the papers of TWG19: Mathematics teacher and classroom practices. In K. Krainer & N. Vondrová (Eds.), *Proceedings of the Ninth Conference of the European Society for Research in Mathematics Education (CERME9, 4-8 February 2015)* (pp. 2968–2973). Prague, Czech Republic: Charles Univeristy in Prague, Faculty of Education and ERME.

Qu, S. Q., & Dumay, J. (2011). The qualitative research interview. *Qualitative research in accounting & management, 8*(3), 238–264. doi:10.1108/11766091111162070

Quennerstedt, M., Öhman, J., & Öhman, M. (2011). Investing learning in physical education – a transactional approach. *Sport, Education and Society, 16*(2), 159–177.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research, 75*(2), 211–246. doi:10.3102/00346543075002211

Remillard, J.T., Herbel-Eisenmann, B., & Lloyd, G.M. (Eds.). (2009). *Mathematics teachers at work: Connecting curriculum materials and mathematics instruction*. New York, NY: Routledge.

Roche, A., Clarke, D. M., Clarke, D. J., & Sullivan, P. (2014). Primary teachers' written plans in mathematics and their perceptions of essential elements of these. *Mathematics Education Research Journal, 26,* 853–870. doi:10.1007/s13394-014-0130-y

Skott, J., Mosvold, R., & Sakonidis, C. (2018). Classroom practice and teachers' knowledge, beliefs, and identity. In T. Dreyfus, M. Artigue, D. Potari, S. Prediger, & K. Ruthven (Eds.), *Developing research in mathematics education. Twenty years of communication, cooperation and collaboration in Europe* (pp. 162–180). Oxon, UK: Routledge.

Sullivan, P., Clarke, D., Clarke D., Gould, P., Leigh-Lancaster, D., & Lewis, G. (2012). Insights into ways that teachers plan their mathematics teaching. In J. Dindyal, L. P. Cheng, & S. F. Ng (Eds.), *Mathematics education: Expanding horizons. Proceedings of the 35thannual conference of the Mathematics Education Research Group of Australasia* (pp. 696–703). Singapore: MERGA, Inc.

Sullivan, P., Clarke, D. M., Clarke, D. J. Farrell, L., & Gerrard, J. (2013). Processes and priorities in planning mathematics teaching. *Mathematics Education Research Journal, 25*, 457–480. doi:10.1007/s13394-012-0066-z

Superfine, A. C. (2008). Planning for mathematics instruction: A model of experienced teachers' planning process in the context of a reform mathematics curriculum. *The Mathematics Educator, 18*(2), 11–22.

Superfine, A. C. (2009). The "problem" of experience in mathematics teaching. *School Science and Mathematics, 109*(1), 7–19. doi:10.1111/j.1949-8594.2009.tb17858.x

Utbildningsdepartementet. (2009). *Uppdrag att utarbeta nya kursplaner och kunskapskrav för grundskolan och motsvarande skolformer m.m.* (U2009/312/S). Retrieved from https://www.regeringen.se/49b714/contentassets/25958d8de58541efa9d46cd8d104da6e/uppdrag-att-utarbeta-nya-kursplaner-och-kunskapskrav-for-grundskolan-och-motsvarande-skolformer-m.m

Zazkis, R., Liljedahl, P., & Sinclair, N. (2009). Lesson plays: Planning teaching versus teaching planning. *For the Learning of Mathematics, 29*(1), 40–47.

Zembylas, M. (2005). *Teaching with emotion*. Greenwich, CT: Information Age Publishing.

Zembylas, M. (2007). Theory and methodology in researching emotions in education. International Journal of Research & Method in Education, 30(1), 57–72. doi:10.1080/17437270701207785

The three-factor model: A study of common features in students' attitudes towards studying and learning science and mathematics in the three countries of the North Calotte region

Päivi Tomperi[1], Inna Ryzhkova[2], Yulia Shestova[2], Oleg Lyash[2], Irina Lazareva[2], Asya Lyash[2], Mona Kvivesen[3], Saeed Manshadi[3] and Stig Uteng[3]

[1] University of Oulu, Faculty of Education, Finland

[2] The Murmansk Arctic State University MASU, Faculty of math and science, Maths, Physics and ICT department, Russia

[3] UiT The Artic University of Norway, Faculty of Humanities, Department of Education, Norway

This study investigated common features of students' attitudes towards studying science and mathematics in comprehensive and secondary schools in three countries. Data were obtained by conducting a survey (N = 581) in Norway, Finland and Russia. A Confirmatory factor analysis (CFA) provided a model with a three-factor solution consisting of factors: the perception of the teacher, anxiety towards science and mathematics, and motivation. The results suggest that most students are motivated to study sciences and mathematics. Data analysis indicate gender differences in attitudes to students' future studies and career plans. Most girls recognized the importance of these subjects for their future studies and careers, while boys showed more interest than girls in local career opportunities in industry. Teachers have a significant role in directing students' attitudes toward science and mathematics. Students experienced that the teachers who use innovative teaching approaches, both motivate and reduce anxiety, in their learning process.

Keywords: attitudes, survey, comparative study, confirmatory factor analysis, secondary school

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 89–106

Received 5 February 2020
Accepted 14 May 2020
Published 1 June 2020

Pages: 18
References: 33

Correspondence:
paivi.h.tomperi@oulu.fi

https://doi.org/10.31129/LUMAT.8.1.1369

1 Introduction

One of the aspects of globalization is sharp qualitative growth and widespread modern technological solutions that cannot but have a significant impact on the cultural values and lifestyle of people. These trends necessitate the development of technical business awareness and motivation to learn science and mathematics among students. There is a need for educated persons, who have scientific competences being able to function in the modern world to meet challenges requiring the integration of scientific and technical knowledge. 21st-century workforce skills (i.e., adaptability, complex communication/social skills, nonroutine problem solving, self-management/self-development, and systems thinking) should be provided in science and mathematics classrooms where students can exercise activities, investigations and experiments to

 | CC BY 4.0

develop these skills (Binkley et al., 2012; Bybee, 2010). It is well known that while students' interest towards school science and technology is quite high, their interest in science and technology careers and occupations has become alarmingly low in developed countries (for example EC, 2004; Lavonen et al. 2008; Osborne, Simon & Collins, 2003; Savelsbergh et al., 2016; Schreiner & Sjøberg, 2010; Wang & Degol, 2013). This article presents the results of the study conducted by an international research team within the Kolarctic CBC project (KO 2071) "Development of common approaches to involve youth into science and technical sphere – Be Tech!"

Students' attitudes toward science refer specifically to students' emotional conception of science – beliefs, values and feelings – and is a complex, multi-dimensional construct (Osborne et al., 2003). In their review of the literature, Osborne et al. (2003) identified several constructs that are determinants of students' attitudes influencing science-choice behaviors, including the perception of the science teacher, the nature of the classroom environment, achievement in science, the value of science, motivation, attitudes of peers and friends towards science, attitudes of parents towards science, enjoyment of science, anxiety towards science, self-esteem at science, and fear of failure on course. The last three components are included in the concept of self-efficacy, which is an expectancy about one's capabilities to learn or perform a given task (Bandura, 1977). Efficacy beliefs are essential for the motivational process since individuals are unlikely to engage in behaviors and activities at which they do not expect to succeed. Sense of self-efficacy has been linked to the adoption of challenging goals, effort investment, persistence and resiliency in the face of difficulty (Bandura, 1997).

According to Walker, Smith and Hamidova (2013) the multi-dimensional structure of attitudes views attitudes as consisting of three distinct domains: affect, behavior, and cognition. Enjoyment for learning science can lead to positive feelings towards science-related activities at school (affective component). Students' positive attitudes towards science are visible when they are reading science magazines for pleasure and visit science exhibitions (behavioral component). Expose to evidence for global warming may influence students' beliefs about the importance of science (the cognitive component). Fishbein and Ajzen (1975) divide attitudes to the affective domain and beliefs to the cognitive domain. They made a notion that beliefs can change as a result of one's attitudes and behavior, and an attitude may influence the formation of new beliefs. If a student performs successfully on a science test, he or she may form a new belief that science is not that difficult after all. A student's attitudes towards studying science and mathematics is a function of his or her beliefs about the attributes relating to studying science and math, and an evaluation of those attributes. Beliefs and attitudes are interrelated so that beliefs are primary and attitudes secondary. It follows that student's beliefs about studying and learning science contribute to the formation of his or her attitudes towards studying and learning science (Fishbein et al., 1975; Walker et al., 2013).

Teacher and the learning environment are considered the main factors in defining the students' attitudes towards science and mathematics. Savelsbergh et al. (2016) reviewed 56 publications to study the effects of different innovative teaching approaches on student's attitudes and achievement. Innovative teaching approaches included context-based, inquiry-based, ICT-enriched, collaborative and extra-curricular. They found significant positive effects of innovative teaching approaches on both attitude and achievement. However, they could not find different effects on different kinds of teaching approaches and concluded that rather than a type of teaching approach, it is the quality of content and the implementation that matters.

Many students perceive science as difficult. Lavonen et al. (2008) found a strong correlation between perceived difficulty (feeling lack of competence) of a subject and the uninterestingness of the subject. In science, the ideas and concepts exist at three different thought levels: macro, micro and symbolic levels (Johnstone, 1991). Students may work with all three levels of the same concept during one lesson and according to Johnston, the interaction of these three levels may cause overloading of the working memory capacity hence causing difficulty in conceptualizing various areas in science. When students use scientific terms and symbols new to them, it may cause difficulty in their conceptualizing process. This is because of the weak connection between their cognitive structures and scientific concepts/symbols, causing overloading of the working memory (Bahar & Polat, 2007). Students often have misconceptions about science phenomena that do not correspond well with the scientific knowledge to be taught. These alternative conceptions are enduring and resistant to change by conventional teaching strategies (Driver, 1981). To be able to cover the science topics given in the curriculum, teachers may adopt teacher-centered teaching approaches as the student-centered teaching approaches are more time-consuming (Bahar et al., 2007).

Positive experiences in school science, including a supportive relationship with teachers and pedagogy, which emphasize the relevance of science, contribute to interest and enjoyment of science. However, these factors and positive parental attitudes to science don't translate into aspirations in science. Aspirations may be nurtured and developed to the point in which students can imagine themselves in some science-related roles and can perceive science careers as possible and achievable. Children whose families have high levels of science capital, for example, parents with science degrees and/or who work in science jobs, are more likely to express science aspirations (DeWitt & Archer, 2015). Recent research in England (Sheldrake, Mujtaba & Reiss, 2017) has measured students' perceived utility in science (valuing science through thinking that science leads to various benefits such as increased skills and facilitating careers) which associated strongly with science-related career aspirations. They concluded that in science education, highlighting the applications and relevance of science to everyday life would be beneficial.

There is an apparent gender difference in attitudes towards science. Gender is not the result of a person's sex but produced through continuous verbal and bodily performances in which a person "do girl" or "do boy" (Butler, 1990). Many girls consider that gender is not a barrier to make study and career choices, yet their actual choices remain traditional. The common association of science with cleverness means that science aspirations are not experienced appropriate for everyone (Archer et al., 2013). The gender difference is the largest in the developed countries. In wealthy countries, few students want to become scientists, and especially girls state that they don't want to work in technology. Girls want to work with people and help other people, whereas boys are less interested in such work. Researchers conclude that to obtain a better gender balance in the future, and the science curricula must become more value-, people-, and environment-oriented (Schreiner et al., Sjøberg, 2010).

Countries with high levels of gender equality, for instance, in Norway and Finland, the gender gap in tertiary level student enrollment in STEM studies and college graduation rates in STEM fields is the largest (World Economic Forum, 2015). Researchers explain that economic and life quality risks are lower in gender-equal countries compared to less gender-equal countries where STEM fields often represent higher salary occupations and stability (Stoet & Geary, 2018).

In their research, Wang, Eccles, and Kenny (2013) noted that people with high mathematical and high verbal abilities could find a wider choice of careers in both STEM and non-STEM fields than those with high mathematical and moderate verbal abilities. The group with high mathematical and high verbal abilities included more girls than boys. In recent research (Stoet et al., 2018), most boys scored relatively higher in science than their all-subject average, and most girls scored relatively higher in reading than their all-subject average. Pupils are usually recommended in secondary education to make choices in their coursework based on their academic strengths and enjoyment. When girls have even abilities in science or mathematics with boys, science, or mathematics is more likely a personal academic strength for boys than girls (Stoet et al., 2018).

1.1 Purpose of the study

In this study, the goal was to find common features in secondary school students' attitudes towards studying and learning science and mathematics, and the factors which have an influence on them, in Finnish, Norwegian, and Russian North Calotte region by using combined data obtained through the same survey. The research questions are:

1. What are the common features in attitudes towards studying and learning science and mathematics among secondary school students?
2. Which factors influence secondary school students' attitudes towards studying and learning science and mathematics?
3. Are there gender differences in attitudes among secondary school students towards studying and learning science?

2 Methodology

2.1 Survey

The BeTech! Instrument was designed as a starting point of the international project and aimed at revealing the existing attitudes towards learning and studying science and mathematics in the participating schools according to project goals. There are cultural differences and similarities in students' interests, priorities, experiences, career aspirations, etc. which are relevant for teaching and learning of science and mathematics. The BeTech! Instrument is based-on common views, perspectives and value positions. There is a specific theoretical framework and precisely defined research questions. According to Fishbein and Ajzen (1975), attitudes are affective variables, so the questionnaire is aimed at assessing students' feelings instead of what they assume to be true about science (i.e., beliefs). The items were created to explore students' attitudes in the context of school science, not the nature and value of science in general (Osborne et al., 2003; Walker et al., 2013). Specific questions, for which we looked for answers through questionnaire separately in three participating countries, and the items with which we aimed at obtaining the answers, were:

1. What are the students' attitudes towards studying science and math? (Items 1, 2, 4-6, 36)
2. What role do science and math play in the students' future (study and work) plans? (Items 3, 7-9)
3. What is the influence of attitudes of parents, peers, and friends to students' attitudes towards studying science and math? (Items 10-17)
4. What is the influence of teaching to attitudes towards studying science and math? (Items 19-35)
5. What is the influence of local industry and work opportunities to students' attitudes towards studying science and math? (Items 8 and 18)

The BeTech! Instrument is a questionnaire consisting mainly of closed, pre-structured questions, and the respondents give their answers by choosing the alternative appropriate to their view. The questionnaire was created using Webropol 3.0 survey and reporting tool and students answered it online anonymously. Closed questions were chosen because then the data is rapidly collected and coded, and easy to compare. Because they do not require any extended writing, they are easily and quickly answered. In addition to multiple-choice questions concerning gender, favorite school subjects, and estimations of one's own skills in science and mathematics, the questionnaire contained 36 items (see Appendix) on a 5-point Likert-scale ranging from 1 = strongly agree through 3 = not sure to 5 = strongly disagree. Items deal with each of the nine components which are known to contribute an individuals' attitudes towards science: the perception of the science teacher (items 22, 23, 27-29, 32), the nature of the classroom environment (items 19-22, 24, 28-36), achievement in science (items 4-6, 25, 26, 36), the value of science (items 3, 7-9, 18), motivation towards science (items 1, 2, 4-9, 16-18, 36), attitudes of peers and friends towards science (items 10, 11, 13, 15, 17), attitudes of parents towards science (items 12, 14, 16, 17), enjoyment of science (items 1, 2, 4, 8, 10, 11, 17, 36), and self-efficacy (items 4-6, 21, 24-26, 36) (e.g., Osborne et al., 2003).

We chose a simple Likert scale because it has advantages when the instrument is used in different cultures and translated into other languages. The risks of the middle category, "not sure," was recognized and discussed. The BeTech! Instrument was developed in English and translated into Finnish, Norwegian, and Russian. Each item is simple and rather short so that possible translation errors could be reduced to a minimum. Research partners come from a variety of backgrounds and they carry with them their own perspectives, theoretical approaches, and research interests, which was also a challenge in the development of the questionnaire, but it also enables partners to learn from each other. To ensure that the questionnaire would address the issues that it was intended to do, the instrument was developed through a process of discussion, reflection, trying out, improving, and trying out again because it was the starting point of the BeTech! The project and the time to develop it was short. The questionnaire is a product of international collaboration, but in the end, it was the Finnish partner that took the final decision.

The questionnaire was translated into Finnish and piloted in a Finnish classroom consisting of 16 eight graders. Through it we obtained experience on procedural matters and practicalities on organizing the survey. The researcher was face-to-face with respondents and got spontaneous reactions from the students and their teacher to the items. Based on their feedback, the questionnaire was revised.

2.2 Participants

580 students in total, aged 12-16, answered the questionnaire. The age distribution of respondents was: 42% 13-years, 10% 14-years, 40% 15-years, and 8% 16-years.

In Murmansk and the Murmansk region, Russia, four comprehensive schools participate in the project and 268 students (118 girls and 144 boys) answered the questionnaire. Natural sciences are composed of physics, chemistry, biology, and geography. Besides, the questionnaire studied interest in mathematics and ICT. All these subjects are compulsory in Russian schools: mathematics is studied throughout the whole school period from grade one to eleven; biology and geography start in grade five; physics starts in grade seven, chemistry and ICT start in grade eight (in some schools ICT can be taught earlier as an optional subject). In grades five to eleven, natural sciences are studied as separate subjects by subject teachers. Subject teachers are usually specialized in one or two subjects.

In Oulu, Finland, two comprehensive schools participate in the project, and 175 students (105 girls and 70 boys) answered the questionnaire. Natural sciences are composed of physics, chemistry, biology, and geography. ICT is not compulsory. In grades seven to nine, natural sciences are taught as separate subjects by subject teachers. Subject teachers are usually specialized in two or three subjects such as mathematics, physics, and chemistry, or biology, and geography. Mathematics is studied throughout the whole school period in grades one to nine.

In Alta, Norway, two schools participate in the project, one comprehensive school and one secondary school. 138 students (63 girls and 75 boys) answered the questionnaire. Natural sciences are composed of physics, biology, chemistry and geology, and are studied as one subject in grades one to ten. Mathematics is studied throughout the whole school period in grades one to ten. In Norway, ICT is not an own subject but compulsory in all subjects.

2.3. Confirmatory factor analysis (CFA)

To examine the underlying factor structure of the questionnaire, a series of exploratory latent structure analyses (EFA) were conducted. We applied mainly the fa-function from the psych-package written for R (R Core Team, 2019) and SPSS (IBM, 2017) statistic program package to get the factors with corresponding items. Both packages gave similar results. Retained factors were rotated using oblique (oblimin) rotation (Hendrickson & White, 1964). These factors were then used as a base for a confirmatory factor analysis (CFA), where the resulting model is depicted (see Figure 1). The lavaan (Revelle, 2015) and SemPlot (Epskamp, 2015) packages for R was used here. The fit of the model to the data was evaluated using standard fit indices (chi-square, comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR)). The non-significant chi-square test statistic, CFI of .90 or greater, RMSEA of .08 or lower, and SRMR of .08 or lower each reflect an adequate model fit (Kline, 2015). In our model, the chi-square statistic was significant with a value of 330.5. However, this statistic tends to be significant with larger samples, here respondents (Mair, 2018). Thus, it is not that important in this study. Further, the CFI was 0.958, the RMSEA was 0.075, and the SRMR was 0.069. Thus, it is an adequate fit.

Three factors extracted from attitude items with factor loadings and rounded percentages of students' responses to the questionnaire are shown in Table 2. Additionally, a T-test was conducted to compare differences between boys and girls. We chose the independent T-test, which was done by the GNU PSPP-package.

3 Results and discussion

The results are presented in two parts. The results from the survey with examples and gender differences are presented first. Secondly, we report the results of the CFA-study, the obtained three-factor model.

3.1. Survey

With six items, we investigated students' attitudes towards studying science and math (see Table 1). More than half of the respondents indicated that they enjoyed studying science. At the same time, about one-fourth of respondents in Finland and Russia feared that they might fail in their studies, while in Norway, respondents' fear of failure was distinctly lower. As the results show, among respondents, girls in Finland and Russia felt a little bit more insecure in their development in science and mathematics, but in Norway, more boys than girls experienced a fear of failure.

When asked what role science and math played in the students' future study and work plans, over half of the respondents recognized the importance and necessity of studying natural sciences and mathematics for the successful development of other school subjects (item 7). More girls than boys agreed in this matter in each country, and there is a significant gender difference. Also, the importance of studying natural sciences and mathematics for admission to the desired upper secondary school was expressed (item 9). This allows us to conclude that students are motivated to study natural sciences and mathematics, but this extrinsic motivation is mainly related to continuing education at the upper secondary level.

Table 1. Item examples with gender differences in attitudes. Rounded percentages of students' responses in the two positive extremes of "strongly agree" and "agree."

Items		**NOR** %	**RUS** %	**FIN** %	**SD**
What are the students' attitudes towards studying science and math? Items 1, 2, 4-6, 36					
1. I enjoy learning science.	Boys	70	61	53	1,044
	Girls	41	59	48	
4. Studying science and math is risky: I can fail.	Boys	13	22	24	1,108
	Girls	8	29	26	
What role do science and math play in the students' future (study and work) plans? Items 3, 7-9					
7. I need math to learn other school subjects.	Boys	53	60	61	1,066*
	Girls	54	65	74	
9. I need to do well in science and math to get into the upper secondary school I want.	Boys	47	60	47	1,193
	Girls	35	65	55	
What is the influence of attitudes of parents, peers, and friends on pupils' attitudes towards studying science and math? Items 10-17					
16. My parents are proud of my achievements in science and math.	Boys	60	56	64	1,115
	Girls	52	60	70	
15. My friends encourage me to study science and math.	Boys	9	35	11	1,317
	Girls	8	33	32	
What is the influence of teaching to attitudes towards studying science and math? Items 19-35					
21. I always know clearly the goal of learning in math.	Boys	60	60	64	1,139**
	Girls	44	47	61	
22. Teacher listens to our experiences and opinions and takes them into account in teaching	Boys	64	44	47	1,174*
	Girls	52	33	52	
23. Teacher is enthusiastic about the subject she/he is teaching.	Boys	64	57	51	1,070*
	Girls	54	53	69	
31. We memorize science facts and principles in every lesson.	Boys	43	55	53	0,958*
	Girls	38	40	60	
What is the influence of local industry and work opportunities to students' attitudes towards studying science and math? Items 8 and 18					
18. I would like to work in local industry or company in the future.	Boys	27	14	24	1,254
	Girls	10	6	8	
8. I would like a job where I use science and math.	Boys	17	45	19	1,220
	Girls	18	34	17	

*p < 0,05; **p < 0,0001 in T-testing

It is well known that the attitudes of parents, peers, and friends have an influence on students' attitudes towards studying and learning science and math. More than half of the respondents experienced that their success in studying mathematics and science is important for their parents (item 16); In Finland and Russia, more girls than boys agreed with this statement, while in Norway, more boys than girls agreed. The influence of the friends on the attitudes (item 15) dispersed considerably in three countries. Among respondents, one-third of Russian pupils and Finnish girls had friends who encouraged them to study science and math, while only one-tenth of Norwegian pupils and Finnish boys had such friends.

The influence of teaching on attitudes towards studying and learning science and mathematics is crucial according to research. Among our respondents, teaching brought up the most significant gender differences in attitudes (items 21-23, 31). In all three countries, there are both teacher-centered and student-centered approaches used, excursions and fieldwork were not widely used, and the computers were not used in improving learning, like processing and analyzing data. Student-centered approaches (e.g., item 22) seem to be more widely used in Norway than teacher-centered (e.g., item 31) compared to Finland and Russia. In general, the majority of students noted the enthusiastic attitude of teachers to the taught subject (item 23).

When asked about the influence of local industry and work opportunities on students' attitudes towards studying science and math (item 18), the responses to this issue showed that despite a fairly high motivation for studying natural sciences and mathematics, as well as experienced support from parents and friends, a very small number of students wanted and exhibited a readiness to work at local industry enterprises. It can be seen from the above data (see Table 1) that the traditional gender bias exists here: boys are more interested than girls in the practical use of knowledge gained in the field of science and mathematics.

3.2. Confirmatory factor analysis

The model (see Figure 1) consists of three factors: The perception of the (science/mathematics) teacher (FA1), anxiety towards science and mathematics (FA2), and motivation (FA3) (see Table 2). The factors are named after components, of which the attitude construct is known to comprise (Osborne et al., 2003). The perception of the teacher correlates positively with the motivation to learn and study science and mathematics, and negatively with the anxiety towards science and mathematics (covariances 0,262, -0,167, and -0,247, respectively). Teachers have a significant role in directing students' attitudes positively towards learning and studying science and mathematics. Based-on students' responses to the questionnaire, we found out that there are both teacher-centered and student-centered approaches used in teaching, but this model (Items 22 and 32) portrays especially teachers who hold a constructivist view of learning. They are aware of ideas that students bring to the learning occasion and provide them with opportunities to utilize their ideas in different contexts. The classroom atmosphere encourages students to express and discuss ideas. According to research, constructivist teaching approaches like inquiry-based and collaborative learning have positive-

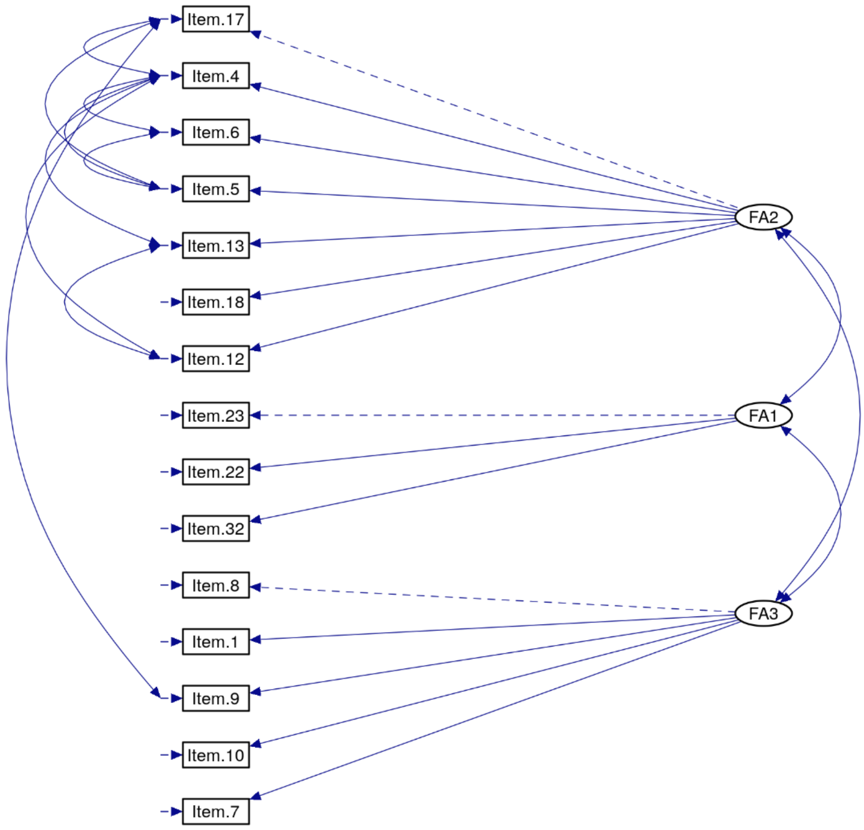


Figure 1. Three-factor model (CFA) of pupils' attitudes towards learning and studying science and mathematics.

effects on attitudes and achievement (Savelsbergh et al., 2016). Science teachers work to understand students' thinking, challenge misconceptions, and help students to make links to science concepts that lead to a meaningful and comprehensive scientific understanding. Teachers need to find a balance of teacher-centered and student-centered activities when deciding how much explicit instruction to provide and to what extent students can assume responsibility for their own learning. When science is taught as inquiry, it presents challenges to students, as it requires critical attitude, scientific skepticism, tolerance for ambiguity, and patience. These challenges are greater for students whose homes do not encourage inquiry practices but appreciate conventional teaching methods (Lee & Luykx, 2007).

Table 2. Overview of the factors.

Description	Loading	Agree %	Disagree %
FA1: The perception of the teacher			
23. Teacher is enthusiastic about the subject she/he is teaching.	1.00	59	12
22. Teacher listens to our experiences and opinions and takes them into account in teaching.	1.282	46	23
32. Teacher encourages us to decide our own problem-solving procedures in math.	0.891	42	19
FA2: Anxiety towards science and mathematics			
17. Negative attitudes of the people in my close circle towards science and math negatively affects my eagerness.	1.00	29	51
4. Studying science and math is risky: I can fail.	- 0.285	32	37
6. Biology is more difficult for me than for many of my classmates.	0.678	20	52
5. Physics is more difficult for me than for many of my classmates.	0.224	28	41
13. My siblings often help me with my science and math homework.	- 0.946	21	66
18. I would like to work in local industry or company in the future.	- 1.082	27	41
12. My parents often help me with my science and math homework.	- 0.679	33	50
FA3: Motivation			
8. I would like a job where I use science and math.	1.00	39	32
1. I enjoy learning science.	0.888	63	12
9. I need to do well in science and math to get into the upper secondary school I want.	0.651	60	17
10. Most of my friends like studying science	0.676	32	27
7. I need math to learn other school subjects.	0.810	67	13

The second-factor, "Anxiety towards science and mathematics," correlates negatively with the other two factors. It is mainly caused by negative attitudes of the people in students' close circle (Item 17). Fortunately, half of the students disagree with the statement. All students experience anxiety sometimes. State anxiety is defined as unpleasant emotional arousal in response to situations that are perceived as threatening (Spielberger, 1983). Fear of failure (Item 4) is experienced by one-third of students, but it loads negatively on this factor. However, items 17 and 4 have a positive correlation. Self-determination is the ability to have choices and some degree of control in what we do and how we do it (Deci, Vallerand, Pelletier, & Ryan, 1991). To promote self-determination in students, science teachers should give students opportunities to organize their own experiments instead of requiring them to follow rote directions. At worst, when students lack self-determination, they can develop learned helplessness believing they will fail no matter what they do, so they don't practice or improve their science and mathematics skills and abilities. Self-regulated learners select more challenging tasks, make more effort on assignments, and if they fail, they attribute their failure to controllable, internal causes such as a lack of preparation.

Anxiety can also be caused by a lack of competence. Self-efficacy is domain-specific, for example, a student can have high self-efficacy with respect to knowledge and skills in biology (Item 6) but low self-efficacy with respect to knowledge and skills in physics (Item 5). It is known that students' self-efficacy predicts their performance in science and mathematics. It derives from mastery experiences, vicarious experiences, and social persuasion (Bandura, 1997). Mastery experiences are students' actual experiences of which success increases self-efficacy, and failure decreases it. Vicarious experiences connect with the observation of others (role models) such as teachers, parents, siblings, peers, or celebrities. The more students identify with their role models, the stronger the influence is on them. Social persuasion can also influence students and make them try harder in science and math. Help available with science and math homework by siblings and parents (Items 12 and 13) possibly reduces the anxiety due to negative loadings on this factor.

Motivation is an internal state that arouses, directs, and sustains students' behavior (Koballa, Jr. & Glynn, 2007). Attitudes influence motivation, which in turn influences learning and ultimately behavior. Motivation explains why students pursue certain goals when learning science, how intensively and how long they pursue, and what feelings and emotions characterize them in that process. Motivation to perform an activity for its own sake is intrinsic, whereas learning to earn grades or avoid detention represents extrinsic motivation. Students are often motivated to perform tasks for both intrinsic and extrinsic reasons. The extent to which students are intrinsically motivated depends on how self-determined they are, their goal-oriented behavior, their self-regulation, their self-efficacy, and the expectations that teachers have of them. Intrinsically motivated activities promote feelings of competence and independence (Koballa, Jr. & Glynn, 2007). A student who is interested or curious about a science topic has a readiness to pursue it and enjoys the learning process (Item 1) but may also be motivated by the prospect of good grade which may secure entry into the upper secondary school one intends (Item 9) or support career aspirations (Item 8). Student's motivation to achieve at a high level in mathematics is more likely if he/she recognizes that struggling with it benefits him/her when studying and learning other school subjects, too (Item 7). On the other hand, there is a correlation between items 17 and 9 (see Figure 1) showing the existence of the contradictory atmosphere, which can influence students. Negative attitudes of the people in a close circle towards science and math affects student's eagerness to study those subjects, and at the same time, in order to get admission to the desired upper secondary school, he/she should succeed in them.

In general, the model implies that students who answered the questionnaire in the three countries of the North Calotte region experienced that enthusiastic teachers using innovative teaching approaches both motivate and reduce anxiety in their learning process. This result encourages us to proceed in our project to find those best practices that support student-centered approaches in science and mathematics teaching and learning.

4 Conclusions and implications

Despite the differences and national characteristics in studying sciences and mathematics at schools in Norway, Finland and Russia (in which grade subjects are studied, how long studies last, etc.), most respondents liked studying sciences. Students recognized the importance of mathematics for studying other school subjects and for future education at the upper secondary level. Unfortunately, the career aspirations in the fields of science and mathematics were modest, especially among respondents from Finland and Norway.

Based on the research results, the factors influencing secondary school students' attitudes towards studying and learning science and mathematics, are attitudes of parents and friends, and the teaching. In teaching, both teacher-centered and student-centered approaches were used, but according to the three-factor model, a student-centered approach is directly linked to motivation and indirectly to anxiety. In all three countries, field trips or fieldwork were seldom used. Surprisingly, computers were rarely used in promoting learning.

Responses to the questionnaire revealed gender differences in attitudes to implemented teaching approaches at schools and to future study and work plans. In all three countries, more girls than boys had realized the importance of studying science and mathematics for their prospects in the future. On the other hand, boys were more interested in local career opportunities in the industry than girls.

Affective elements in learning have become an important topic in science education research. Science learning experiences that are fun and personally fulfilling are likely to foster positive attitudes towards science learning and lead to improved achievement. Professional learning opportunities should be provided for teachers that will help prepare them to encourage unmotivated science students. In the North Calotte region, for example, career guidance excursions to local enterprises and out of school learning opportunities, as well as the use of computers in learning, would help students to understand the crucial role of natural sciences and mathematics in the future professions.

5 Acknowledgements

We express our gratitude to schools and teachers collaborating with us. The project is funded by the Kolarctic CBC, EU, Russia, Norway and Finland. This article has been produced with the assistance of the European Union. The contents of this article are the sole responsibility of the writers and can in no way be taken to reflect the views of the European Union.

References

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., and Wong, B. (2013). 'Not girly, not sexy, not glamorous': primary schoolgirls' and parents' constructions of science aspirations. *Pedagogy, Culture & Society, 21*(1), 171–194. https://doi.org/10.1080/14681366.2012.748676

Bahar, M., and Polat, M. (2007). The science topics perceived difficult by pupils at primary 6-8 classes: Diagnosing the problems and remedy suggestions. *Educational Sciences: Theory and Practice*, *7*(3), 1113–1130.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*, 191–215. https://doi.org/10.1037/0033-295X.84.2.191

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., and Rumble, M. (2012). Defining 21st-century skills. In P. Griffin, B. McGaw & E. Care (Eds.*), Assessment and Teaching of 21st century skills*, pp.17–66. Dordrect: Springer.

Butler, J. (1990). *Gender trouble: Feminism and the subversion of identity*. London: Routledge.

Bybee, R. (2010). *The teaching of science: 21st-century perspectives*, p.133. Arlington, VA: National Science Teacher Association (NSTA) Press.

Deci, E.L., Vallerand, R.J., Pelletier, L.G., Ryan, R.M. (1991). Motivation and education: The self-determining perspective. *Educational Psychologist*, *26*, 325–346. https://doi.org/10.1080/00461520.1991.9653137

DeWitt, J., and Archer, L. (2015). Who aspires to a science career? A comparison of survey responses from primary and secondary school students. *International Journal of Science Education*, 37(13), 2170–2192. https://doi.org/10.1080/09500693.2015.1071899

Driver, R. (1981). Pupils' alternative frameworks in science. *European Journal of Science Education*, *3*(1), 93–101. https://doi.org/10.1080/0140528810030109

Epskamp, S. (2015). semPlot: Unified Visualizations of Structural Equation Models. *Structural Equation Modeling*. doi:10.1080/10705511.2014.937847

European Commission (2004). *Europe needs more scientists*!

Fishbein, M., and Ajzen, I. (1975). *Belief, attitude, intention, and behavior: An introduction to theory and research,* Reading, MA: Addison-Wesley.

Hendrickson, A. E., & White, P. O. (1964). Promax: A quick method for rotation to oblique simple structure. *British Journal of Statistical Psychology*. https://doi.org/10.1111/j.2044-8317.1964.tb00244.x

Johnstone, A. (1991). Why science is difficult to learn? Things are seldom what they seem? *Journal of Computer Assisted Learning*, 7, 75–83. https://doi.org/10.1111/j.1365-2729.1991.tb00230.x

Kline, R. B. (2015). Principles and practices of structural equation modelling Ed. 4. *Methodology in the social sciences*. New York: The Guilford Press

Koballa, Jr., T.R., & Glynn, S.M. (2007). Attitudinal and motivational constructs in science learning, in S.K. Abell & N.G. Lederman (Eds.) *Handbook of Research on Science Education*, pp. 75–102, Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Lavonen, J., Gedrovics, J., Byman, R., Meisalo, V., Juuti, K., and Uitto, A. (2008). Students' motivational orientations and career choice in science and technology: A comparative investigation in Finland and Latvia, *Journal of Baltic Science Education*, *7*(2), 86–102.

Lee, O., & Luykx, A. (2007). Science education and student diversity: Race/Ethnicity, language, culture, and socioeconomic status, in S.K. Abell & N.G. Lederman (Eds.) *Handbook of Research on Science Education*, pp. 171-198, Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Mair, P. (2018). Modern Psychometrics with R. Springer.

Osborne, J., Simon, J., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049–1079. https://doi.org/10.1080/0950069032000032199

Revelle, W. (2015). Package 'psych' - Procedures for Psychological, Psychometric and Personality Research. *R Package*.

R core Team, (2019). *R: A language and environment for statistical computing*

Savelsbergh, E. R., Prins, G. T., Rietbergen, C., Fechner, S., Vaessen, B. E., Draijer, J. M., & Bakker, A. (2016). Effects of innovative science and mathematics teaching on student attitudes and achievement. *Educational Research Review*, *19*, 158–172. https://doi.org/10.1016/j.edurev.2016.07.003

Sheldrake, R., Mujtaba, T., and Reiss, M. J. (2017). Science teaching and students' attitudes and aspirations: The importance of conveying the applications and relevance of science. *International Journal of Educational Research, 85*, 167–183. https://doi.org/10.1016/j.ijer.2017.08.002

Schreiner, C., and Sjøberg, S. (2010). The Rose Project. An overview and key findings. University of Oslo. https://roseproject.no/network/countries/norway/eng/nor-Sjoberg-Schreiner-overview-2010.pdf

Spielberger, C.D. (1983). *Manual for the state-trait anxiety inventory (STAI)*. Palo Alto, CA: Consulting Psychologists Press.

Stoet, G., and Geary, D.C. (2018). The gender-equality paradox in science, technology, engineering, and mathematics education, *Psychological Science*, *29*(4), 581–593. https://doi.org/10.1177/0956797617741719

Walker, D.A., Smith, M.C., and Hamidova, N.I. (2013). A structural analysis of the attitudes toward science scale: Students' attitudes and beliefs about science as a multi-dimensional composition. *Multiple Linear Regression Viewpoints*, *39*(2), 38–48.

Wang, M-T., Eccles, J., and Kenny, S. (2018). Not lack of ability but more choice: Indvidual and gender differences in choice of careers in science, technology, engineering, and mathematics. *Psychological Science*, *24*(5), 770–775. https://doi.org/10.1177/0956797612458937

Wang, M-T., and Degol, J. (2013). Motivational pathways to STEM career choices: Using expectancy value to understand individual and gender differences in STEM fields. *Developmental Review*, *33*, 304–340. https://doi.org/10.1016/j.dr.2013.08.001

World Economic Forum (2015). *The Global Gender Gap Report 2015*. Geneva, Switzerland: World Economic Forum. http://reports.weforum.org/global-gender-gap-report-2015/

IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.

Appendix

Items in the questionnaire

No.	Item
1	I enjoy learning science.
2	Math is boring.
3	I think that the natural work scientists do is important.
4	Studying science and math is risky: I can fail.
5	Physics is more difficult for me than for many of my classmates.
6	Biology is more difficult for me than for many of my classmates.
7	I need math to learn about other school subjects.
8	I would like a job where I use science and math.
9	I need to do well in science and math to get into the upper secondary school I want.
10	Most of my friends like studying science.
11	Most of my friends like studying math.
12	My parents often help me with my science and math homework.
13	My siblings often help me with my science and math homework.
14	My parents encourage me to study science and math.
15	My friends encourage me to study science and math.
16	My parents are proud of my achievements in science and math.
17	Negative attitudes of the people in my close circle towards science and math negatively affect my eagerness.
18	I would like to work in local industry or company in the future.
19	There are too many pupils in my science class.
20	There are too many pupils in my mathematics class.
21	I always know clearly the goal of learning in math.
22	Teacher listens to our experiences and opinions and takes them into account in teaching.
23	Teacher is enthusiastic about the subject she/he is teaching.
24	The topics we study in science are relevant to me.
25	Test questions are different from what is studied in the classroom.
26	Tests measure my actual learning.
27	Teacher assigns homework and always monitors whether the homework was completed.
28	We usually listen to the teacher explaining the science content in every class.
29	We usually watch when the teacher demonstrates and explains an experiment or investigation.
30	We present and interpret data from experiments we do.
31	We memorize science facts and principles in every lesson.
32	Teacher encourages us to decide our own problem-solving procedures in math.
33	We practice skills and procedures using computers.
34	We use computers to process and analyze data.
35	In science lessons, we often do field trips and fieldwork as part of the school work.
36	My efforts and problems in learning math are being overlooked, and this decreases my interest in studying.

Learning mathematics by project work in secondary school

Elina Viro and Jorma Joutsenlahti

Tampere University, Finland

In project-based learning, pupils have two central learning objectives: to understand the content of the subject and to develop their twenty-first-century skills. This article concerns the use of project work in mathematics learning, considered here in the context of the Finnish national core curriculum, mathematical proficiency, and pupils' previous level of attainment. The research consisted of two case studies in which a coordinate system project and a statistics project were tested with secondary school pupils (N=59+58). The main findings show it is possible to study the mathematics of the curriculum and to develop all types of mathematical proficiency using project work. Additionally, the pupils' grades on the project work correlate positively with their overall grades in mathematics.

Keywords: project work, project-based learning, mathematical proficiency, curriculum

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 107–132

Received 27 May 2019
Accepted 27 May 2020
Published 1 June 2020

Pages: 26
References: 31

Correspondence:
elina.viro@tuni.fi

https://doi.org/10.31129/LUMAT.8.1.1372

1 Introduction

As a learning method, project work is not a new idea. The roots of project work can be found in American pragmatism, a movement that began at the turn of the twentieth century (Markham, Lamer, & Ravitz, 2006). Across the world, the popularity of project work has increased in recent years because of learning theories transitioning from behaviourism to social constructivism and the requirements of the modern work environment (Markham et al., 2006).

The principles of project work have long been established in the Finnish education system (e.g., Pehkonen, 2001). Especially at the turn of the 1990s, learning projects from kindergarten to the university level have been widely reported (e.g., Vähätalo & Kanervisto, 1988; Sarras, 1994) and systematically studied (e.g., Leino, 1992; Heinonen, 1994).

In Finland, the national core curriculum for basic education 2014, which was published by the Finnish National Board of Education (FNBE, 2016), emphasises the elements of project work, especially multidisciplinary projects. It requires *the inclusion of at least one multidisciplinary learning module for every school year* (FNBE, 2016, p. 33). The aim of the modules *is to link knowledge of and skills in various fields and, in interaction with others, to structure them as meaningful*

Published by the University of Helsinki, Finland / LUMA Centre Finland | CC BY 4.0

entities (FNBE, 2016, p. 32). The pupils should perceive the significance of topics they learn at school for their own life and community (FNBE, 2016). Teachers have to permit pupils to take part in the planning of the modules so that the pupils can highlight their interests (FNBE, 2016). Indeed, interest is a significant predictor of mathematical achievement (Middleton, Jansen & Goldin, 2016).

Additionally, the conception of learning in the Finnish national core curriculum underlines an active role for the pupil and the development of learning-to-learn skills. Teachers are to encourage pupils to increase their self-assessment and to instruct them to work in groups. The practice of working and thinking skills plays a major role in every school subject (FNBE, 2016).

The latest Finnish core curriculum highlights the importance of project work in schools, which has increased the need both to support and research project work as one way of studying school subjects. For example, the StarT programme, which is organised by LUMA Centre Finland, supports teachers with multidisciplinary project work in science, mathematics and technology (StarT, 2019). In the context of the StarT programme, Aksela and Haatainen (2019) and Viro et al. (2020) studied the teachers' view of project-based learning in practice. Correspondingly, StarT projects have been examined from the viewpoint of mathematics and academic literacy (Viro & Joutsenlahti, 2018a). The problematics and the development proposals of the mathematical projects in Finland have been presented by Viro and Joutsenlahti (2018b). That article focuses on the achievement of the learning objectives in project work rather than the learning of mathematics.

2 Theoretical framework

2.1 Project work

Project-based learning can be defined as a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks (Markham et al., 2006, p. 4). Here, student-directed and teacher-facilitated emphasis is placed on teachers' and pupils' sharing of responsibility for pupils' learning (Erdogan & Bozeman, 2015). Pupils have two learning objectives: to understand the contents of the subject and develop their twenty-first-century skills (Larmer, Mergendoller, & Boss, 2015). In the present article, we describe the concept of project work as an organising method of teaching adapted from project-based learning.

By twenty-first-century skills, we mean the skills that are necessary for success in everyday life, both at school and in the modern workplace. These skills are also called success skills (Larmer et al., 2015) or transversal competence (FNBE, 2016). The contents of twenty-first-century skills vary among sources. According to Gold Standard PBL (Larmer et al., 2015), twenty-first-century skills consist of critical thinking, collaboration and self-management. Correspondingly, the p21 network (Partnership for 21st Century Skills, 2007) defines twenty-first-century skills as learning and innovation skills; information; media and technology skills; and life and career skills.

Project work has several advantages (e.g., Yetkiner, Anderoglu, & Capraro, 2008). However, studies in this area are typically quite small, and it is consequently difficult to generalise any results. First, project-based learning has a positive effect on pupils' motivation (Larmer et al., 2015). Second, pupils in project-based learning classrooms seem to learn science content better than pupils in the more traditional classroom (Drake & Long, 2009; Rivet & Krajcik, 2004; Schneider, Krajcik, Marx, & Soloway, 2002). Correspondingly, in mathematics, the pupils experiencing project-based learning are better able to use mathematics in everyday life situations (Boaler, 1998) and apply it in new situations (Hung & Jonassen, 2007). Additionally, project-based learning as a working method also makes it easier to remember the learned content longer (Wirkala & Kuhn, 2011).

In general, the implementation of project work is difficult at first. Both teachers and pupils need support in their work (Larmer et al., 2015). Project work has sometimes been criticised from the viewpoint of learning, especially learning the contents of the subject (Hakkarainen, Bollström-Huttunen, Pyysalo, & Lonka, 2005; Lamer et al., 2015). A project might be a "dessert project," including hands-on activities where pupils make a low-quality product. These poorly designed projects are usually a waste of time and do not support the achievement of the learning objectives (Lamer et al., 2015). The result of the project might often be an output that is visually excellent, but where the learning process itself is not (Hakkarainen et al., 2005).

Some teachers want to assess project work, especially the learning of the content, with an exam (Erdogan & Bozeman, 2015). Many twenty-first-century skills are not measurable through standardised tests (Bell, 2010). Student-directed and teacher-facilitated project work needs authentic evaluation: formative evaluation, self-assessment and peer reviews (Bell, 2010; Erdogan & Bozeman, 2015).

2.2 Mathematical proficiency

Another learning objective of project work is to understand the content of the subject. In the current article, we concentrate only on mathematics. Kilpatrick, Swafford, and Findel (2001) created a model to describe a pupil's mathematical proficiency. The model consists of five intertwined strands: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning and productive disposition. Moschkovich (2015), for example, widened the model to academic literacy, which consists of the five strands of mathematical proficiency (Kilpatrick et al., 2001), mathematical practices and mathematical discourse.

Conceptual understanding includes the comprehension of mathematical concepts, operations and the relations between them (Kilpatrick et al., 2001), and it is about the meanings that a pupil gives for mathematical solutions. It is essential to understand what a particular result means: why a procedure works, and why the result is the right answer. The pupil should understand why a mathematical concept is important and what kind of situation it can be used in. Additionally, a pupil should be able to connect new ideas to them that he or she is already familiar with (Moschkovich, 2015). The essence of this branch is usually described as 'understand' (Joutsenlahti & Sahinkaya, 2006). In project work, conceptual understanding may involve becoming familiar with new concepts in groups. However, it is also important to be able to connect the new concept to those the group has learned earlier.

Procedural fluency can be seen as knowing how to compute (Moschkovich, 2015), the ability to use mathematical procedures flexibly, efficiently, accurately and appropriately. This mechanical counting and simplifying is often emphasised in schools but is only one component of mathematical proficiency. Conceptual understanding and procedural fluency are closely related because a pupil remembers the procedures better if he or she understands them and can connect new knowledge with prior knowledge (Kilpatrick et al., 2001). Procedural fluency is described as 'can-do' (Joutsenlahti & Sahinkaya, 2006). Most mathematical projects require routine counting. A pupil must repeat familiar procedures and acquire routine ones or learn the new ones.

Strategic competence refers to the ability to formulate, represent and solve mathematical problems that are not routine exercises. Especially outside of school, a pupil can come across problems that he or she has to formulate before he or she can solve them using mathematics. This strand of mathematical proficiency is also called problem solving (Kilpatrick et al., 2001). Here, mathematics in the projects is not necessarily insight at the beginning, but the group has to formulate the problem in a mathematical format.

Adaptive reasoning can be seen as the capacity to think logically about the relationships between concepts and situations. It is not only reflection, explanation and justification, but also intuitive reasoning (Kilpatrick et al., 2001). Adaptive reasoning can be described as ‘apply’ (Joutsenlahti & Sahinkaya, 2006). In the project work, a pupil connects information from different sources and applies it to the situation of the project. Finally, the groups have to evaluate their results critically.

Productive disposition means a pupil’s perceptions of mathematics as sensible, useful and worthwhile; this also includes a pupil’s confidence in diligence and his or her own efficacy (Kilpatrick et al., 2001). In the present article, the productive disposition is replaced by the view of mathematics advocated, for example, by Joutsenlahti (2005). As a concept, this view of mathematics is wider and includes pupils’ beliefs about mathematics; beliefs about oneself as a learner and a user of mathematics, and beliefs about learning and teaching mathematics. Mathematical projects should be authentic, and their theme should be linked to pupils’ everyday lives (Larmer et al., 2015); they should also require diligent and persevering working.

All of these strands interact with each other. In problem solving, for example, pupils use their strategic competence to formulate and represent a problem, but they need adaptive reasoning when determining the legitimacy of a proposed strategy. On the other hand, adaptive reasoning includes conceptual and procedural knowledge (Kilpatrick et al., 2001).

2.3 Direct proportionality and statistics in Finnish national core curriculum

Mathematically, the current article focuses on the concepts of direct proportionality and statistics at the lower secondary school level. The Finnish core curriculum for basic education (FNBE, 2016) introduces direct proportionality for the first time in grades 7–9. However, pupils are first introduced to the first quarter of the system of coordinates (FNBE, 2016) in grades 3–6.

Table 1. Direct proportionality and statistics in the Finnish national core curriculum (FNBE, 2016). The text that links to conceptual understanding is highlighted with green, the text to procedural fluency with yellow and the text to adaptive reasoning with turquoise.

	Key content area	Objectives of instruction	Assessment targets in the subject	Knowledge and skills for grade 8
Direct proportionality	*C4 Functions: Correlations are depicted both graphically and algebraically. The pupils familiarise themselves with direct proportionality. They get acquainted with the concept of the function. The pupils draw straight lines in the coordinate system. They learn the concepts of the angular coefficient and the constant term. They interpret graphs, for example, by examining the increase and decrease of a function. They determine the null points of functions.* (p. 404)	*O15 to guide the pupil to understand the concept of the variable and to acquaint him or her with the concept of the function. To guide the pupil to practise interpreting and producing the graph of a function.* (p. 403)	*The concept of the variable and the function as well as the interpretation and production of graphs.* (p. 407).	*The pupil understands the concept of the variable and the function and is able to draw a graph for a first-degree and a second-degree function. The pupil is able to interpret graphs diversely.* (p. 407)
Statistics	*C6 Data processing, statistics, and probability: The pupils deepen their skills in collecting, structuring, and analysing data. It is ensured that the pupils understand the concepts of the average and mode. They practice defining frequency, relative frequency, and median. The pupils familiarise themselves with the concept of dispersion. They interpret and produce different diagrams.* (p. 405)	*O19 to guide the pupils in determining statistical key figures* --. (p. 403).	*Statistical key figures*	*The pupil masters central statistical key figures and is able to give examples of them.* (p. 408)
	C2 Numbers and operations: It is ensured that the pupils understand the concept of percentages. The pupils practice calculating percentages and calculating the amount a percentage expresses of a whole. (p. 404)	*O13 to guide the pupil in expanding his or her understanding of percentage calculation.* (p. 403)	*The concept of percentages and percentage calculation.* (p. 407)	*The pupil is able to describe the use of the concept of percentages. The pupil is able to calculate percentages, the amount a percentage expresses of a whole, and the percentage of change and comparison. The pupil is able to use his or her knowledge in different situations.* (p. 407)

The studying of statistics already starts in primary school. In the curriculum, one objective in grades 1–2 is *to familiarise the pupil with tables and diagrams* (FNBE, 2016, p. 137). In grades 3–6, pupils must prepare and interpret tables and diagrams and use key figures, such as the greatest and smallest value, mode and average. Additionally, systematic data collection is a part of the key content areas. Understanding percentages, which is essential in statistics, develops in grades 3–6. Table 1 summarises what the Finnish core curriculum for grades 7–9 states about direct proportionality and statistics.

Both subject areas are studied in versatile ways in lower secondary school. The study of direct proportionality starts from the beginning, but a secondary school teacher can assume that pupils have prior knowledge of statistics. In particular, knowledge of the roles of strategic competency and conceptual understanding are emphasised instruction objectives and knowledge for grade 8 in the Finnish core curriculum.

2.3 Research questions

The role of the authors has been active in the reform movement of project-based learning in Finnish mathematical education. The authors have created the project instructions to the Finnish lower secondary school level and educated the pre- and in-service teachers in project-based learning. Research-based development is essential, and we must know more about mathematics learning in project work in order to provide good project practices for schools.

The focus of the current study is to examine mathematics learning and the possibilities to learn mathematics in project work at a lower secondary school level. The strands of mathematical proficiency and the Finnish national core curriculum provide tools for the evaluation of the learning processes. The following research questions are posed:

- How is the mathematical content of the projects based on (a) project instructions and (b) the project implementation in line with the demands of the Finnish core curriculum?
- What strands of mathematical proficiency does the project work develop per the project instructions?
- Were there any connections between the grades of the pupils' project work and their previous grades in mathematics in project implementation? What kind of pupils succeed, or who do not?

There are two parts of the research: (a) the research of project instructions and (b) the observation of project implementations. In the first research question, we cover the mathematical contents of the projects from the perspective of both project instructions and project implementations. The second question focuses only on the project instruction, while the third looks at the implementation in the schools.

3 Methods

The research covers two project instructions and realisations of project work in mathematics at the Finnish lower secondary school level: a coordinate system project and a statistics project. The research was carried out in two parts: the design and implementation of the projects.

3.1 Design of projects

The mathematics teacher who participated in the project implementation designed the project instructions in close collaboration with the researchers. The national core curriculum and available time set some limits for the project. The teacher also asked the wishes of his pupils who participated in the project implementation be accounted for. The final instructions for pupils were detailed in both projects, but the pupils still had a choice regarding the details.

The coordinate system project starts with an experimental part. Here, groups can choose their own research topics from the directly proportional quantities in accordance with their interests. The instructions include some examples of suitable topics. The pupils can weigh candies, coins, water and cooking oil or rice and rice crispies on the scales; gauge the speed of a walker and runner, or look for the prices of vacation trips. For example, pupils weighed 1 dl, 2 dl, ..., 9 dl and 10 dl of water and the same volumes of cooking oil. Then, they plotted the measuring points to the coordinate system by hand, where the x-axis is mass (g) and y-axis volume (dl).

The measuring points of every group had to form two lines (two situations) because the quantities were directly proportional. After that, the pupils plotted the same graph using Excel. Excel also gives the equation of a line. Using their graphs, the pupils had to find out where two lines intersected.

As a part of the project, the pupils defined the concepts of an angular coefficient, the intersection of two lines, the intersection of the x-axis and the intersection of the y-axis. They also had to consider what these concepts mean in practice and in their project. The slope of a line may, for example, represent the density. At the end of the project, the pupils aggregated their results, placed them on a poster and presented them to their classmates.

In the statistics project, the pupils made an online statistical study using Office 365. To start with, they chose the subject of their own research – the topic could have been, for example, the quality of school food or the use of social media. The pupils created an online questionnaire that had to include at least one numerical question. The other classmates answered the questionnaire. The groups then analysed their data quantitatively using Excel, counting frequencies, relative frequencies, modes, medians, averages and dispersions. They also made diagrams. The pupils made a PowerPoint presentation and a poster about their research. At the end of the project, the groups presented their outputs to the class.

In both projects, it was important for the teacher that assessing the project work be many-sided. The teacher assessed the project work using numerical grades: the whole group was given the same grade for the project output, but project work was assessed individually. The assessment of the project work consisted of work done in the lessons, self-assessment (statistics project), peer review (coordinate system project), learning diary, doing homework and points in a final test, in addition to the project output. Using the final test, the teacher wanted to verify that the pupils learned mathematics. The significance of the tests was a small portion of the whole grade.

The teacher's impression of the assessment, the goals in mathematics and twenty-first-century skills, and the general framework are collected in Table 2. These goals were set during the design process.

Table 2. The description of the project.

	Coordinate system project	Statistics project
Prior knowledge	A point in the coordinate system.	Percentages.
The mathematical goal defined by the teacher	- Familiarising with the direct proportionality and learning to draw straight lines in the coordinate system. - Practice using Excel.	- Conducting statistical research. - Calculating statistical key figures by hand and using Excel. - Preparing and interpreting the tables and diagrams.
Other goals	Collaboration and communication skills, self-management, IT skills, problem solving and scheduling.	
Duration	About nine lessons. (45 min)	About 12 lessons. (45 min)
Working	In three-person groups.	In three-person groups.
Output	A poster and a presentation.	A PowerPoint presentation and a poster.
Assessment	The output of project work (two-thirds of the grade), a small final test (one-third of the grade), working in the lessons (± 0.5 grade), the peer review of their own group (± 0.5), homework (± 0.5) and learning diary. (max -0.25)	The output of the project work (65% of the grade), a small final test (8% of the grade), working in the lessons (± 1 grade), self-assessment (7% of the grade), learning diary (20% of the grade) and homework. (max. -0.5)

In the current research, both project instructions were analysed qualitatively from the perspective of mathematics found in the Finnish national core curriculum and from the viewpoint of mathematical proficiency. The analysis method was a theory-based content analysis (Tuomi & Sarajärvi, 2018). First, we examined the project instructions to look for the connection to the content area and the objective of instruction defined by the curriculum. We then separated the concepts from the skills. Second, we classified the stages of the projects according to the strands of mathematical proficiency. This division was based on two researchers' opinions of which strands the stage may especially develop.

3.2 Implementation of the projects

These projects were tested in two different schools in Western Finland, both of which had more than 500 pupils. The pupils worked in approximately three-person groups chosen by their teacher. The group members had heterogeneous skills in mathematics and in using Excel. The teacher talked about the goals with pupils at the beginning of the project. In both projects, the pupils were motivated to work with the possibility of choosing their research topics as a way to affect the difficulty level of their work and design an individual final output. The instructions only drew up guidelines and boundary conditions. The teacher helped the groups find a suitable difficulty level and tried to keep the groups' distribution of work balanced.

The coordinate system project had a test run of 59 seventh-grade pupils and one teacher in the spring of 2018. Correspondingly, 58 eighth-grade pupils and one teacher participated in a statistics project in the spring of 2017. In both projects, the pupils worked in three classrooms supervised by their own teacher. Overall, there were 64 girls and 53 boys. Before the project began, the pupils were attuned to more traditional teaching in mathematics, and their previous grades in mathematics were known. The average was 8.3 in the coordinate system project and 7.6 in the statistics project. No diagnostic pre-test was used.

These test runs were analysed as two case studies using a mixed methods design. Table 3 presents the research data, which consist of pupils' learning diaries, previous grades in mathematics, the grades of the project work, self-assessments and peer reviews. Additionally, we utilised the teachers' interviews and the groups' project outputs. In both projects, there were a total of 18 groups.

Table 3. Description of the data.

The data	*N* (coordinate system project)	*N* (Statistics project)
a. Previous grades in mathematics	59	56
b. Assessment of project work	57	58
c. Project outputs	18	18
d. Learning diaries	46	53
e. Self-assessments	48	57
f. Peer review	48	57
g. Final test	56	55
h. Interview with the teacher	1	1
i. Project instruction	1	1

Based on the interview with the teacher and the project outputs of the groups, both implementations were examined using the national core curriculum framework. We observed the final outputs to find a connection with the contents of the curriculum. Now, we got information on the achievement of the goals at the group level.

The pupils' previous mathematics grades and the grades for the project work and small final tests were analysed quantitatively using two-by-two frequency tables. The pupils, whose grades differed significantly (non-parametric statistical tests) from previous grades in mathematics, were qualitatively examined in addition to using their self-assessments, peer reviews, and their own and their group mates' learning diaries. Using a data-driven content analysis, the aim of the analysis was to find the main reason for their high or low grades in project work. The pupils were classified into groups based on the researchers' impressions of these reasons.

Permission to use the research data was obtained from both the teachers and the pupils' parents. Personal data were processed according to the EU General Data Protection Regulation (GDPR).

4 Results

4.1 Mathematical base of the projects

The coordinate system project combined direct proportionality with drawing straight lines. The statistics project combined all the mathematical statistics found in Finnish basic education. Table 4 summarises what kind of concepts and skills pupils practised during the project (based on data i) and how they are similar to the Finnish national core curriculum (FNBE, 2016). The content area 6 for example, it is:

> "C6 Data processing, statistics, and probability: The pupils deepen their skills in collecting, structuring, and analysing data. It is ensured that the pupils understand the concepts of the average and mode. They practice defining frequency, relative frequency, and median. The pupils familiarise themselves with the concept of dispersion. They interpret and produce different diagrams. They calculate probability." (FNBE, 2016)

The area includes both understanding concepts and learning skills.

Table 4. The mathematical content of the projects from the viewpoint of the key content areas in the Finnish national core curriculum for basic education 2014 (FNBE, 2016). C indicates the content area, and O is the objective of instruction in the curriculum (see Table 1).

	Curriculum	Concepts	Skills
Coordinate system project	C4, O15	Angular coefficient. Constant term.	Depicting correlations graphically. Drawing straight lines in the coordinate system. Depicting correlations algebraically. Interpreting graphs.
Statistics project	C6, O19	Average. Mode. Frequency. Relative frequency. Median. Dispersion.	Deepening pupils' skills in collecting, structuring and analysing the data. Interpreting and producing different diagrams.
	C2, O13		Calculating percentages.

Before the implementation of the coordinate system project, the pupils had little previous experience of a coordinate system, direct proportionality or drawing a graph in a coordinate system. Correspondingly, the pupils were familiar with percentages before the statistics project but had probably never made a statistical study or calculated statistical key figures.

Every project group made their own project output, and the processes were always of a different kind. The depth and richness of the mathematics used varied. Few groups totally missed the practising of some skills, and on the other hand, some groups handled them very deeply. Based on project outputs and learning diaries (data c and d), Table 5 and Table 6 present the skills practised and the concepts per group. This material does not give information on individual pupils.

Table 5. Skills practised during project work (based on data *c* and *d*). N (groups) = 18 per project. 'Well-done' projects met the requirements of the Finnish core curriculum for skills excellently (FNBE, 2016). If a skill is 'missing,' the group ignored the topic.

		f **(missing)**	***f*** **(done)**	***f*** **(well done)**
Coordinate system project	Depicting correlations graphically	0	11	7
	Depicting correlations algebraically	0	16	2
	Interpreting graphs	2	11	5
	Angular coefficient as a concept	2	15	2
Statistics project	Depicting correlations algebraically	0	16	2
	Interpreting graphs	2	11	5
	Angular coefficient as a concept	2	15	2
	Calculating percentages	0	19	0

In the statistics project, there were two groups that did not use diagrams. On the other hand, two groups in the coordinate system project lacked the ability to interpret graphs and define an angular coefficient. In principle, almost all the groups achieved the required standard and became familiar with the mathematical concepts, but only a few groups treated the issues thoroughly.

Table 6. Seeing the concepts in the groups' project outputs. N (groups) = 18.

		f (missing)	*f* (explained)	*f* (calculated)	*f* (explained and calculated)
CSP	*Angular coefficient*	0	0	1	17
	Constant term	0	0	18	0
Statistics project	*Average*	0	5	4	9
	Mode	1	1	3	13
	Frequency	0	0	18	0
	Relative frequency	0	0	18	0
	Median	0	4	3	11
	Dispersion	2	7	2	7

In the statistics project, all the groups calculated the angular coefficient and constant term, but any group did not explain what the constant term is. 17 groups explained what an angular coefficient means.

The concepts of average, frequency, relative frequency and median were found in every group's statistics project; a couple of groups lacked the concepts of mode and dispersion. Most groups calculated statistical key figures, although not every group explained what these meant. In several of the project outputs, procedural fluency was emphasised at the expense of conceptual understanding. There were also some groups that only explained what a key figure means, but they did not calculate an example.

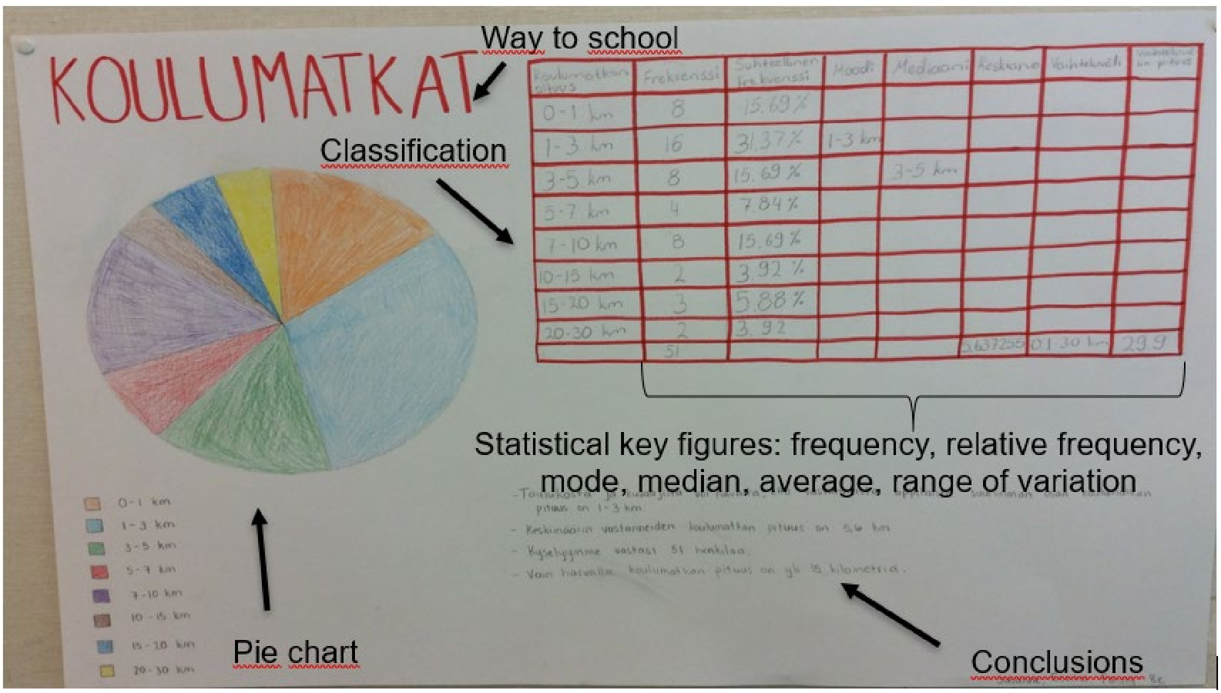


Figure 1. Poster displaying an output of the pupils' statistics project.

Figure 1 presents a typical output of the statistics project; this group had studied the length of the journey to school. In the poster, the pupils calculated statistical key figures, illustrating the frequencies with a pie chart. The groups also drew some conclusions from their study. In addition to the poster, the pupils made a more comprehensive PowerPoint presentation in which they explained what their calculated key figures meant.

4.2 Development goals of mathematical proficiency

According to written project instructions (data *i*), the coordinate system project started by organising the measurement and the statistics project by planning the questionnaire. The groups had to consider how they could study the problem mathematically; in other words, they needed strategic competency.

After that, the groups created their own view of the mathematics required by using the Internet, textbooks and the help of their teacher. They also had to apply mathematics in their textbook to the project problem. This stage involved a combination of conceptual understanding, adaptive reasoning and procedural fluency. In the statistics project, the groups familiarised themselves with the conception of statistical key figures and worked out how to apply these concepts to their data. They then calculated, for example, the frequencies, relative frequencies and modes of the data.

Correspondingly, in the coordinate system project, the groups studied how to draw a line in the coordinate system using their textbook and then adapted it to their data with pen and paper and by using Excel. The groups also had to read values in the line and think about what they mean. They clarified their understanding of concepts like the angular coefficient, the intersection of two lines, the intersection of the x-axis and the intersection of the y-axis while also comparing their results in Excel with their lines on paper.

Finally, in both projects, the groups evaluated their results and considered what the results meant in practice. Table 7 details the required mathematical proficiency in both projects.

Table 7. The projects from the viewpoint of mathematical proficiency.

Proficiency	Coordinate system project	Statistics project
Conceptual understanding	• Understanding direct proportionality • Explaining the concepts of the angular coefficient, the intersection of two lines, the intersection of the x-axis and the intersection of the y-axis	• Explaining and understanding the concepts related to statistical key figures. E.g. *Explain your classmates what mode, median and average mean. What do they mean in your study?* (data *i*)
Procedural fluency	• Plotting a point to the coordinate system. E.g. *Plot your points to the coordinate system* (data *i*) • Drawing straight lines in the coordinate system. • Reading values in the coordinate system	• Calculating statistical key figures by hand and using Excel • Drawing diagrams by hand and using Excel
Strategic competence	• Organisation of measurement • Linking the results and physics	• Making the questionnaire. E.g. *Create a questionnaire. You must think how you formulate your questions. You need numerical data.* (data *i*)
Adaptive reasoning	• Applying the examples of the textbook to the situation in the project • Comparison between the line made by hand or Excel. E.g. *Compare the line made by hand and Excel. Are they different? How?* (data *i*) • Estimation of the results	• Applying learned concepts to the situation in the project • Estimation of the results
View of mathematics	• Usability of mathematics as a tool	• Usability of mathematics as a tool

Figure 2 summarises the big picture of these two projects from a mathematical proficiency viewpoint. At the beginning of the projects, the pupils had to formulate the problem as a mathematical expression using strategic competence. Over the course of the project, they effectively studied mathematics in many different ways, developing their conceptual understanding and procedural fluency, and their competence with applying what they had learned to their project. The projects concluded with a discussion of the results. The pupils' view of mathematics was an integral part of working throughout the entire project, highlighting the significance and importance of mathematics in everyday life.

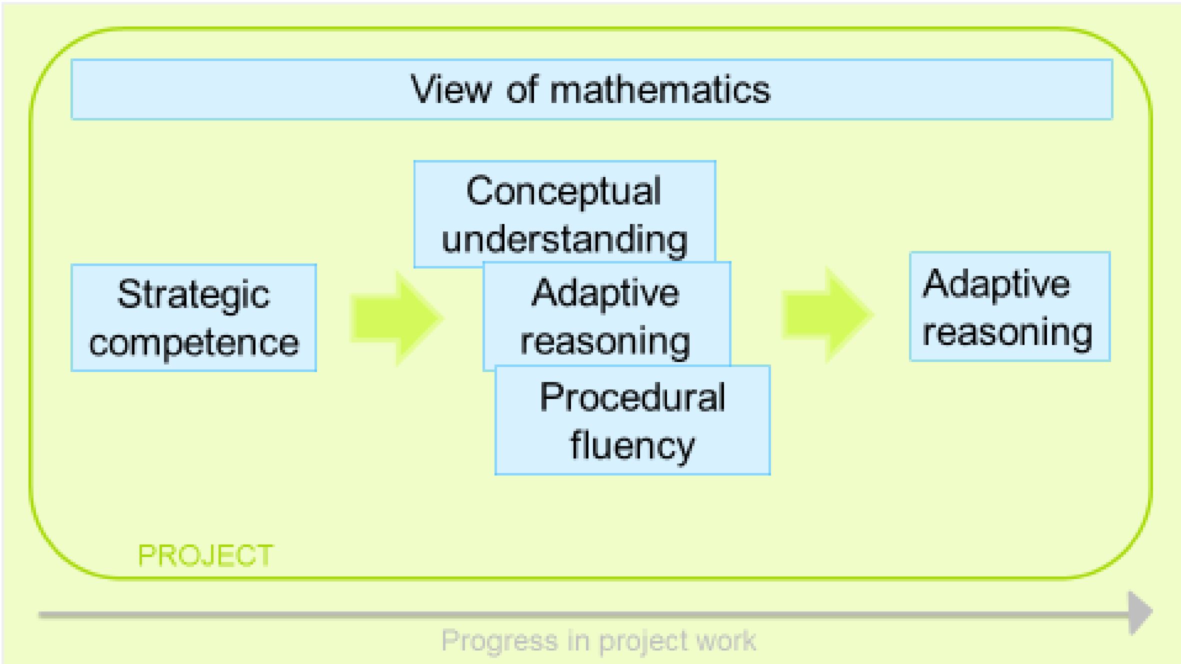


Figure 2. Mathematical proficiency needed during project work.

These data do not afford an opportunity to observe the attainment of assumed goals precisely. In the project implementation, the strands of mathematical proficiency were visible (based on data c and d). The boundary conditions set by the teacher ensured that every strand was needed in the project. In the coordinate system project, the meaning of strategic competence only held a minor role because the groups needed lots of guidance in the organisation of measurement, and some groups' topics were not connected with physics.

4.3 Connection between the project work grades and mathematics grades

The data from the studied projects were combined with increasing the size of the random sample. In both projects, the pupils worked in groups, with each group making a project output. The teacher assessed these outputs with number grades; hence, the made groups were allotted the same grade.

Figure 3 presents the data on the pupils' grades in their project output in relation to their previous mathematics grades (based on data a and b). The first quarter (I) shows the pupils whose previous grades in mathematics were 8 or better and the project output grade 7.5 or better. On the other hand, the pupils with the mathematics grade being under 8 and the project output grade under 7.5 are shown in the third quarter (III). The pupils whose previous grade in mathematics was at least 8 but less than 7.5 for the project output are shown in the fourth quarter (IV), and in the second quarter (II), there are the unexpected achievers, whose previous mathematics grades were under 8 but had a project output grade of at least 7.5.

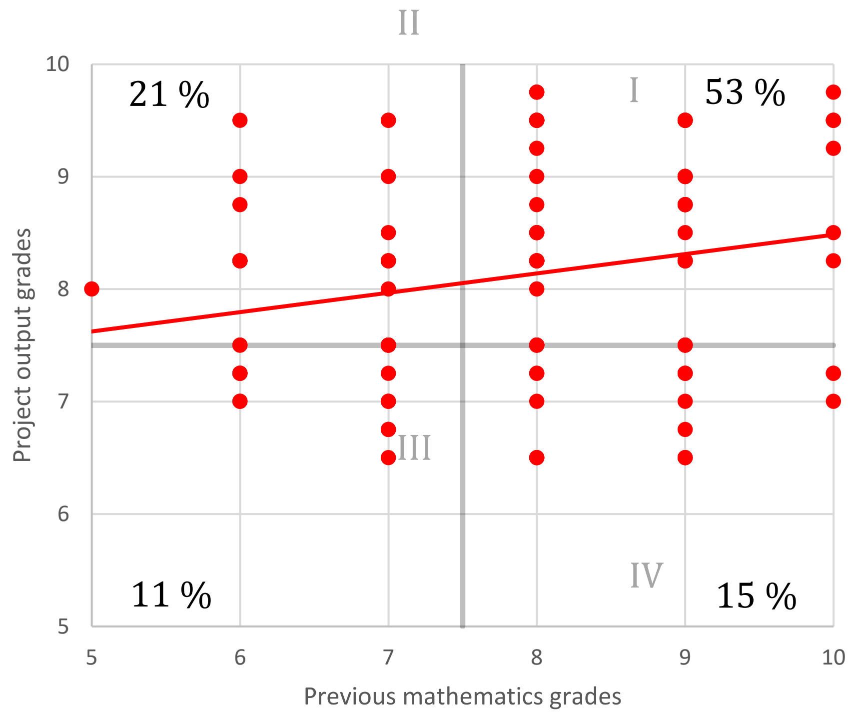


Figure 3. The project output grades in relation to the previous mathematics grades (N = 112).

The pupils' grades for the project output seem to be, on average, slightly better than their previous mathematics grades – about 74% of the pupils achieved at least 7.5. The difference is not statistically significant (p = 0.392, Wilcoxon). There is a weak positive correlation between these grades (rs = 0.223, p = 0.018). Between the projects, there was no statistically significant difference (p = 0.269, Mann-Whitney U test) in the grades for the project outputs.

Each pupil's grade in the project work (Figure 4) was assessed using a combination of work in the lessons, peer review of their own group, self-assessment and learning diary, the small final test and homework, in addition to the project output. Figure 4 shows that there is a strong positive correlation between the pupils' total grades in the project work and their previous mathematics grade ($r_s = 0.711$, $p < 0.001$). There was no statistically significant difference ($p = 0.079$, Mann-Whitney *U* test) for the whole project work between the projects (based on data *a* and *b*).

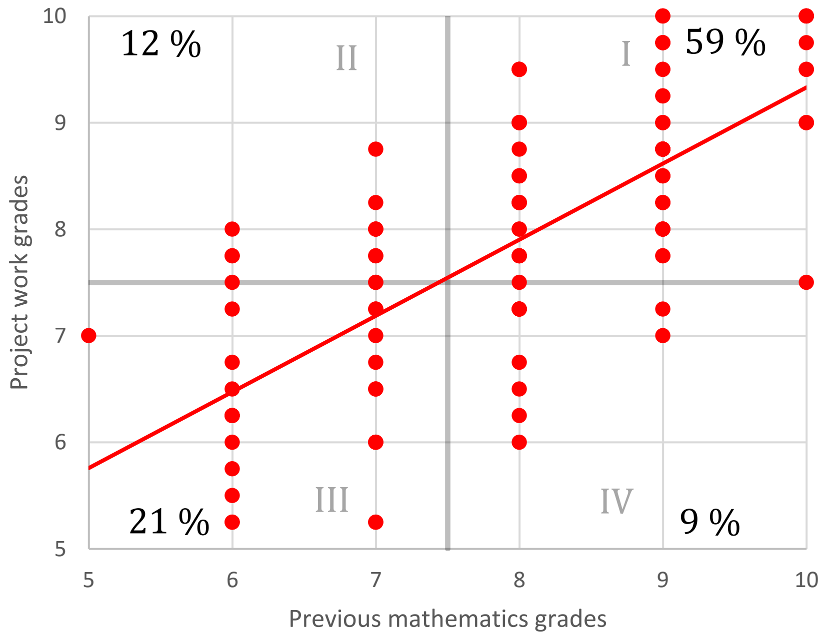


Figure 4. The project work grades in relation to the previous mathematics grades (N = 112).

Figure 5 indicates there is a moderate positive correlation between pupils' previous mathematics grades and the grade on the test after project work (rs = 0.624, p < 0.001; based on data a and g). No significant difference was found between the projects in the final test (p = 0.781, Mann-Whitney U test).

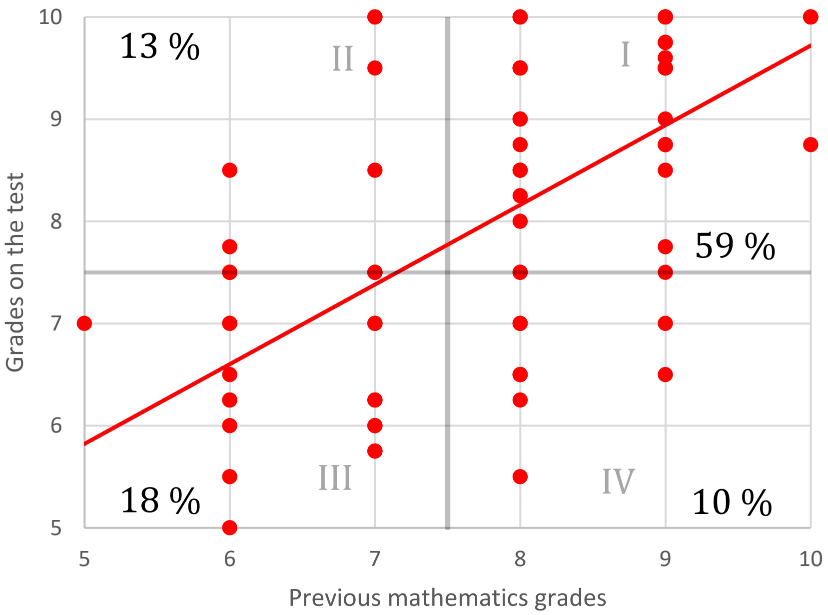


Figure 5. The grade on the test in relation to the previous grade in mathematics (N = 110).

From a research perspective, the significant groups are II and IV; it is interesting to see why some pupils succeeded and others did not. These reasons were examined using a combination of data a, d, e and f. The reasons are listed in Table 8. The first column is based on the project work grade, and the second is the test grade with relation to the previous mathematics grade.

Table 8. Feedback on belonging to groups II and IV. The first column is based on the project work grade, and the second is the test grade.

The project work grade (Figure 4)		**The test grade (Figure 5)**	
Group II (*N* = 13)	**f**	**Group II (*N* = 14)**	**f**
Better learning as a result of the support of the group	8	Support for his/her group	13
Taking advantage of others without learning	5	The working method is good	1
Group IV (*N* = 10)	**f**	**Group IV (*N* = 11)**	**f**
Taking advantage of others without learning	4	Taking advantage of others without learning	4
Other group members did not work	2	Other group members were a burden	2
Pupil did not do his/her best	2	There was too little time to learn	2
Absences	2	The group did not do their best	1
		Pupil did not study for a test	1
		Not to be classified	1

The make-up of the group had a major influence on the total grade. Most unexpected achievers in the project work experienced improved learning with the support of their group.

> "It was easier to concentrate in groups." (Pupil 1, data e)

On the other hand, a few pupils only took advantage of their group mates and got a better grade for the project output, though they did not participate in the group work. Some of them also got a better grade in the project work because the project output grade was good enough. We called them 'passengers' (Schuck, 2002).

The general reason for the expected weaker scores was also taking advantage of others without learning. These pupils could get a good grade on the project output, but the test results, working in the lessons and the peer review decreased their grade. They were also 'passengers.' These data do not tell reliably why some pupils did not participate as much in the group work.

> "One pupil of our group worked less. I and other groupmates did nearly all." (Pupil 2, data f)

Based on the learning diaries (*d*) and self-assessment (*e*), the other reasons for weak scores were absences and a lack of effort.

> "One pupil was at the project lesson only once. Another pupil wanted only to write. I had to do everything alone." (Pupil 3, data d)

Some pupils showed a noticeable difference in the grades between the project output and the entire project work. Altogether, 12 pupils increased their grades and moved from group IV to group I. Most of these (9 of 12) belonged to groups where there were either disagreement and 'passengers.' The teacher was able to assess pupils' mathematical content knowledge in the post-project test. A few pupils (3 of 12) did not produce a good project output but learned mathematics normally. The grades of 11 pupils decreased from group II, dropping them into III; in these cases, it was the other group members who were responsible for the good project output, but these pupils had not participated in the work and they were 'passengers.'

In total, there were 11 pupils in group IV based on the post-test. The reasons given for doing poorly on the test were linked to teamwork problems (7 of 11). Other reasons were too fast of a working pace or the lack of revision for the test. It is important to note here that the teacher did not give any advance warning of the test.

The pupils in group II obtained better test results than expected – nearly all of these pupils (13 of 14) said (data *d*, *e* and *f*) that their good group encouraged working hard. One pupil learned better by working in groups than by listening to a teacher.

Pupils' own opinions on their learning were asked in the self-assessment. As a whole, 99 pupils (85%) answered the question. The views were distributed evenly among the students: 37 pupils (37% of the respondents) believed that they learned better through project work than through traditional teaching, 34 pupils (34% of respondents) thought they learned worse, and 28 pupils (28% of respondents) thought that it was the same.

> "If I believe I don't need that kind of mathematics in my everyday life, then I don't bother to study. Now, I know that I need these mathematics, so I want to learn, and I am really learning." (Pupil 4, data e)

> "I learn more quickly in traditional teaching." (Pupil 5, data e)

There is no statistically significant difference ($p = 0.121$) between the projects (based on data e).

After the coordinate system project, a control group ($N = 18$) took the same test as the intervention group ($N = 59$). This control group learned the same content traditionally before the test, and their average mathematics grade (avg. = 8.3) was the same as that of the intervention groups. In the groups' scores for the final test, there was no statistically significant difference when using the Mann-Whitney U test ($p = 0.950$). Based on the results, it is possible to assume that project work does not seem to dilute the quality of learning.

5 Discussion

In summary, it is possible to study mathematics using project work as a working method. The coordinate system and the statistics projects are good examples of projects in which the mathematical objectives are clear. In a well-designed project, the objectives of project-based learning can also be achieved (Larmer et al., 2015). However, the depth of mathematics handling was shown to have many differences between the studied groups. Some groups only calculated, and the others explained more what and how they calculated.

Kilpatrick et al. (2001) defined the mathematical proficiency of an individual. In the current article, we assume that the mathematical proficiency of a group is at least the sum of the group members' skills. A pupil said the following in his learning diary:

> "We work as a team, and everybody helps according to their skills. With the help of everyone's little skills, we made very good project output." (Pupil 6, data d)

In both projects, every branch of mathematical proficiency was needed at the group level. The groups could share pieces of work, in which case a pupil may not participate in some of the tasks. Now, we examine only the instructions, not implementation. Here, the instructions offer the possibility to develop every branch. In the future, further data collection is required to determine exactly how well the expectations can be realised in practice.

The examined project instructions were quite closed. It would be important to examine pupils' mathematics learning during more student-centered and open projects. Is it possible to achieve the learning objectives in mathematics if pupils can influence more their own projects? How can teachers instruct their pupils on the handling of essential mathematics without well-designed project instructions?

Taken together the implementation in the schools, the current study indicates that it is good to assess project work in various ways. The project output does not show the whole truth at the individual level, so we also need other assessment methods, such as the self-assessment and peer review. Compared with previous success in mathematics, an unexpected good or weak grade in project work is generally because of the groups. A hard-working group can support and inspire a pupil to work and learn more, but on the other hand, a strong group may encourage a pupil to be a 'passenger.' If the other pupils in the group are a lot weaker, a pupil can experience these members as a burden.

At all, the 'passenger' phenomenon is interesting, and this article does not tell reliably why some pupils are 'passengers.' The 'passengers' could be both weak and gifted in mathematics. Some 'passengers' got a good grade in the project work, but most of them only got a better project output grade due to their group. There were also 'passengers' who had good previous grades in mathematics, but they got a lower grade in the project work. These gifted pupils might have suffered from inefficient group mates, where the result would be a low grade for the project output. The difficulty level of the project might have been too easy for them. In the future, it would be important to know why somebody is a passenger.

On the other hand, assessing project work is a useful addition to teachers' evaluation methods. The Finnish core curriculum (2016) emphasises using a versatile assessment method. The success of group work was seen in the project work and project output grades. Group work – or collaboration – is a twenty-first-century skill, or a part of the transversal competence, in the curriculum.

As a whole, project work supports mathematics learning while diversifying traditional teaching methods and the evaluation of mathematics. It can also encourage inquiry- and phenomenon-based learning when in accordance with the curriculum. According to the research, the teachers must focus on the tutoring of group work and helping pupils to go towards their learning objectives.

The most important limitation of the current study was the small sample size, and it should not be assumed that its findings could be applied in another context. Also, when we compare the grade in the project work with a pupil's previous mathematics grade, there may have been in connection with a different aspect of mathematics, so the grades are not fully comparable.

Future work should focus on learning in project work on a larger scale. Nowadays, multidisciplinary learning modules and projects are being made annually in Finland (FNBE 2016), so this type of research material would be available.

Acknowledgements

We gratefully acknowledge the help provided by mathematics teacher, M.Sc. Juuso Linnusmäki.

References

Aksela, M., & Haatainen, O. (2019). Project-based learning (PBL) in practise: Active teachers' views of its' advantages and challenges. *5th International STEM in Education Conference Proceedings: Integrated Education for the Real World*. Brisbane, Australia: Queensland University of Technology.

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The Clearing House*, *83*, 39–43.

Boaler, J. (1998). Open and closed mathematics: Student experiences and understandings. *Journal for Research in Mathematics Education*, *29*(1), 41–62.

Drake, K. N., & Long, D. (2009). Rebecca's in the dark: A comparative study of problem-based learning and direct instruction/experiential learning in two fourth grade classrooms. *Journal of Elementary Science Education*, *21*(1), 1–16.

Erdogan, N., & Bozeman, T. D. (2015). Models of project-based learning for the 21st century. In A. Sahin (Ed.), *A practice-based model of STEM teaching* (pp. 31–42). Sense Publishers.

Finnish National Board of Education. (2016). *National core curriculum for basic education 2014.* Porvoo, Finland: Porvoon Kirjakeskus.

Hakkarainen, K., Bollström-Huttunen, M., Pyysalo, R., & Lonka, K. (2005). *Tutkiva oppiminen käytännössä: Matkaopas opettajille*. Helsinki, Finland: WSOY.

Heinonen, M. (1994). *Projektiopiskelu opettajan työn kehittämisen välineenä*. Acta Universitatis Ouluensis, serie E scientiae rerumsocialium 17.

Hung, W., Jonassen, D. H., & Liu, R. (2007). Problem-based learning. In J. M. Spector, J. G. van Merriënboer, M. D. Merrill, & M. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 1503–81). Mahwah, NJ: Erlbaum.

Joutsenlahti, J. (2005). *Lukiolaisen tehtäväorientoituneen matemaattisen ajattelun piirteitä - 1990-luvun pitkän matematiikan opiskelijoiden matemaattisen osaamisen ja uskomusten ilmentämänä*. Tampere, Finland: Tampere University Press.

Joutsenlahti, J., & Sahinkaya, N. (2011). Finnish and Turkish national core curriculum for basic education in mathematics. In L. Burman, O. Björkqvist, & A. Röj-Lindberg (Eds.), *Proceedings of the FMSERA Annual Symposium in Long-term Research in the Didactics of Mathematics and Science, Vaasa, Finland, 27–28 October 2006*. Vaasa, Finland: Åbo Akademi University.

Kilpatrick, J., Swafford, J., & Findell, B. (2001). *Adding it up: Helping children learn mathematics*. Washington, DC: National Academies Press. Retrieved from https://doi.org/10.17226/9822.

Larmer, J., Mergendoller, J., & Boss, S. (2015). *Setting the standard for project-based learning: A proven approach to rigorous classroom instruction*. Alexandria, VA: ASCD.

Leino, J. (1992). The importance of project work in teaching mathematics. In Leino J. (Ed.), *Mathematics teaching through project work*. Hämeenlinna: Tampereen yliopiston Hämeenlinnan opettajankoulutuslaitos.

Markham, T., Lamer, J., & Ravitz, J. (2006). *Project-based learning handbook* (2nd ed.). Novato, CA: Buck Institute for Education.

Middleton, J., Jansen, A., & Goldin, G. (2016). Motivation. In M. S. Hannula, G. A. Goldin, E. Heyd-Metzuyanim, A. Jansen, R. Kassila, S. Lutovac, P. Di Martino, F. Morselli, J. A. Middleton, M. Pantziara, & Q. Zhang (Eds.), *Attitudes, beliefs, motivation, and identity in mathematics education: An overview of the field and future directions*. New York, NY: Springer Open.

Moschkovich, J. (2015). A sociocultural approach to academic literacy in mathematics for adolescent English learners: Integrating mathematical proficiency, practices, and discourse. In D. Molle, E. Sato, T. Boals, & C. Hedgspeth (Eds.), *Multilingual learners and academic literacies: Sociocultural contexts of literacy development in adolescents* (pp. 75–104). New York, NY: Routledge.

Partnership for 21st Century Skills. (2007). *Beyond the three Rs: Voter attitudes toward 21st century skills*. Tucson, AZ: Author. Retrieved from http://www.p21.org/storage/documents/P21_pollreport_singlepg.pdf (accessed on 17 April 2019).

Pehkonen, L. (2001). *Täydestä sydämestä ja tarkoituksella - Projektityöskentelyn käsitteellistä viitekehystä jäljittämässä*. Helsinki, Finland: University of Helsinki.

Rivet, A. E., & Krajcik, J. S. (2004). Achieving standards in urban systemic reform: An example of a sixth-grade project-based science curriculum. *Journal of Research in Science Teaching*, *41,* 669–92. Retrieved from https://doi.org/10.1002/tea.20021

Sarras, S. (1994). Projektioppimisen kehittämiskeskus. In R. Kauppinen, M. Riihelä, & R-M. Vesanen (Eds.), Esiopetuksen kuperkeikka. Käyntikortteja lapsipedagogiikasta. Stakes. *Raportteja*, *168*, 63–81.

Schneider, R., Krajcik, J., Marx, R. W., & Soloway, E. (2002). Student learning in project-based science classrooms. *Journal of Research in Science Teaching*, *39*(5), 410–22.

Schuck, S. (2002) Using Self-Study to Challenge My Teaching Practice in Mathematics Education. *Reflective Practice 3*(3), 327–337.

StarT (2019). Retrieved from http://start.luma.fi/en

Tuomi, J., & Sarajärvi, A. (2018). Laadullinen tutkimus ja sisällönanalyysi. (2018). Helsinki, Tammi.

Viro, E., & Joutsenlahti, J. (2018a). The StarT project competition from the perspective of mathematics and academic literacy. *Education Sciences*, *8*(2), 67–78. Retrieved from https://doi.org/10.3390/educsci8020067

Viro, E., & Joutsenlahti, J. (2018b). Projektityöskentelyn kehittäminen yläkoulun matematiikan opetuksessa. *FMSERA Journal*, *2*(1), 90–99. Retrieved from https://journal.fi/fmsera/article/view/69879

Viro, E., Lehtonen, D., Joutsenlahti, J., & Tahvanainen, V. (2020). Teachers' perspectives on project-based learning in mathematics and science. *European Journal of Science and Mathematics Education*, *8*(1), 12-31. Retrieved from http://scimath.net/articles/81/813.pdf

Wirkala, C., & Kuhn, D. (2011). Problem-based learning in K–12 education: Is it effective and how does it achieve its effects? *American Educational Research Journal*, *48*(5), 1157–86. doi:10.3102/0002831211419491

Vähätalo, P., & Kanervisto, S. (1988). Projektityöskentelystä uusi työtapa lahjakkaille. Kokeilua Turun normaalikoulussa. *Kasvatus, 19*(5), 383–5.

Yetkiner, Z., Anderoglu, H., & Capraro, R. (2008). *Research summary: Project-based learning in middle grades mathematics*. Novato, CA: Buck Institute for Education.

Scrutinizing two Finnish teachers' instructional rationales and perceived tensions in enacting student participation in mathematical discourse

Jennifer Luoto

Department of Teacher Education and School Research, Oslo University, Norway

This study employs interviews and observations to investigate instructional rationales of two purposefully sampled teachers with divergent classroom discourse practices in Swedish-speaking Finnish lower secondary mathematics classrooms. Studies on classroom discourse often point to beliefs and contextual factors shaping teachers' discourse practices. Less is known about how tensions perceived by teachers can influence the instructional rationale in a context such as Finland, known for traditional and teacher-centered mathematics instruction. The findings of this study suggest that these Finnish teachers' instructional rationales for differently enacted classroom-discourse practices are grounded in similar concerns of student needs, related to student learning, well-being, and equity. One of the teachers perceived tension between these concerns and mathematics education literature's ideals of classroom discourse and avoided engaging students in discussions other than in tightly teacher-led format. The other embraced the idea of discourse as facilitating learning and created methods for giving all students equal access to the perceived benefits of mathematical discussions. The identified tensions of student learning, well-being, and equity can be used as guiding principles in developing teachers' discourse practices in professional development in Finland and beyond.

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 133–161

Received 14 April 2020
Accepted 11 June 2020
Published 15 June 2020

Pages: 29
References: 75

Correspondence:
j.m.luoto@ils.uio.no

https://doi.org/10.31129/LUMAT.8.1.1329

Keywords: classroom discourse, student participation, teachers' instructional rationale

1 Introduction

Student verbal participation in classroom discourse e.g., talking mathematics by sharing thoughts and justifying reasoning, is widely recognized as mediating mathematics thinking and learning (Lampert & Blunk, 1998; Kieran, Forman, & Sfard, 2001; Franke, Kazemi & Battey, 2007; Organisation for Economic Co-operation and Development [OECD], 2016a) and positively affecting motivation (Kiemer, Gröschner, Pehmer, & Seidel, 2015). These ideas of learning mathematics through participating in mathematics discourse are often referred to as sociocultural and Western ideas (e.g., Xu & Clarke, 2019). They were emphasized in American (e.g., National Council of Teachers of Mathematics, 1989) and some European curricular contexts (see Gravemeijer, Bruin-Muurling, Kraemer, & Van Stiphout, 2016) as part of a "paradigm shift" away from traditional, teacher-centered approaches and toward

 | CC BY 4.0

"reform-oriented" instruction focusing on student engagement and inquiry-based learning (Ellis & Berry, 2005). This shift has been less prominent in the Finnish context, where instructional practices at the lower secondary level are characterized by teacher-centered instruction and individual seatwork, with scarce opportunities for students to participate in mathematical discussions (e.g., Klette et al., 2018; Taajamo, Puhakka, & Välijärvi, 2014). In addition, mathematical argumentation has not been a part of the traditional Finnish school mathematics education (Kaasila, Pehkonen, & Hellinen, 2010), and teachers are viewed as well-established authorities on content knowledge (Pehkonen, Ahtee, & Lavonen, 2007). Thus, perhaps not surprisingly, participation in mathematics discourse has traditionally not been emphasized in national curricula. However, the latest national curriculum (Finnish National Agency for Education, 2014, pp. 438-441) promotes mathematics instruction that develops students' ability to communicate, interact, and cooperate through presenting and discussing solutions and working in groups as well as individually. Furthermore, the previously high PISA scores—which, in a way, have protected the status quo of traditional instructional practices (see Simola et al., 2017)—are now in decline, while Finnish mathematics educators report a decrease in interest and skills in mathematics in lower secondary schools (Portaankorva-Koivisto, Eronen, Kupiainen, & Hannula, 2018). It is thus timely to study teachers' instructional rationales and potential tensions that might prevent teachers from prompting discourse among students in a Finnish context. This is important insight for teacher education, as targeting potential tensions that might constrain teachers from discursive practices is needed to develop instruction in line with the curriculum, which also may elevate students' motivation for mathematics (Kiemer et al., 2015). The goal of the present study is therefore to investigate two Finnish teachers' instructional rationale for their differently enacted classroom discourse practices and identify perceived tensions related to enabling discourse among students in lower secondary mathematics classrooms.

2 Classroom discourse

Discourse practices in mathematics classrooms are considered contextually bound and collectively developed patterned ways of communicating (e.g., O'Connor, 1998; Xu & Clarke, 2013). Yet, classroom interaction research has been able to categorize some generic teacher moves shaping student participation in classroom discourse (e.g., Alexander, 2006; Cazden, 1988; Solomon & Black, 2008). This study uses the categorization of authoritative and dialogic teacher moves by Furtak and Shavelson (2009), building on Mortimer and Scott (2003), to distinguish between teacher moves in which students engage in co-construction of discussions and moves in which the teacher constructs the discussion.

2.1 Authoritative teacher moves

Authoritative teacher moves imply information transmissions from teacher to students and are the most common moves in mathematics classrooms (Alexander, 2006). A common pattern associated with authoritative teacher moves is questioning in the pattern called Initiation-Response-Evaluation/Feedback (IRE/IRF) (Cazden, 1988), where the teacher calls for single responses from students, interspersed within longer sections of teacher talk, and student answers often receive short evaluative responses. Other authoritative teacher moves are *repeating formulaic phrases* and *marking significance* to help students remember information (Furtak & Shavleson, 2009), and *instruction/exposition*, in which the teacher controls the narrative of information, activities, facts, principles, and procedure (Alexander, 2006). In addition, *repeated questions* and *cued elicitation of student contributions* are considered authoritative teacher questions, as they lead students to the right answer, also known as a "funneling pattern" (Wood, 1998). A final example of an authoritative move is if teachers *promote consensus* and *select particular student contributions* as being correct (Furtak & Shavelson, 2009), thus puncturing discussions of misconceptions or alternative solutions. All these listed moves are authoritative (Mortimer and Scott, 2003), as such moves facilitate teacher control over the discourse while not inviting students to contribute to shaping the discourse or knowledge construction.

2.2 Dialogic teacher moves

Dialogic teaching moves promote discussions and give students opportunities to participate in the construction of knowledge and discourse (Ball & Bass, 2000). Dialogic teacher moves thus enable what Fennema et al. (1996) call "productive mathematical discourse" that supports inquiry-based learning where students actively grapple with mathematical problems (Artigue & Blomhøj, 2013). Such teacher moves are *open and "real" questions*, in which the teacher does not necessarily know the answer, as well as providing *neutral responses to student ideas* (Furtak & Shavelson, 2009). Dialogic moves are further in line with a "focusing pattern" (Wood, 1998), in which teachers *prompt students to explain* their mathematical ideas. Explaining helps students grasp principles, construct rules for solving problems, and become aware of misunderstandings or lack of understanding as well as develop new understandings (Ingram, Andrews, & Pitt, 2019). Teachers may *re-voice or elaborate on student explanations* by using materials to further illustrate ideas or *ask for justifications* to probe student thinking and direct student contributions to become mathematical (Franke et al., 2009; Walshaw & Anthony, 2008). Taken together, the dialogic teacher moves thus invite students to shape the discussions and their understanding of content (see Mortimer & Scott, 2003).

2.3 Balancing teacher moves

The authoritative/dialogic dichotomy presented above is useful for describing discourse patterns within classrooms but less useful for judging discourse quality (Drageset, 2015). Both types of moves have their place in mathematics classrooms. Authoritative moves, such as IRE-patterned questions, may be effective in discussions of previously learned content (Temple & Doerr, 2012), while dialogic moves are beneficial for grappling with new mathematical concepts (Fennema et al., 1996). However, teachers socialize students into ways of thinking and reasoning about mathematics through discourse (O'Connor, 1998), and if teachers use only authoritative moves and never engage students in challenging discourse, students may miss opportunities to develop mathematical reasoning (Cobb & Bowers, 1999). Several scholars thus recommend that teachers balance authoritative and dialogic moves so that students can both explore ideas and learn relevant content (Boerst, Sleep, Ball, & Hyman, 2011; Scott, Mortimer, & Aguiar, 2006).

It is contested whether participation in discourse is equally important for all students. For example, studies show that students may learn just as much by vocal or silent participation in discourse (O'Connor, Michaels, Chapin, & Harbaugh, 2017), and that participation in discourse is not necessarily beneficial for students with learning disabilities (e.g., Gersten et al., 2009). It is also questioned what type of activity format is most beneficial for student participation in discourse. Traditional whole-class instruction is considered inequitable, as it engages only volunteering students (Emanuelsson & Sahlström, 2008). While in group work, some group partners are more engaged in discussions than others; hence not all students have the same opportunities to engage in content discussions (Bergem & Klette, 2010; Webb, Nemer, Chizhik, & Sugrue, 1998). To establish norms and expectations for social behavior in the content-focused discourse, teachers need to pay attention to both social (eliciting contributions from different students) and analytical scaffolding (prompting students to explain reasoning) (Kovalainen & Kumpulainen, 2005). Consequently, just as teachers need to balance authoritative and dialogic moves, they also need a broad repertoire of techniques for orchestrating classroom discussions that function as productive learning situations for all students (Sfard, 2003; Bergem & Klette, 2016). Moreover, as the following review suggests, there are several different factors that may shape teachers' instructional decisions about classroom discourse practices.

3 Teachers' instructional rationale for enacted discourse practices

Instructional rationale in this study refers to how teachers rationalize their instruction in the complex and situated environment of mathematics classrooms (Confrey, 2017). Similarly to Jeppe Skott's (2001) concept of *school mathematics images*, instructional rationale is concerned with teachers' idiosyncratic and subjective accounts of their mathematics teaching. Instructional rationale is thus limited to teachers' explicit, avowed, and uttered views of their enacted practices (Fives & Gill, 2015), in contrast to *teacher beliefs*, which refer to psychologically held understandings, premises, or propositions about the world that are thought to be true (Pajares, 1992; Philipp, 2007). From the literature, we know that beliefs (e.g., Atweh, Cooper, and Bleicher, 1998; Brendefur & Frykholm, 2000; Reichenberg, 2018; Sztajn, 2003; Spillane, 2002; Skott, 2001; Pehkonen, 2007) as well as contextual factors (e.g., Ayalon & Even, 2016; Herbel-Eisenmann, Lubienski, and Id-Deen, 2006; Davis et al., 2019; Raymond, 1997) explicitly and implicitly shape classroom discourse practices. For example, Brendefur and Frykholm (2000) found that beliefs about *mathematics* and *the role of the teacher* influence the instructional rationales of teachers' enacted discourse practices in the classroom. The instructional rationale of a teacher with teacher-centered instruction was shaped by beliefs of mathematics as fixed and knowledge as transmissible—believing that learning occurred when students watched examples and listened to explanations. The instructional rationale of another teacher with reform-oriented practices, including group work, was shaped by beliefs that mathematics should be an active endeavor and that mathematics communication facilitated learning and students' construction of knowledge. In a study by Reichenberg (2018), a mathematics teacher rationalized about his preference for individual seatwork over discussion-based activities. This teacher stressed that individual work was important for developing higher-order skills and logical thinking, which this teacher considered as non-verbal skills, while he perceived discursive practices in whole-class teaching as mainly promoting verbal skills and lower-order thinking.

Sztajn (2003) and Spillane (2002) in their respective studies demonstrate that teachers' instructional rationales may be related to beliefs about the *needs* of students with different socioeconomic status (SES); low-SES students are believed to need teacher-centered direct instruction of basic skills, while high-SES students need to be challenged intellectually—for example, through discourse. Similarly, Atweh et al. (1998) suggest that beliefs about other student needs—depending on gender, abilities, and their futures—shape the instructional rationale of teachers. A teacher who saw his male students as high achievers and future mathematicians stressed student independence and self-control of learning, while a teacher who perceived his female students as middle achievers with a future in tertiary studies preferred direct instruction (Athew et al., 1998). In a study by Skott (2001), the teacher enacted different discourse practices depending on beliefs about the *main concern* for particular students—when the concern was building student confidence, interactions with students were more direct than when the main priority was mathematical learning.

The instructional rationales for discourse practices may also be shaped by tensions and constraints related to *contextual factors*. In Raymond's study (1997), *a large group size*, *lack of time and resources*, and *standardized tests* were perceived as constraining a teacher from prompting students to engage in discussions. Similarly, Davis et al. (2019) show how a teacher who generally embraced reform-based teaching, perceived tension between reform-based teaching and *accountability systems*, such as curricula, resources, and expectations from parents and the school. Moreover, Herbel-Eisenmann et al. (2006) found that *parents' demands*, *curriculum materials*, and *students' own preferences* were factors a teacher perceived as constraining reform-oriented teaching approaches. Also, more *specific situational factors* influence classroom discourse. Ayalon and Even (2016) show that a specific mathematical topic, the specific teacher, and the characteristics of a specific class shaped students' opportunities for diverging into argumentative discussions, stressing that the mathematical topic and the students themselves shape classroom discussions.

In the Finnish context, empirical research from classrooms is scarce (Simola, 2017) and only a few studies shed light on teachers' instructional rationales of mathematics teachers' discourse practices. For example, in Pehkonen's (2007) interview study on Finnish mathematics teachers' beliefs, teachers implemented teacher-centered methods and the use of textbooks, viewing this as a safe method for delivering content. Kupari (2003), drawing on Trends in International Mathematics and Science Study (TIMSS) survey data, identified how two diverging groups of Finnish mathematics teachers' beliefs reflected their reported practices: the group holding constructivist beliefs embracing understanding as essential for learning were more likely to engage their students in group work than the teachers holding traditional transmissive beliefs. More research is scarcely needed to nuance how such different beliefs may be enacted in classroom practice and instructional decisions in a Finnish context.

In summary, the reviewed studies point to several different factors teachers may perceive as shaping students' participation in mathematics discussions. This study contributes to the field of mathematics education by identifying rationales and possible tensions two teachers with different discursive practices perceive in engaging students in discourse. Situated in a Finnish context, where classroom discourse is not traditionally a part of mathematics education (Kaasila et al., 2010), this study may also nuance the discussion about ideal practices in classroom discourse, as research from different national contexts can contribute to the field by "challenging the relevance of culturally specific evaluative concepts" (Hemmi & Ryve, 2015, p. 504; Skott, 2019). Knowledge of how teachers rationalize their different classroom discourse practices in a Finnish context may thus inform teacher training and professional development on issues that need to be addressed in order to develop teachers' repertoire of enacted discourse practices. The following overarching research question guided the analysis: *How do two Finnish mathematics teachers with diverging practices perceive and enact student participation in discourse?* In order to approach this question, three sub-questions were posed:

1. What instructional moves do the two mathematics teachers use to engage students in classroom discourse, and to what extent are these moves used?
2. What is the instructional rationale for the two mathematics teachers' instructional moves in classroom discourse?
3. What kind of possible tensions do teachers with different practices perceive as hindering or enabling student participation in discourse?

4 Methods

4.1 Participants

The participating teachers are Anna and Bea (pseudonyms), sampled from the LISA video study focusing on instructional practices in Nordic lower secondary classrooms (see Klette, Blikstad-Balas, & Roe, 2017). These teachers were purposefully sampled (Patton, 2015), since they displayed contrasting and illustrative patterns of different classroom discourse practices in another study involving eight Swedish-speaking Finnish mathematics classrooms (Luoto et al., in rev). Anna was sampled due to her atypical practice, in which she constantly engaged her students in discussions in various ways. Bea represents a more typical practice, providing few opportunities for students to discuss mathematics. Thus, they represent different types of classroom discourse practices. In this study, I focus on their ninth grade[1] classes in 2018, when the students are 15 years old. Both teach in schools located in urban, high-SES areas around Helsinki. Anna teaches an "advanced" class, and Bea teaches a "basic" class, but they follow the same curriculum. This kind of tracking was officially discontinued in compulsory education in Finland in the mid-1980s (Pekkarinen & Uusitalo, 2012, p. 132), as it was considered inequitable. However, the national curriculum allows temporary grouping as a means for differentiation (Finnish National Agency for Education, 2014), and over 50% of Finnish principals report some form of ability-based grouping for ninth graders (OECD, 2016b).

4.2 Video observations

Three consecutive mathematics lessons from each teacher were video recorded. Two cameras were strategically placed in each classroom, one facing the teacher and one the entire classroom. The teacher wore one microphone, while the other captured student talk. The author was present in the classroom during the filmed lessons, in the role of "observer as participant"— an outsider watching the lesson without intervening (Bernard, 2011). The field notes consisted of pictures of student work and descriptions of tasks and other instructional materials.

[1] The 9th grade is the final year of compulsory school in Finland.

4.3 Interviews

The interviews were semi-structured (Harding, 2013), with mostly open-ended questions on five preselected themes: teachers' perceptions of their own teaching, how students learn mathematics, student participation in general, student participation in discourse in their classroom, and what teachers saw as possibilities and constraints for student participation in discourse (Table 1). The themes in the interview guide were built on the reviewed previous research on beliefs and contextual factors shaping classroom discussions, to broadly include possible factors shaping teachers' instructional rationales. The interview guide was also refined after piloting the interview with two mathematics teachers, to clarify questions that were unclear.

Table 1. Overview of interview themes.

Theme	**1. Own teaching practices**	**2. How students learn mathematics**	**3. Student participation**	**4. Student participation in discourse**	**5. Possibilities/ constraints for student participation in CD**
Example question	*How would you describe your own instructio n?*	*What instructional methods do you perceive as important for your students to learn mathematics?*	*What is student participation in discourse in your classroom?*	*In what ways do you encourage this group of students to participate in classroom discourse?*	*Are there any constraints in engaging your students in classroom discourse? If so, what are they?*
Purpose	To gain an overview of how the teachers perceive d their instructi on in the classroo m	Investigate whether and how teachers shape their instructional practice with a specific view of learning mathematics (Brendefur and Frykholm, 2000; Kupari, 2003; Reichenberg, 2018)	Investigate how teachers perceive student participation in general	Investigate discursive practices the teachers perceived they enacted and why they enacted it for that particular class (Ayalon & Even, 2016; Atweh et al., 1998; Spillane et al, 2001)	Investigate possible constraints teachers perceive as hindering them from engaging students in discourse (Herbel-Eisenmann et al., 2006; Skott, 2001, Raymond, 1997; Davis et al., 2019)

The interviews were focused (Cohen, Manion, & Morrison, 2011), targeting the teachers' subjective responses to a situation (their instruction) in which they were involved. In line with focused interviews, some questions were tailored to the observed practice. For example, Anna was questioned about the rationale for her group-work practices, and Bea was questioned about the consistent use of teacher-led whole-class sessions. In general, the questions were posed in the same order to both teachers, while still allowing them to pursue topics important to them (Silverman, 1993). The interviews were audio-recorded, lasted approximately one hour, and took place immediately after the last observed lesson so that the teachers would remember the lessons, thus limiting recall bias. Both interviews were transcribed verbatim.

4.4 Application and adaptions of the analytical framework

Furtak and Shavelson's (2009) framework of dialogic and authoritative teacher moves (Table 2), building on a body of previous research (Cazden, 1988; Lemke, 1990; Mortimer & Scott, 2003; Scott, 1998, and others), served as an analytical lens to facilitate a detailed presentation of teacher moves that enable or constrain student participation. It has previously been applied in other video studies in different subjects (see, for example, Andersson & Klette, 2016). The framework was applied on *classroom discourse episodes* (e.g., instances of mathematics discussion in whole class or among peers). This excludes individual teacher-student talk, which is not considered to constitute a joint discussion and understanding of mathematics (Mercer & Hodgkinson, 2008). Teacher utterances during discourse episodes were coded as *authoritative*, *dialogic*, *blended*, or *not applicable*. The blended code was applied when a teacher enacted both dialogic and authoritative moves within a single utterance, such as when Anna, in the below example, both controls the narrative by constructing the guidelines and purpose of the group activity (authoritative) and prompts students to discuss mathematics (dialogic).

> "We will do this task together in groups so you can test what you remember and so I can check that you understand. Discuss within the group. I don't want the person who thinks he or she knows best to respond immediately. Check with each other that everybody knows." (Anna)

Some teacher utterances did not fall into any category and were coded *not applicable*, such as non-content-related questions and comments. These utterances are not included in the results.

Table 2. Teaching moves (Furtak & Shavelson, 2009, pp. 183-184)

Dialogic Teaching Moves – Teacher and students jointly construct narrative/discussion	
Asking "real" or open questions.	Teacher asks a question of a student or entire class to which the answer is not necessarily known or expected by the teacher.
Spontaneous contributions.	Students provide unsolicited comments not directly elicited by teacher.
Revoicing/reflecting on student responses.	Teacher repeats verbatim what a student has responded without changing or altering the meaning of the statement. Includes when a teacher repeats in a question-style format or asks student to clarify what he or she said or to direct that comment to another student.
Meaning into matter.	Teacher uses materials to illustrate or respond to a point or idea raised by student or teacher.
Promoting disagreement / leaving lack of consensus.	Teacher asks students to share divergent ideas and air differences or encourages them to disagree or not reach consensus.
Providing neutral responses to students.	Teacher repeats student responses or provides comments that do not indicate whether student statements are correct or incorrect.
Teacher prompts students to explain to peers.	Teacher prompts students to explain their mathematical ideas, strategies, procedures, or concepts to peers.
Teacher encourages students to talk mathematics together.	Teacher encourages peer talk about mathematical content.
Authoritative Teaching Moves - Teacher controls course of narrative/discussion	
Cued elicitation of students' contributions.	Teacher asks questions while simultaneously providing heavy clues — such as the wording of a question, intonation, pauses, gestures, or demonstrations—to the information required.
Sequence of repeated questions.	Teacher asks the same/similar questions repeatedly to seek a particular answer and continues asking the question(s) until answer is provided by students.
Selecting and/or ignoring students' Contributions.	Teacher ignores a student's contribution or selects a particular contribution from a chorus of different ideas stated by students.
Reconstructive paraphrase or recap.	Teacher recasts or paraphrases what student has said in a more complete or acceptable form or in preferred terminology, including when the teacher adds to or changes the meaning of what the student has said.
Narrative.	Teacher lectures or reviews storyline of unit, lesson, or activity or speaks in an uninterrupted flow to students
Formulaic phrases.	Teacher uses a particular phrase that is easy for students to remember and repeats it over and over again
Marking significance.	Speaking slowly or changing tone so students know that what is being said or what has been said is important
Promoting/establishing a consensus.	Teacher encourages students to agree or come to a consensus.
Providing evaluative responses.	Teacher clearly indicates, through words or intonation, that a student's comment is correct or incorrect.

Two additional codes were developed to capture teacher moves specific to peer work: *Teacher prompts students to explain to peers* and *teacher encourages students to talk mathematics together* (added as dialogic codes in Table 2). While these can be interpreted as authoritative moves since the teacher controls the activity, they are labeled dialogic here as they prompt student explanations and joint construction of knowledge, which are key indicators of dialogic teaching (e.g., Alexander, 2006). In Figure 1, application of the framework is illustrated in a short excerpt from a lesson about triangles using the software GeoGebra[2], in which Anna instructs a pair of students to "change two of the points of the triangle while maintaining the same area."

SPEAKER	**CODE**	**D/A**
Student: That's easy		
Teacher: "Oh? How do you think then?"	*Asking real questions*	Dialogic
S: "You just change it, so you keep the shape but at different points."		
T: "You mean exactly the same shape? Then let's say you cannot have the same shape. Change two points and try to think if there is a systematic way of doing it, do you know anything that could help you about triangles?"	*Cued elicitation*	Authoritative
S: "The formula for the areal b*h/2 [clicks on the computer]. So, I can change it like this!"		
T: "Mm, now you can pretend you are a teacher and tell your partner what you figured out."	*Teacher prompts students to explain to peers*	Dialogic

Figure 1. Example of coding.

As illustrated above, teacher utterances were coded on the sentence level, and this example shows how dialogic and authoritative moves may be intertwined in teacher-student interactions.

[2] https://www.geogebra.org/about

4.5 Phases of analysis

The analysis was performed in four phases. In the first phase, drawing on video observations and field notes, all lessons were viewed several times, transcribed, and mined for identifiable discourse episodes. The focus in Anna's lessons was on triangles (e.g., constructing and calculating angles), and in Bea's, the focus was on exponent rules (e.g., how to simplify and multiply exponents). While the topic of the lessons may encourage different discourse practices, I study these lessons as examples representing different teaching approaches to discourse, and not as a comparison on these two particular teachers (see Section 6.3).

In the second phase, the teacher utterances in classroom discourse episodes were coded using the framework by Furtak and Shavelson (2009) (Table 2), and their frequency counted. These analyses answer the first research sub-question: *What instructional moves do the two mathematics teachers use to engage students in classroom discourse, and to what extent?*

In the third phase, the interviews were transcribed and analyzed in order to answer the second and third sub-questions: *What is the instructional rationale for the two mathematics teachers' instructional moves in classroom discourse?* And *What kind of possible tensions do teachers with different practices perceive as hindering or enabling student participation in discourse?* Two themes were extracted in an iterative process guided by the literature and influenced by the interview guide and the data: *perceptions of student participation* and *perceived factors shaping student participation in classroom discourse*. Together, these themes shaped the understanding of the teachers' instructional rationale and possible tensions in engaging students in classroom discourse.

5 Findings

Six episodes were identified as classroom discourse episodes: two group-work episodes (10 and 60 minutes) and one whole-class episode (three minutes) in Anna's lessons, and three whole-class episodes, each lasting just under 20 minutes, in Bea's lessons. In the following, the different episodes and discursive moves are described (see detailed results in the Appendix), followed by interview findings of the teachers' instructional rationales.

5.1 Anna's classroom discourse practice

Anna engaged her students in classroom discourse mainly through assigning group work of complex tasks. In Anna's Episode 1, students work in pairs using GeoGebra with triangle tasks. The episode contains 82 dialogic moves, 61 authoritative moves, and nine blended moves. This episode especially provoked the dialogic moves *asking real/open questions* (N=27) and *spontaneous contributions from students* (N=26) commenting on content or asking Anna questions such as "To construct a perpendicular line—was it like this?" The most common authoritative move by far was *narrative* (N=52), manifested in Anna controlling the narrative by guiding and managing group work ("Now I want you to focus on this task").

During group work, Anna frames the rules for participation, illustrated in the following excerpt (lines 3-4) from Episode 2, when she checks in on a peer discussion, requiring all students to be involved in the mathematical discussions. She challenges her students in line with a focusing pattern (Wood, 1998) (lines 6-11), prompting them to explain their mathematical ideas. The task at hand is to figure out whether any of a set of triangles are right triangles.

Anna: Maja, you tell me what your group has done.
Maja: I didn't have a calculator. I couldn't hear what they said.
Anna: Now you [to the group] need to share so that Maja also hears what you are doing.
Lotta: We just take $a^2 + b^2 = c^2$
Anna: Yes, and what is that?
Lotta: I don't know . . . I don't remember
Anna: Do you remember, Jani?
Jani: I don't know.
Anna: Maja?
Anna: Why can we use this? Why does it work? I let you think about that.

This example illustrates how Anna balances authoritative and dialogic moves, as she controls the students' discussion, yet uses dialogic moves encouraging students to continue exploring mathematics in their discussions by asking for justifications and prompting students to explain their ideas (Franke et al., 2009).

In Anna's Episode 2, three to four students work in groups on triangle tasks, equipped with a whiteboard, which they use to show their process and solution. In this episode, there is a balance of dialogic (N=21) and authoritative moves (N=20); a few moves are blended (N=4). This episode also provoked *asking real/open questions* (N=9) and *spontaneous contributions from students* (N=5), while the most common authoritative moves were *narrative* (N=8) and *providing evaluative responses*

(N=8). During both group-work episodes, there were a combined 15 instances of the peer-work codes *prompting students to explain to peers* and *encouraging students to talk mathematics*.

Anna's Episode 3 is a short whole-class episode summarizing peer work on triangles. In contrast to Anna's first two episodes, this is characterized by authoritative teacher moves (N=5).

> Anna: Okay, let's freeze here. All groups have realized that we need to use the Pythagoras' theorem in some way. Some didn't remember its name, but you all knew it. But what is difficult is to know why we use Pythagoras'. I heard at least two groups who could tell why. So, Mia, you can tell me since you knew why do we use Pythagoras' theorem?
>
> Mia: Because it only works on a right triangle to find the hypotenuse.
>
> Anna: So the requirement for Pythagoras' theorem is that the sum of all the squared lengths is the hypotenuse squared—this formula. In this case it is $a^2 + b^2 = c^2$. If you know the length of two sides, you can find out the length of the third side, but the whole point here is that this only works in a right triangle, and that is why you can use it to test whether this triangle is a right-angle one.

Anna sums up why the Pythagorean theorem is needed for solving this task by selecting a student contribution she emphasizes as correct, providing an evaluative response (lines 4-5), then paraphrasing what the student said, and lecturing (*narrative*) on why the Pythagorean theorem works to test whether a triangle is a right triangle (lines 7-12). Such authoritative moves help bring the lesson forward and give all students a chance to recall why a particular method worked (Temple & Doerr, 2012).

5.2 Anna's instructional rationale

Anna is in her fourth year of teaching. She teaches both mathematics and science and actively participates in professional development programs. In the interview, Anna uses the term *inquiry-based* to describe her teaching. She states that she wanted to move away from patterns "where you just review theory and procedures, and students perform the same procedures individually." She found this "traditional way" lacking in respect to student learning: "I wanted to find a new way of teaching, a way where students would learn more." According to Anna, her teacher education did not provide tools for teaching mathematics in a way other than the traditional, but she found a like-minded mentor and a network of study friends with whom she shares tasks, ideas, and experiences. Parents have questioned her methods, but she perceives that the school leadership and the new curriculum support her way of teaching: “I realized that the people behind the curriculum think the same way as me.” The combination of having a network, a mentor, and support in the curriculum and school leadership appears to have given her a sense of having a professional knowledge base and security to continue developing student-engaging and inquiry-based teaching.

Perceptions of student participation. For Anna, student participation in classroom discourse means students engaging in peer discussions around whiteboards, initiated by questions she poses, or students replying individually on digital devices. Anna states that peer work and student engagement in discussions are necessary for teaching inquiry-based and complex problems and that discussions “make them think.” But she states that students also must learn how to work productively in groups, as simply placing them into groups does not automatically enhance learning. In the observed lessons, Anna frames student discussions in multiple instances (N=15) by prompting them to explain to their peers (e.g., checking whether all students in the group follow the discussion) or encouraging them to discuss mathematics (e.g., focusing discussions toward justification of solutions instead of simply providing solutions).

Perceived factors shaping student participation in classroom discourse. Anna mentions both school-based and student-related factors as constraining student participation in classroom discourse. The key school-based factor was the necessity to maintain the same pace as all other ninth-grade classes because they have the same tests, preventing her from longer explorations of a topic, which is similar to curriculum constraints reported by Herbel-Eisenmann et al. (2006). Student-related constraints were social factors, such as balancing equity while simultaneously paying attention to students’ well-being and sense of security. Anna perceived the traditional method of students raising hands in a whole-class setting as “only activating the ablest ones.” She states that the inquiry-based approach demands active students, which provokes insecurity in some students not used to working on tasks without prescribed procedures: “Some students do not feel safe in my way of teaching; they miss the traditional way.” To tackle their insecurity, she explicitly credits such students’ performance in front of the class and provides mathematical challenges on all levels so that even the most skilled students sometimes struggle, thus normalizing incorrect answers. Nevertheless, Anna states that some students must be “left alone,” as they are so uncomfortable speaking spontaneously in class. Hence, even though Anna embraces the idea that students learn through participating in discussions, there seems to be a tension between that and another more pressing concern of certain students' well-being.

5.3 Bea's classroom discourse practice

The following example illustrates how classroom discourse in all three of Bea's episodes consisted of long, uninterrupted flows of teacher lecture (lines 10-21), punctuated by short student contributions in IRE format (Cazden, 1988) (lines 7 and 9), with a focus on rules and procedures. Bea reviews a task she has noticed several of her students struggling with. The task is to solve $3\frac{1}{3}^{-2}$ and it is written on the board.

Bea: First, I want to remove the 3, so I multiply 3 with this part of the fraction, 3*3, which is 9 + 1. I write it as $\frac{10}{3}^{-2}$ Can you see this? Then I look at my rules. I think it was our rule 8; look in your notebooks. If I have a negative exponent, what should I do with the nominator and denominator to make it plus, positive? What shall I do with it? Fredrik, what should I do with the 10 and the 3?
Fredrik: We should solve them.
Bea: No, we don't solve them. What did you do, Allan?
Allan: You change their positions.
Bea: We change their positions. That was our last rule. It is in your books, and we also wrote it down. If I have $\frac{a}{b}^{-n}$, to get rid of the negative here, I can absolutely not put it in front of here with a minus—like put the minus in front of the fraction and then the parenthesis, and then it is good. No, to remove the negative exponent, I change the positions. So b, the denominator, will be up in the nominator, and the old nominator will be the denominator, and then I change from minus to plus. So 3 here, and 10 down here, and the parenthesis is from -2 to +2; do you follow? So the next rule, I write here 8 since it is our rule number 8. Then I use rule number 7 to remove the parenthesis. What shall I do when I have a parenthesis with a nominator and denominator squared? How do I remove it?

In Bea's Episode 1, she reviews exponent tasks and elicits student answers on these tasks in whole-class format. The discursive moves Bea uses include mostly different authoritative moves (87%), especially *narrative* (N=25), *providing evaluative responses* (N=20), *cued elicitations* (N=11), and *sequences of repeated questions* (N=11). Dialogic moves used were students providing *spontaneous contributions* (N=8), *providing neutral responses* to students (N=2), and *asking real/open questions* (N=1).

In Episode 2, almost all moves are authoritative (97%). Bea reviews a list of exponent rules and occasionally engages students by asking questions in the form of cued elicitation, as exemplified in the following excerpt (lines 1-2) when Bea gives Ludde a heavy clue of the right mathematical operation to apply when dividing 8^{13} and 8^{11}.

Bea: When we have division between 8^{13} and 8^{11}, it is the same base. What do you think it will be here? If it is not addition, it could be . . . Ludde?
Ludde: Erhm . . . subtraction?

In Episode 3, Bea reviews homework tasks in whole-class format, again guided by mostly authoritative moves (77%), and the most common ones were *narrative* (N=14), *providing evaluative responses* (N=6), and *cued elicitation of students' contributions* (N=5). The dialogic moves (17%) consisted of *spontaneous student contributions* (N=5) and *re-voicing/reflecting on student responses* (N=3).

The following table summarizes the different moves Anna and Bea enacted in their discourse episodes.

Table 3. Overview of teaching moves.

	Authoritative moves	Dialogic moves	Blended moves
Anna Ep 1	40%	54%	6%
Anna Ep 2	44%	45%	9%
Anna Ep 3	100%	0%	0%
Bea Ep 1	87%	13%	0%
Bea Ep 2	97%	3%	0%
Bea Ep 3	77%	17%	6%

5.4 Bea's instructional rationale

Bea has been teaching for 30 years in different grades. She has a double degree in mathematics and special education and actively participates in professional development courses and workshops. While colleagues inspire her, she states that the new curriculum has not changed her instruction. Bea describes her instruction in her basic group as different from in a mixed or advanced group: "I explain more and use more everyday language so that they won't get lost." She states that she spends less time reviewing theory in advanced groups, who then have more time for seatwork on difficult tasks.

Perceptions of student participation. For Bea, student participation in discourse means students listening and answering her questions. In Bea's class, verbal participation is voluntary, which she ensures by letting "everyone who raises their hands gets to answer." Nevertheless, she appreciates students' questions: "I like when there is discussion among me and the students, when they ask things, not only me answering my own questions." Students' spontaneous questions and comments are also the most common dialogic move observed across Bea's episodes (N=6). However, the majority of student utterances were short replies given when Bea tried to elicit the right answers to procedural tasks (see above example). Yet Bea also states that students giving the wrong answer is helpful, as she then can try to detangle misunderstandings. In Bea's view, the teacher reviewing content followed by individual seatwork is the most common instructional pattern for her and her colleagues: "I have been a teacher for many years, and I help out in many classrooms, and this is what we all do."

Perceived factors shaping student participation in classroom discourse. Bea remarks on student-related factors as constraining student participation in classroom discourse. In her view, pressing participation in discourse would be detrimental for her students' well-being, as some students have strong negative feelings about mathematics and may have other problems that pressure them. She has agreed with some students to never ask them anything when they are unprepared. For Bea, her most important job as a teacher is to "see my students and let them know that I care," and that is why she prefers to guide and discuss with students individually during seatwork. Another student-related concern is her view of the learning needs of her "basic" students: "Mathematics is a lot about structure and students who have issues concentrating need strict guidance on how to apply rules to not get lost." This resembles results in other studies, where teachers who perceive students as struggling academically or having low future aspirations in mathematics "need" basic mathematics (e.g., Sztajn, 2003; Atweh et al., 1998). Bea thus doubts the learning value of peer discussions in her ninth-grade classroom: "I'm not sure what kind of mathematics these students could discuss. They would discuss everything else but mathematics." Further, she views discussions of complex problems as disadvantageous for struggling students: "I tried it once. It was chaos. Only the high-achieving students understood." These statements imply what other studies have highlighted before (e.g., Brendefur & Frykholm, 2000), which is that beliefs about how students learn and what mathematics is shape instruction, as Bea perceives that these students learn best by listening and that engaging in discourse would be a waste of time. Nevertheless, Bea reflects that the future of mathematics instruction will be different: "I think it will be that you start with a phenomenon or a problem, and then you build it up from there. I could never do it with my ninth-graders because everybody has to learn. I would have to guide every one of them. But I think it is the future and a huge challenge for teachers.” Thus, while Bea appears to perceive a tension between student participation in discourse and the needs of struggling students, she also recognizes that mathematics teaching and the role of the mathematics teacher is changing in an inquiry-based and discourse-rich direction.

6 Discussion

As agreement about the benefits of student participation in mathematics discourse grows (e.g., OECD, 2016a; Walshaw & Anthony, 2008), national curricula in Finland and beyond are starting to promote such instructional practices. This study scrutinized two teachers’ instructional rationales and perceived tensions related to student participation in discourse with the combined analytical foci of teacher perspectives and instructional moves. Findings indicate that the teachers use different discursive moves to engage students. By balancing dialogic and authoritative teacher moves, Anna exemplifies instruction that provides opportunities for all students to participate in what may be called productive mathematical discourse (Fennema et al., 1996). Bea’s authoritative moves exemplify instruction where classroom discourse is limited, and student participation means giving short answers in IRE format (Cazden, 1988) and answering cue-elicited questions (Wood, 1998). While their discourse practices varied vastly, their instructional rationales reflected similar concerns. The following discussion will focus on three main concerns reflected in their rationales—student learning needs, equity, and student emotional well-being—and how teachers with different discourse practices may perceive them as in agreement or in tension with engaging students in classroom discourse.

6.1 Instructional rationale for student participation in discourse

The rationales for the diverging discourse practices seem to be shaped by and grounded in similar values and concerns of student needs, emphasizing student learning, student emotional well-being, and equity. Anna’s and Bea’s instructional rationales reflected different views of what it means to learn mathematics and what kind of instruction addresses their students’ learning needs, a difference often demonstrated in research on beliefs and practices (see Kupari, 2003), including research on different classroom discourse practices (e.g., Brendefur & Frykholm, 2000; Sztajn, 2003). Anna's views of learning mathematics were in agreement with the strand of mathematics education research and reform curricula, emphasizing that *all students* should learn how to think and construct knowledge by discussing (e.g., Lampert & Blunk, 1998). Bea held more traditional views of learning mathematics and viewed peer discussions as fruitless for *struggling students*, as she perceived that they needed strict procedural guidance implemented with traditional teacher-centered instruction, similar to the study by Atweh and colleagues (1998). The teachers' different perceptions of student learning needs were also reflected in how they mentioned *equity* as a motivation for their enacted discourse practices, and they differed in how they sought to facilitate equitable practices. Equitable practice for Anna was activating all students through group work, while for Bea, it was giving all students structure and rules through teacher-centered instruction as well as individual guidance.

While the teachers reflected on different views of student learning needs and how to enact equitable practice, they shared concerns about *insecure and shy students* never participating in any kind of classroom discourse. They both suggested that mathematics anxiety and out-of-school issues impaired student engagement in discussions, and challenging such students verbally would conflict with attending to student emotional well-being. They had different ways to engage the most insecure students: Anna gave explicit public recognition to insecure students and attempted to normalize wrong answers by asking all students challenging questions, and Bea discussed mathematics privately during individual seatwork, as she perceived that this was how she could attend to unique student needs.

6.2 Overcoming tensions in engaging students in discourse

Teachers such as Anna and Bea socialize students to participate in mathematical discussions in very different ways, likely resulting in very different communication skills (O`Connor, 1998). Anna seems to have embraced the idea of communicative learning for all students, while Bea, though recognizing it as the future of mathematics education, does not seem convinced that such instruction is beneficial for her basic-level students. Drawing on the literature's ideals of mathematics discourse, the discourse practice represented by Anna, balancing authoritative and dialogic moves, are preferred over the discourse practice represented by Bea, of mainly authoritative moves (e.g., Scott et al., 2006; Boerst et al., 2011). Bea's practice may even be seen as problematic, as participation in discourse is considered to improve learning (e.g., OECD, 2016a), as well as motivation (Kiemer et al., 2015). However, Bea's rationale for not engaging low-achieving students in group discussions receives support in research suggesting that peer work does not necessarily benefit the learning of struggling students (Bergem & Klette, 2016; Gersten et al., 2009). In diverse classrooms, students have different instructional needs, and some teachers, such as Bea in this study, perceive a tension between talking mathematics and student needs. This finding implies a need for more nuance into the discussion that a high degree of dialogic teacher moves and active students in classroom discourse is a goal independent of student characteristics and classroom context, as assessments of classroom discourse should not neglect how contextual factors shape instruction (Skott, 2019). Instead of focusing solely on the beneficial learning opportunities in "talking mathematics," perhaps tensions between dominant discourses in mathematics education literature and local teachers' concerns—such as student learning needs, student well-being, and equity—could be addressed and recognized in teacher education when focusing on practices that enable "productive mathematical discourse" (Fennema et al., 1996). In addition, the different discourse practices that these teachers represent in the classroom, in combination with their different rationales, might be applicable to the rationales of other teachers with similar patterns of practices. To build more knowledge on this topic, I suggest that future research also focuses on how different styles of teaching relates to instructional rationales. Moreover, research on tensions and teachers' concerns and more good examples of instructional practices balancing discursive moves while attending to different students' needs may assist teachers in developing instructional repertoires that allow all students the opportunity to experience learning mathematics while also developing skills to participate in mathematics discourse (see Sfard, 2003). Anna's instruction—supported by the new curriculum, a mentor, a network of colleagues, and school leadership—may give indications of how teachers' classroom discourse practices can address some of the tensions *and* develop equitable norms for participation. For example, Anna's framing of peer work by scaffolding discourse (Kovalainen & Kumpulainen, 2005) socially (e.g., checking for equal participation in groups) as well as analytically (e.g., prompting students to explain solutions) shows potential for developing productive norms for student participation in content-related discussions. Such knowledge of how to scaffold discourse is especially important to address in in-service and pre-service teachers in the Finnish context, since the traditional instructional patterns in mathematics education (e.g., Kaasila et al., 2010; Taajamo et al., 2014) may not be sufficient to give equitable opportunities for students to develop mathematical thinking and communicative skills or address the decline in student motivation and achievement in mathematics (Portaankorva-Koivisto et al., 2018).

6.3 Limitations of the study

Three aspects of this study in particular limit the conclusions that can be drawn; sample size, differences in mathematical content, and ability groups. First, small samples have received criticism for providing understandings that are so context-specific that they cannot generate any generalizable knowledge (e.g., Richardson, 1996). However, such small case studies highlighting different aspects of teacher rationales build a theory on factors shaping classroom discourse, as shown in the review part (see Chapter 3) of this paper. The short period of three lessons may also be seen as a limitation — however the purpose of this study was not to map out the instructional repertoire of these specific teachers, but to demonstrate different discursive practices. Second and third, the different mathematical content taught (Ayalon & Even, 2016) and the different ability levels of the students (Atweh et al., 1998) are likely to shape classroom discourse. Regardless of these differences, it is by contrasting the instructional rationales of teachers with differing discourse practices that we can learn about perceived tensions and how teachers deal with them, which in turn may inform teacher educators of issues that are important to address in teacher education and professional development.

7 Concluding remarks

The significance of the study lies in its approach to studying the instructional rationale behind different kinds of classroom discourse practices in a Finnish context, which facilitates understanding of possible tensions and perspectives associated with classroom discourse practices. This study has shown that teachers' instructional rationales for differently enacted classroom discourse practices may be motivated by concerns for student well-being, learning, and equity, which some teachers perceive as in tension and contradictive to mathematics education literature's ideals of classroom discourse. This study thus provides nuance for contemporary ideals for mathematics classroom discourse by highlighting how teachers with similar values perceive tensions and find solutions for developing discourse practices, which is an insight that could inform teacher educators in a Finnish context and beyond.

Acknowledgements

This study is part of the Linking Instruction to Student Achievement (LISA) study, funded by the Norwegian Research Council (#222620/F10). I would like to thank my research group SISCO, the rest of the LISA team, and my colleagues Guri and Jelena, for your constructive comments and support.

References

Alexander, R. J. (2006). *Towards dialogic teaching: Rethinking classroom talk* (3rd ed.). Cambridge, UK: Dialogos.

Andersson, E., & Klette, K. (2016). Teachers' use of questions and responses to students' contributions during whole class discussions: Comparing language arts and science classrooms. In K. Klette, O. K. Bergem, & A. Roe (Eds.), *Teaching and learning in lower secondary schools in the era of PISA and TIMSS* (pp. 63-84). Cham, Netherlands: Springer.

Artigue, M., & Blomhøj, M. (2013). Conceptualizing inquiry-based education in mathematics. *ZDM*, *45*(6), 797–810.

Atweh, B., Cooper, T. J., & Bleicher, R. E. (1998). The construction of the social context of mathematics classrooms: A sociolinguistic analysis. *Journal for Research in Mathematics Education, 29*(1), 63–82. https://doi.org/10.2307/749718

Ayalon, M., & Even, R. (2016). Factors shaping students' opportunities to engage in argumentative activity. *International Journal of Science and Mathematics Education*, *14*(3), 575–601. https://doi.org/10.1007/s10763-014-9584-3

Ball, D., & Bass, H. (2000). Making believe: The collective construction of public mathematical knowledge in the elementary classroom. In D. Phillips (Ed.), *Yearbook of the national society for the study of education, constructivism in education* (pp. 193-224). Chicago, US: University of Chicago Press.

Bergem, O. K., & Klette, K. (2010). Mathematical tasks as catalysts for student talk: Analysing discourse in a Norwegian mathematics classroom. In Y. Shimizu, B. Kaur, R. Huang, & D. Clarke (Eds.), *Mathematical tasks in classrooms around the world* (pp. 35-62). Rotterdam, Netherlands: Sense Publishers.

Bergem, O. K., & Klette, K. (2016). Conversations as learning tools in mathematics: What do pupils actually learn? In K. Klette, O. K. Bergem, & A. Roe (Eds.), *Teaching and learning in lower secondary schools in the era of PISA and TIMSS*. Cham, Netherlands: Springer International Publishing.

Bernard, H. R. (2011). *Research methods in anthropology: Qualitative and quantitative approaches* (5th ed.). Lanham, USA: AltaMira Press.

Boerst, T., Sleep, L., Ball, D., & Hyman, B. (2011). Preparing teachers to lead mathematics discussions. *Teachers College Record, 113*, 2844–2877.

Brendefur, J., & Frykholm, J. (2000). Promoting mathematical communication in the classroom: Two pre-service teachers' conceptions and practices. *Journal of Mathematics Teacher Education, 3*(2), 125–153. https://doi.org/10.1023/A:1009947032694

Cazden, C. B. (1988). *Classroom discourse: The language of teaching and learning*. Portsmouth, USA: Heinemann.

Cobb, P., & Bowers, J. (1999). Cognitive and situated learning perspectives in theory and practice. *Educational Researcher, 28*(2), 4–15. https://doi.org/10.2307/1177185

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education*. London, UK: Routledge.

Confrey, J. (2017). Research: To inform, deform, or reform? In J. Cai (Ed.), *Compendium for research in mathematics education*. Reston, US: National Council of Teachers of Mathematics.

Davis, B., Towers, J., Chapman, O., Drefs, M., & Friesen, S. (2019). Exploring the relationship between mathematics teachers' implicit associations and their enacted practices. *Journal of Mathematics Teacher Education*. https://doi.org/10.1007/s10857-019-09430-7

Drageset, O. G. (2015). Different types of student comments in the mathematics classroom. *The Journal of Mathematical Behavior, 38*, 29–40. https://doi.org/10.1016/j.jmathb.2015.01.003

Ellis, M. W., & Berry, R. Q., (2005). The paradigm shift in mathematics education: Explanations and implications of reforming conceptions of teaching and learning. *Mathematics Educator, 15*(1), 7–17.

Emanuelsson, J., & Sahlström, F. (2008). The price of participation: Teacher control versus student participation in classroom interaction. *Scandinavian Journal of Educational Research, 52*(2), 205–223. https://doi.org/10.1080/00313830801915853

Fennema, E., et al. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for Research in Mathematics Education 27*(4): 403–434.

Finnish National Agency for Education. (2014). *Grunderna för läroplanen för den grundläggande utbildningen* [National core curriculum for basic education]. http://www.oph.fi/lp2016/grunderna_for_laroplanen

Fives, H., & Gill, M. G. (2015). *International handbook of research on teachers' beliefs* (Vol. 13). New York, US: Routledge.

Franke, M. L., Kazemi, E., & Battey, D. (2007). Understanding teaching and classroom practice in mathematics. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 225-256). Charlotte, USA: Information Age Publishing.

Franke, M. L., Webb, N. M., Chan, A. G., Ing, M., Freund, D., & Battey, D. (2009). Teacher questioning to elicit students' mathematical thinking in elementary school classrooms. *Journal of Teacher Education, 60*(4), 380–392. https://doi.org/10.1177/0022487109339906

Furtak, E. M., & Shavelson, R. J. (2009). Guidance, conceptual understanding, and student learning: An investigation of inquiry-based teaching in the US. In T. Janik & T. Seidel (Eds.), *The power of video studies in investigating teaching and learning in the classroom* (pp. 181-205). Münster: Waxmann.

Gersten, R., Chard, D. J., Jayanthi, M., Baker, S. K., Morphy, P., & Flojo, J. (2009). Mathematics instruction for students with learning disabilities: A meta-analysis of instructional components. *Review of Educational Research, 79*(3), 1202–1242. https://doi.org/10.3102/0034654309334431

Gravemeijer, K., Bruin-Muurling, G., Kraemer, J.-M., & Van Stiphout, I. (2016). Shortcomings of mathematics education reform in the Netherlands: A paradigm case? *Mathematical Thinking and Learning, 18*(1), 25–44. https://doi.org/10.1080/10986065.2016.1107821

Harding, J. (2013). *Qualitative data analysis from start to finish*. Los Angeles, USA: SAGE.

Hemmi, K., & Ryve, A. (2015). Effective mathematics teaching in Finnish and Swedish teacher education discourses. *Journal of Mathematics Teacher Education, 18*(6), 501–521

Herbel-Eisenmann, B. A., Lubienski, S. T., & Id-Deen, L. (2006). Reconsidering the study of mathematics instructional practices: The importance of curricular context in understanding local and global teacher change. *Journal of Mathematics Teacher Education, 9*(4), 313–345. https://doi.org/10.1007/s10857-006-9012-x

Ingram, J., Andrews, N., & Pitt, A. (2019). When students offer explanations without the teacher explicitly asking them to. *Educational Studies in Mathematics*, *101*(1), 51–66. https://doi.org/10.1007/s10649-018-9873-9

Kaasila, R., Pehkonen, E., & Hellinen, A. (2010). Finnish pre-service teachers' and upper secondary students' understanding of division and reasoning strategies used. *Educational Studies in Mathematics, 73*(3), 247–261. https://doi.org/10.1007/s10649-009-9213-1

Kiemer, K., Gröschner, A., Pehmer, A.-K., & Seidel, T. (2015). Effects of a classroom discourse intervention on teachers' practice and students' motivation to learn mathematics and science. *Learning and Instruction, 35*(C), 94–103. https://doi.org/10.1016/j.learninstruc.2014.10.003

Kieran, C., Forman, E., & Sfard, A. (2001). Guest editorial learning discourse: Sociocultural approaches to research in mathematics education. *Educational Studies in Mathematics, 46*(1), 1–12. https://doi.org/10.1023/A:1014276102421

Klette, K., Blikstad-Balas, M., & Roe, A. (2017). Linking instruction and student achievement: Research design for a new generation of classroom studies. *Acta didactica, 11*(3): 1–19.

Klette, K., et al. (2018). "Justice through participation: student engagement in Nordic classrooms." Education Inquiry 9(1): 57–77.

Kovalainen, M., & Kumpulainen, K. (2005). The discursive practice of participation in an elementary classroom community. *Instructional Science: An International Journal of Learning and Cognition, 33*(3), 213–250. https://doi.org/10.1007/s11251-005-2810-1

Kupari, P. (2003). Instructional practices and teachers' beliefs in Finnish mathematics education. *Studies in Educational Evaluation, 29*(3), 243–257. https://doi.org/10.1016/S0191-491X(03)90012-5

Lampert, M., & Blunk, M. L. (1998). *Talking mathematics in school: Studies of teaching and learning*. Cambridge, UK: Cambridge University Press.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, USA: Ablex.

Luoto, J., Klette, K., & Blikstad-Balas, M. (in review) Comparing activity formats and instructional patterns in mathematics classrooms: Cases of instruction in Norwegian and Swedish-Speaking Finnish lower secondary classrooms.

Mercer, N., & Hodgkinson, S. (2008). *Exploring talk in schools: Inspired by the work of Douglas Barnes*. London, UK: SAGE.

Mortimer, E., & Scott, P. (2003). *Meaning making in secondary science classrooms*. Maidenhead, UK: McGraw-Hill Education.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, US: NCTM.

O'Connor, C. (1998). Language socialization in the classroom. In M. Lampert & M. L. Blunk (Eds.), *Talking mathematics in school: Studies of teaching and learning in school* (pp. 17-55). New Yoork, US: University Press.

O'Connor, C., Michaels, S., Chapin, S., & Harbaugh, A. G. (2017). The silent and the vocal: Participation and learning in whole-class discussion. *Learning and Instruction, 48*, 5–13. https://doi.org/10.1016/j.learninstruc.2016.11.003

Organisation for Economic Co-operation and Development. (2016a). *Equations and inequalities making mathematics accessible to all*. PISA, OECD Publishing. Retrieved from: https://read.oecd-ilibrary.org/education/equations-and-inequalities_9789264258495-en#page5

Organisation for Economic Co-operation and Development. (2016b). Selecting and grouping students. In *PISA 2015 results (volume II): Policies and practices for successful schools*. Paris: OECD Publishing.

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307–332. https://doi.org/10.3102/00346543062003307

Patton, M. Q. (2015). *Qualitative Research & Evaluation Methods* (4 ed.). Los Angeles: Sage.

Pehkonen, E., Ahtee, M., & Lavonen, J. (2007). *How Finns learn mathematics and science*. Rotterdam: Sense.

Pehkonen, L. (2007). To change or not to change. *Nordic Studies in Mathematics Education, 12*(2), 57–76.

Pekkarinen, T., & Uusitalo, R. (2012). Peruskoulu-uudistuksen vaikutukset [The reformation of compulsory school]. *Kansantaloudellinen aikakauskirja, 2*(108), 128–139. Retrieved from https://www.taloustieteellinenyhdistys.fi/images/stories/kak/KAK22012/kak22012pekkarinen.pdf

Philipp, R. A. (2007). Mathematics teachers' beliefs and affect. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 257-315). Charlotte, USA: Information Age.

Portaankorva-Koivisto, P., Eronen, L.-., Kupiainen, S., & Hannula, M. S. (2018). Lukion ensimmäinen ytheinen matematiikan kurssi - mielekästä ja merkityksellistä? [The first common mathematics course in upper secondary – meaningful and worthwhile?]. *FMSERA Journal, 2*(1), 57–65.

Raymond, A. (1997). Inconsistencies between a beginning elementary teacher's mathematics beliefs and teaching practice. *Journal for Research in Mathematics Education, 28*(5), 550–576.

Reichenberg, O. (2018). Identifying mechanisms of teaching practices: A study in Swedish comprehensive schooling. *Scandinavian Journal of Educational Research*, *62*(2), 213–228.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. In J. Sikula, T. Buttery, & E. Guyton (Eds.), *Handbook of research on teacher education* (Vol. 2, pp. 102-119). New York, US: Macmillan.

Scott, P. (1998). Teacher talk and meaning making in science classrooms: A Vygotskian analysis and review. *Studies in Science Education, 32*(1), 45–80. https://doi.org/10.1080/03057269808560127

Scott, P., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*(4), 605–631. https://doi.org/10.1002/sce.20131

Sfard, A. (2003). Balancing the unbalanceable: The NCTM standards in light of theories of learning mathematics. In J. Kilpatrick, G. W. Martin, & D. Schifter (Eds.), *A research companion to principles and standards for school mathematics* (pp. 353-392). Reston, US: National Council of Teachers of Mathematics

Silverman, D. (1993). *Interpreting qualitative data: Methods for analysing talk, text and interaction*. London: Sage.

Simola, H., Kauko, J., Varjo, J., Kalalahti, M., & Sahlström, F. (2017). *Dynamics in education politics: Understanding and explaining the Finnish case:* London, UK: Routledge.

Skott, J. (2001). The emerging practices of a novice teacher: The roles of his school mathematics images. *Journal of Mathematics Teacher Education*, *4*(1), 3–28.

Skott, J. (2019). Understanding mathematics teaching and learning "in their full complexity." *Journal of Mathematics Teacher Education, 22*(5), 427–431. https://doi.org/10.1007/s10857-019-09446-z

Solomon, Y., & Black, L. (2008). Talking to learn and learning to talk in the mathematics classroom. In N. Mercer & S. Hodgkinson (Eds.), *Exploring talk in schools: Inspired by the works of Douglas Barnes* (pp. 73-90). London: SAGE Publications Ltd.

Spillane, J. P. (2002). Challenging instruction for "all students": Policy, practitioners, and practice. JCPR Working Papers 253, Northwestern University/University of Chicago Joint Center for Poverty.

Sztajn, P. (2003). Adapting reform ideas in different mathematics classrooms: Beliefs beyond mathematics. *Journal of Mathematics Teacher Education, 6*(1), 53–75. https://doi.org/10.1023/A:1022171531285

Taajamo, M., Puhakka, E., & Välijärvi, J. (2014). *Opetuksen ja oppimisen kansainvälinen tutkimus TALIS 2013: Yläkoulun ensituloksia* [The international TALIS 2013 study of learning and teaching]. Retrieved from: https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/75219/okm15.pdf?sequence=1

Temple, C., & Doerr, H. (2012). Developing fluency in the mathematical register through conversation in a tenth-grade classroom. *Educational Studies in Mathematics, 81*(3), 287–306. https://doi.org/10.1007/s10649-012-9398-6

Walshaw, M., & Anthony, G. (2008). The teacher's role in classroom discourse: A review of recent research into mathematics classrooms. *Review of Educational Research, 78*(3), 516–551. https://doi.org/10.3102/0034654308320292

Webb, N. M., Nemer, K. M., Chizhik, A. W., & Sugrue, B. (1998). Equity issues in collaborative group assessment: Group composition and performance. *American Educational Research Journal, 35*(4), 607–661.

Wood, T. (1998). Alternative patterns of communication in mathematics classes: Funneling or focusing? In H. Steinbring, M. G. B. Bussi, & A. Sierpinska (Eds.), *Language and communication in the mathematics classroom* (pp. 167-178). Reston, USA: National Council of Teachers of Mathematics.

Xu, L., & Clarke, D. (2013). Meta-rules of discursive practice in mathematics classrooms from Seoul, Shanghai and Tokyo. *ZDM, 45*(1), 61–72.

Xu, L., & Clarke, D. (2019). Speaking or not speaking as a cultural practice: Analysis of mathematics classroom discourse in Shanghai, Seoul, and Melbourne. *Educational Studies in Mathematics, 102*(1), 127–146.

Appendix. Results: teacher moves*

Dialogic moves	*Anna Ep 1*	*Anna Ep 2*	*Anna Ep 3*	*Bea Ep 1*	*Bea Ep 2*	*Bea Ep 3*
Asking real/open questions	27	9	0	1	0	0
Spontaneous contributions	26	5	0	8	1	5
Revoicing/reflecting on student responses	5	2	0	0	0	3
Meaning into matter	9	0	0	0	0	0
Promoting disagreement / leaving lack of consensus	0	0	0	0	0	0
Providing neutral responses to students	16	5	0	2	0	0
Teacher prompts students to explain to peers	5	2	0	0	0	0
Teacher encourages students to talk mathematics together	6	2	0	0	0	0
Authoritative moves	*Anna Ep 1*	*Anna Ep 2*	*Anna Ep 3*	*Bea Ep 1*	*Bea Ep 2*	*Bea Ep 3*
Cued elicitation of students' contributions	9	5	0	11	4	5
Sequence of repeated questions	0	2	0	11	1	1
Selecting and/or ignoring students' contributions	0	0	1	0	0	0
Reconstructive paraphrase or recap	0	0	1	2	2	0
Formulaic phrases	0	1	0	0	1	1
Marking significance	1	0	0	2	1	1
Narrative	52	8	2	25	18	14
Promoting/establishing consensus	0	0	0	0	0	0
Providing evaluative responses	9	8	1	20	2	6

*This includes overlaps, e.g., blended moves when utterances were coded for both authoritative and dialogic moves

The Finnish matriculation examination in biology from 1921 to 1969 – trends in knowledge content and educational form

Jakke Neiro[1] and Niko Johansson[2]

[1] Department of Zoology, University of Oxford, United Kingdom
[2] Finnish Museum of Natural History, University of Helsinki, Finland

The history and evolution of science assessment remains poorly known, especially in the context of the exam question contents. Here we analyze the Finnish matriculation examination in biology from the 1920s to 1960s to understand how the exam has evolved in both its knowledge content and educational form. Each question was classified according to its topic in biology, and its cognitive level by Bloom's taxonomy. Overall, the exam progressed from a rather dichotomous test of botany and zoology to a modern exam covering biology from biochemistry to environmental science, reflecting the development of biology as a scientific discipline. The contribution of genetics increased steadily, while ecology witnessed a decline and a renaissance during the same time period. The biological profile of the questions was established by the 1950s. The educational standard and cognitive demand of the questions was always high and established by the 1940s.

Keywords: Finnish matriculation examination, biology education, Bloom's taxonomy, history of science education, assessment content analysis

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 162–199

Received 12 June 2019
Accepted 13 March 2020
Published 22 June 2020

Pages: 38
References: 77

Correspondence:
jakke.neiro@helsinki.fi

https://doi.org/10.31129/LUMAT.8.1.1376

Tiivistelmä

Luonnontieteellisten koekysymysten historiaa ja kehitystä on tutkittu hyvin vähän. Biologian ylioppilaskokeen kysymyksiä tarkasteltiin 1920-luvulta 1960-luvulle koekysymysten sisällöllisen ja opetuksellisen kehityksen selvittämiseksi. Kysymykset luokiteltiin biologisiin sisältöluokkiin, kun taas kognitiivinen taso arvioitiin Bloomin asteikolla. Tarkastelujakson aikana koe kehittyi kaksijakoisesta kasvi- ja eläintiedettä käsittelevästä kuulustelusta uudenaikaiseksi kokeeksi, joka tarkasteli biologiaa biokemiasta ympäristötieteeseen, heijastaen biologian kehitystä tieteenalana. Perinnöllisyystieteen osuus kokeessa kasvoi tasaisesti, kun taas ekologia koki jonkinasteisen taantuman ja uudelleentulemisen samalla aikavälillä. Kysymysten biologinen profiili vakiintui 1950-luvulla. Kysymysten opetuksellinen taso ja kognitiivinen vaatimustaso oli korkea alusta saakka ja vakiintui jo 1940-luvulla.

Avainsanat: ylioppilaskoe, biologian opetus, Bloomin taksonomia, luonnon-tieteellisen opetuksen historia, arvioinnin sisältöanalyysi

Published by the University of Helsinki, Finland / LUMA Centre Finland | CC BY 4.0

1 Introduction

Current educational research focuses on contemporary issues, and the historical development of education is often overlooked (Eymard-Simonian, 2000; Sáez-Rosenkranz, 2016). However, as in all social sciences and humanities, a historical viewpoint can complement educational research with a systematic synthesis of ideas, facts, and past events to answer problems, identify future trends and delineate different interactions and causalities (Cohen et al., 2013; Gall et al., 1996; Sáez-Rosenkranz, 2016). The research in the history of education has concentrated on the history of educators as well as educational institutions and general practices, and only a few studies have looked into the history of educational content and assessment, let alone in biology (Caroli, 2019; Jenkins, 1979; Rosenthal, 1990; Sáez-Rosenkranz, 2016; Virta, 2014). In order to study the history of biology assessment successfully, expertise from three distinct fields, biology, education, and history, must be integrated in an interdisciplinary way. In this article, we examine the history of formal assessment in biology in view of both knowledge content and educational form by analyzing the biology questions of the Finnish matriculation examination over a timespan of five decades from 1921 to 1969.

1.1 The Finnish matriculation examination

The Finnish matriculation examination (FME) is the final exam of the upper secondary school that was instated in 1852 (Virta, 2014). Initially, the exam sessions were held at the University of Helsinki (known as the Imperial Alexander University before 1919), but from 1874 onwards directly in schools (Virta, 2014). According to Kaarninen and Kaarninen (2002), only four compulsory subjects were tested before 1921: Finnish, Swedish, one elective foreign language (Latin, German, French or Russian) and mathematics. The authors note that the exam questions were prepared by an autonomous Matriculation Examination Committee (from 1921 named the Matriculation Examination Board, MEB), which consisted of academics from the University of Helsinki and senior teachers from upper secondary schools. Therefore, Kaarninen and Kaarninen (2002) emphasize that the exam has always been influenced by the latest advances in Finnish academia, which here is understood as higher or tertiary education, universities and research institutions in Finland. In 1921, the test battery in humanities and natural sciences (Fin. *Reaalikoe*, Swe. *Realprovet*) was introduced, including physics, chemistry, biology, geography, history, and religion. The test battery was unique to school systems within Western Europe, as the examinee could freely choose questions from different subjects in both humanities and sciences, which Kaarninen and Kaarninen (2002) see to reflect the Humboldtian ideal of the Finnish education system. The test batteries consisted of almost exclusively essay-based questions, in accordance with the written exams in Finnish and other languages. Towards the end of the century, this format was criticized for being obsolete and favoring languages over sciences, and the test battery was divided into independent subject-specific tests in 2005, including a separate exam in biology with a more diverse set of question formats. Moreover, the examinee could now choose whether to take the exams in the spring or autumn, whereas before this the autumn exam had been for resits only. In the 2010s, the examination has gradually been digitalized, and in 2018 the exam in biology was taken online for the first time (Tuulosniemi, 2019). Over the years, the number of students matriculating each year has risen from about 1000 in the 1920s to 30 000 today (Tuulosniemi, 2019).

Throughout its entire existence, the MEB and the exam have elicited respect and fear alike in both students and teachers (Vuorio-Lehti, 2007). The questions have always been criticized for being overly academic and demanding, unlinked to normal school teaching, although the exam has also been praised for these very same reasons (Kaarninen & Kaarninen, 2002). In addition, the exam has been claimed to direct the teaching and learning more than the formal curriculum, commonly known as the backwash effect in educational research (Ahvenisto et al., 2013; Virta, 2014). However, backwash is not necessarily negative, as it may clarify and strengthen the formal curriculum, but if the exam assesses some areas disproportionately, it can adversely skew the curriculum (Ahvenisto et al., 2013; Virta, 2014).

1.2 The theory of educational assessment

McTighe and Ferrara (1998) subdivide the assessment of learning into three types: diagnostic, formative and summative. Diagnostic assessment includes, e.g. pre-exams to clarify the starting level of students, formative assessment encompasses routine assignments, e.g. homework, self-evaluations and learning diaries, while summative assessment denotes the final comprehensive assessment, e.g. exams and theses. Historically, as a final essay-based exam of upper secondary school, the FME can be considered to represent a summative assessment of learning, and therefore the history of FME in biology can specifically be seen as the history of summative assessment in science education. The theoretical framework of assessment by

McTighe and Ferrara (1998) has been the most popular in characterizing FME in corresponding contemporary studies (Lindholm, 2017; Rostila, 2014; Tikkanen, 2010).

Bloom's taxonomy or hierarchy is widely used to quantify the success and standard of teaching and learning, and it has become the main approach to study the questions of the FME (Bloom, 1956; Lindholm, 2017; Rostila, 2014; Tikkanen, 2010; Vitikainen, 2014). The taxonomy encompasses six cognitive levels: knowledge, comprehension, application, analysis, synthesis and evaluation (Bloom, 1956). The taxonomy is also called a hierarchy, as the levels are ranked in the order of increasing cognitive difficulty, complexity and abstractness (Bloom, 1956).

Table 1. The revised Bloom's taxonomy (Krathwohl & Anderson, 2009). Short biological example tasks are given for each category.

	Know	Comprehend	Apply	Analyze	Evaluate	Create
Facts	List cell organelles	Interpret organelle image	Use math formula	Categorize organelles	Evaluate article	Create a diagram of a cell
Concepts	List organelle functions	Explain evolution	Interpret crossing	Fossils as evidence for evolution	Evaluate Darwinism	Create new phylogeny
Methods	List steps in the experiment	Explain steps in experiment	Use a method to solve a task	Compare two methods	Evaluate method	Create new method
Metacognition	List learning styles	Describe learning styles	Develop study skills	Compare learning styles	Evaluate learning style	Create new learning style

Bloom's original taxonomy analyzes only the level of cognition, but not the level of facts to be processed, and therefore Krathwohl and Anderson (2009) have complemented the taxonomy by adding a second dimension, the knowledge dimension including facts, concepts, methods and metacognition, and by modifying the cognitive process dimension so that creation (synthesis in Bloom's original taxonomy) is ranked over evaluation (Table 1). Facts and concepts overlap to some extent, but facts include single details and terminology ("Name the organelles of the cell"), while concepts encompass more general understanding ("What is the function of cell organelles?"). Methods include the knowledge of research methodology of an academic discipline ("How have the cell organelles been discovered?"), while metacognition denotes the students' knowledge of the relevance of the knowledge for themselves (Krathwohl & Anderson, 2009). Furthermore, metacognition encompasses the students' awareness of their learning styles and techniques with regard to a given study topic (Krathwohl & Anderson, 2009).

1.3 The education of biology

In the 20th century, biology as a scientific discipline underwent a drastic change from natural history to modern life science (Mayr, 1982). Therefore, the content of the biological curriculum has been gradually revised, mostly due to the advances in genetics, and even today it is being discussed which biological novelties should be included in the revised curriculum (Goldenfeld & Woese, 2007; Kinchin, 2010). Here, we define a biological novelty as a general term encompassing biological discoveries, concepts, and theories. We follow Mayr (1997) and regard a discovery as a single item of novel experimental knowledge of a biological phenomenon and a concept as an item of theoretical knowledge explaining a given discovery and linking it to biological theory. Lastly, a theory is seen as an explanation of a biological phenomenon that integrates a multitude of biological concepts. It is widely assumed that science and especially biology develops faster than ever before, but whether the time of introducing biological novelties into exams has changed over the years has never been properly clarified (Kurzweil, 2014; National Research Council, 2009). In recent years, 21st-century biological novelties have been introduced into Finnish science curricula and exams rather quickly, e.g. CRISPR-Cas9 and induced pluripotent stem cells (iPSC) (Happonen et al., 2016).

The field of biology can be divided into subdisciplines in different ways, e.g. by stressing the studied organism group such as zoology or microbiology, the biological phenomenon such as genetics or physiology, or stressing applied research such as clinical microbiology or conservation biology. A couple of general classification schemes have been devised, but in educational research of the biology exam in the FME the framework of the National Research Council (2012) has emerged as the most popular (Lindholm, 2017; Rostila, 2014). As a simple and general classification, it is well suited for categorizing and comparing biological questions from different historical periods. The classification system subdivides biology into four broad categories:

1. LS1 From molecules to organisms
2. LS2 Ecosystems: interactions, energy, and dynamics
3. LS3 Heredity: inheritance and variation of traits
4. LS4 Biological evolution: unity and diversity

2. Aims and study questions

Was old school a good school? In this article, we inspect the FME in biology to understand how the exam changed in both biological knowledge content and educational form from 1921 to 1969. Previously, the modern FME in biology (2009 – 2015) and its educational characteristics have been analyzed by Rostila (2014) and Lindholm (2017), who applied Bloom's taxonomy and McTighe's and Ferrara's assessment model to the exam questions. The exam in chemistry has been analyzed by Tikkanen (2010) and Vilhunen and Hopia (2012), in religion by Vitikainen (2014), and in history and social studies by Ahvenisto et al. (2013) and Virta (2014). Only Virta (2014) analyzed the exam from a historical perspective, and therefore this study aims to shed light on the development of a science exam in the FME for the first time. The study questions are as follows:

1. **Knowledge content:**
   -What trends can be found in the biological knowledge content of the FME from 1921 to 1969?
   -At what timeframe were biological novelties introduced to the exam?

2. **Educational form:**
   -What types of questions were asked?
   -What trends can be seen with respect to Bloom's revised taxonomy?
   -Were questions in different biological categories (National Research Council) equal with respect to Bloom's revised taxonomy? In other words, is there an interaction with the question topic and its cognitive demand?

The answers to these questions will help us understand how the science curriculum in the Finnish upper secondary school has evolved alongside both national and international trends, which in turn helps us predict the future of biological teaching. Furthermore, this study helps us identify questions of high educational standard, which may be used as an inspiration for devising future exams. Finally, this study is important for seeing whether certain biological subdisciplines have exhibited a certain educational profile compared with other subdisciplines, which will help us identify the special educational character of biology as a whole.

3. Materials and methods

3.1 The exam material

The exams both in Finnish and Swedish from 1921 to 1969 were obtained from the free-access Digital Archives of the National Archives of Finland as scanned images from the online repository (http://digi.narc.fi/ylioppilastehtavat.html). Almost all exams had been preserved, only the exams from autumn 1921 to autumn 1923 were missing. From the test battery in sciences and humanities, only the biological questions from the section of biology and geography were chosen for further analysis. In the first years of the FME, biology and geography were taught as a single subject making it challenging in some instances to distinguish the biological questions from the geographical. Therefore, all geographical questions with some biotic component were considered to also be biological in character ("the nature of Iceland"), but questions with a clear abiotic component were left out (see Supplementary Material for chosen questions). It is possible that some questions from the section of physics and chemistry or psychology had a biological component, but these were not included in this study, as the number of these interdisciplinary questions is known to be minute during the studied time period (Kaarninen & Kaarninen, 2002). Furthermore, the exam questions in Finnish and Swedish as a first language have included essay-type questions on biological and other scientific themes. However, these questions were not included in this study, as the primary purpose of this assessment is to evaluate the student's literal and language skills rather than scientific knowledge (Kaarninen & Kaarninen, 2002).

3.2 Trends in knowledge content

Content analysis combining both qualitative and quantitative aspects was applied to all exam questions. Content analysis is a common approach in educational and social sciences to reduce and synthesize disorganized documents and identify the most important characteristics of the material (Neuendorf, 2016). Furthermore, content analysis can be used to historical documents, and for example, the history of the Finnish chemistry curriculum has been studied with this method previously (Vaskuri, 2017). The exam questions are thankful in the respect that they constitute a limited source of historical material, and therefore the drawback of overlooking important documents does not exist (Faire, 2016). Only some questions from the early 1920s were missing, but there is no reason to believe that the questions would have been radically different from the other questions of the decade.

Content analysis was applied in two regimes, here termed qualitative and quantitative. For qualitative content analysis, the biological knowledge content of each question was interpreted, analyzed and characterized as a representation of a biological subdiscipline. For example, several questions of the form "the plant family x" in the 1920s were synthesized to reflect an emphasis on plant systematics and taxonomy. In our qualitative content analysis, the questions were encoded into open categories of biological knowledge content that were considered to best characterize a given question.

For quantitative content analysis, the exam questions were strictly classified into one of four biological categories according to the National Research Council (2012). If the question had an integrative character, the main category was chosen (see Supplementary Material for classification and detailed criteria). For example, the structure of chromosomes was considered to belong to Genetics and not Molecules to organisms, while the drought tolerance of plants was seen as Ecology and not Molecules to organisms. The questions were classified independently by each author (Rater A and Rater B), and the interrater reliability was evaluated with cross-tabulation and kappa analysis (Hallgren, 2012; McHugh, 2012). Kappa analysis is a common statistical technique used to evaluate whether two or more independent researchers agree on a given classification. The frequencies of each category were calculated for each decade, and the interdecadal (ID) change in question frequencies was compared with the chi-squared test of independence using Yates' correction and Fisher's exact test. Fisher's exact test was used when the sample size was not large enough for the chi-squared test of independence, and Yates' correction was used to prevent overestimation of statistical significance for small data samples (Ross, 2017). Both the chi-squared test of independence and Fisher's exact test are standard statistical tests used to compare frequencies of two or more categories (Ross, 2017).

To quantify the rate of introduction of biological novelties, all questions testing novelties were selected. For each biological novelty, the approximate year of academic establishment (AE) of the novelty was estimated from the history of science literature. Here, AE is understood as the approximate year when the biological novelty was broadly and internationally acknowledged. First, the primary scientific reference of the biological novelty was identified, after which succeeding literature was analyzed. For discoveries, AE is the year when the discovery had been conceptualized and linked to biological theory, while for concepts AE is the year when the concept had been linked to biological theory. Lastly, for biological theories, AE is the year when the theory had been acknowledged in preference of other alternatives. The explanation for how AE was estimated is presented in the Supplementary Material for each biological novelty. The authors estimated AE independently, and the mean of these estimates was used to reduce interrater variability. The time of introduction (T) was calculated as the difference between the year of appearance in the FME and AE (Equation 1).

$$T = FME - AE \qquad \text{(Equation 1)}$$

In order to see whether there was a temporal change in the rate of introduction, linear regression analysis was performed by having the year of appearance as the independent variable and the time of introduction (T) as the dependent variable (see Supplementary Material for details). Linear regression is commonly used to fit a linear model to continuous data and to assess whether the trend has been increasing or decreasing (Ross, 2017). All the statistical tests were performed in the R environment (v. 3.6.0) (R Core Team, 2019).

3.3 Trends in educational form

As for knowledge content, both qualitative and quantitative content analysis was performed on the exam questions in order to capture their educational form. For qualitative content analysis, the questions were classified into open categories of educational form and the types of assessment, according to McTighe and Ferrara (1998). For quantitative analysis, the questions were classified into the revised Bloom's taxonomy cognitive categories by Krathwohl and Anderson (2009). The questions were classified independently by each author (Rater A and Rater B), and the interrater reliability was evaluated with cross-tabulation and kappa analysis (Hallgren, 2012; McHugh, 2012).

To test temporal changes quantitatively, the frequencies of each question type were calculated for each decade, and the ID change was tested with Fisher's exact test. Furthermore, the frequencies of question types were calculated for each biological category, and the category-wise frequencies were compared with Fisher's exact test (see Supplementary Material for details).

4. Results

4.1 General qualitative patterns of educational form from 1920s to 1960s

During the studied time period, almost all questions were essays, i.e. performance-based assessment of the product format according to McTighe and Ferrara (1998), and only a few crossing experiments were presented as solvable problems from the 1940s onwards. A lot of the essay-type assignments were simply listed as headings and not directly as questions such as “The circulatory system of fish” or “The plant family Orchidaceae”. If the essays were written as *bona fide* questions, the language was rather consistent and only the verbs *selittää* ‘explain’, *tietää/veta* ‘know’, *kertoa/berätta om, redogöra* ‘tell’, and *tehdä selkoa/redogöra* ‘clarify’ were used. No figures or illustrations were included in the exam, and therefore all the decade-specific figures (Figures 1-5) have been collected from contemporary schoolbooks to present how the exam topics were visualized in the study material.

4.2 The 1920s - Plant systematics and comparative zoology

From the 1920s, 46 questions in total had been preserved. During the 1920s, the questions in biology and geography comprised five to six questions, of which usually three to four were devoted to biology and the rest to geography. The focus on botany and zoology was clearly visible, as about 80 % (35/46) dealt with these topics, while the remainder examined more general biological areas, including genetics, biogeography, evolutionary theory, microbiology, and anthropology (Figure 1).

In botany, a typical question of the decade inspected plant systematics, and altogether 12 taxa were tested (Table 2). Thus, the systematical questions constituted about half of all the botanical questions. Meanwhile, the other questions examined plant physiology, morphology, development, and also, some ecological aspects were included (Table 2).

In zoology, the emphasis was on different aspects of morphology, physiology and embryology (Table 3). A noteworthy proportion of these questions were from a comparative viewpoint, integrating evolutionary thought to the exam, and only a few were testing comprehension of particularly human physiology. The other questions inspected animal behavior, community ecology, and systematics (Table 3).

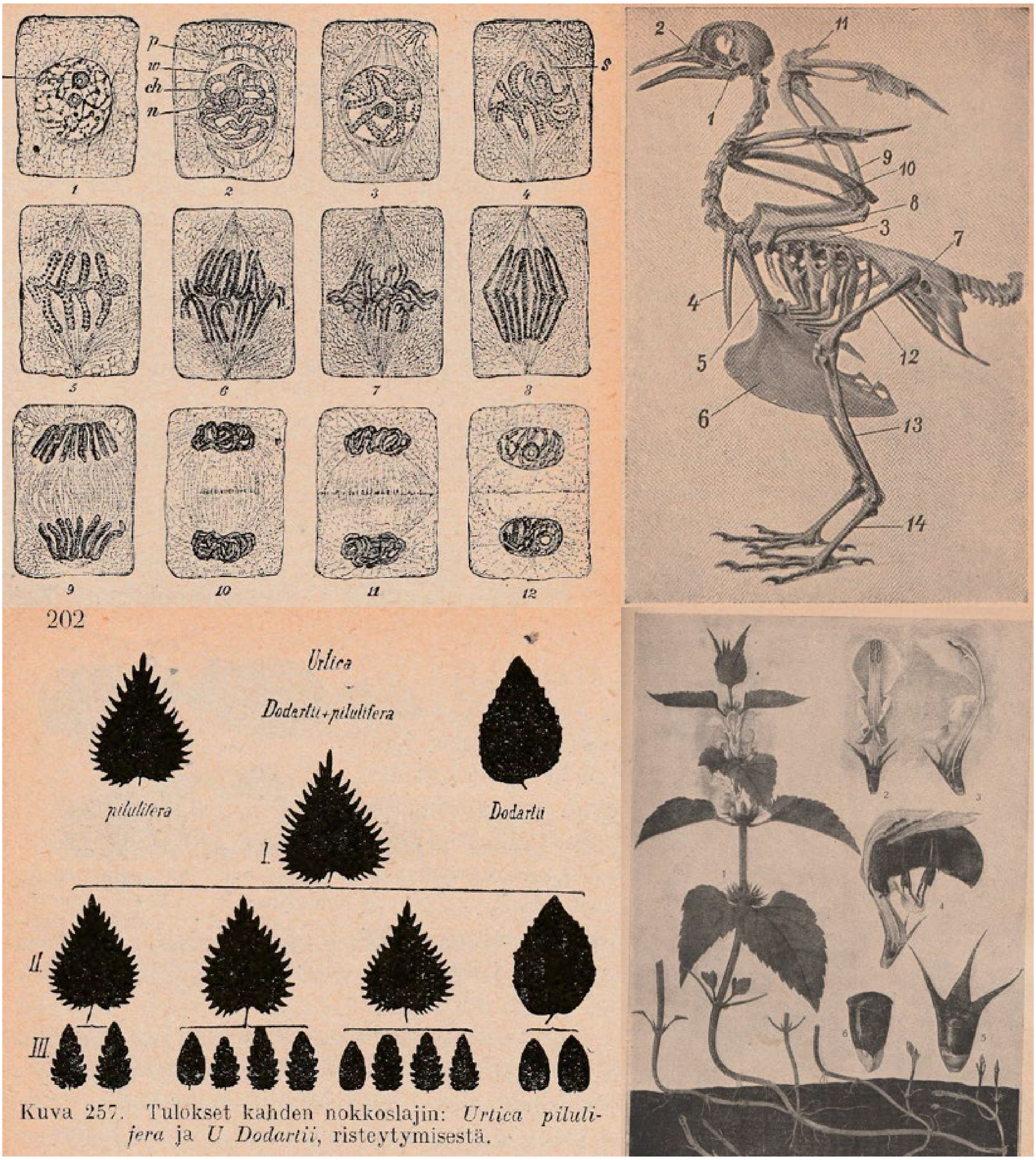


Figure 1. Visual overview of the exam question themes in the 1920s as illustrated in contemporary schoolbooks. (Top left) The structure and reproduction of plant cells. (Top right) Functional morphology of birds. (Bottom left) Mendelism. (Bottom right) The mint family (Lamiaceae). (Kivirikko, 1923).

Table 2. Questions in plant systematics, morphology, physiology and development in the 1920s.

Plant systematics: families	Plant systematics: higher taxa	Plant morphology, physiology and development	Plant ecology
Umbelliferae (the carrot family) Lamiaceae (the mint family) Scrophulariaceae (the figwort family) Liliaceae (the lily family) Orchidaceae (the orchid family) Poaceae (the grasses) Arecaceae (the palms) Brassicaceae (the cabbage family)	Cryptograms Phanerogams (seed plants) Lichens Algae	Respiration Adaptation to arid and moist environments Rhizomes The life cycle of ferns Structure of plant cells and their reproduction	Dispersal of seed plants

Table 3. Animal and human morphology, physiology and development in the 1920s.

Animal morphology	Animal physiology and development	Human anatomy and physiology	Animal ecology, behavior and systematics
Morphological adaption of birds for flight Functional morphology of insect mouthparts Mammalian tooth morphology Morphology of the cross spider Functional morphology of bird legs	The cardiovascular system of fish Development of frogs The digestive system of ruminants	Digestive system Eye Blood Nervous system	Migration in fish Brood behavior of passerine birds Parasitism Protective mechanisms of prey against predators Salmonid fish

Regarding other subdisciplines of biology, there were a few questions on microbiology, but only one question was stated on genetics, namely an essay on Mendelism and its relevance for biology (Table 4). In ecology, the tasks focused on biogeographical and faunistic and floristic aspects (Table 4). The final question of the decade was the ominous “What do you know about negroes?”, reflecting the attitudes toward human races of the time (Table 4).

Table 4. Microbiology, genetics, evolution and ecology in the 1920s.

Microbiology	Genetics	Evolution	Ecology
Bacteria Protozoa	Mendelism	Negroes and human races	Biogeography of Africa Biogeography of Australia Biogeography of Iceland Tundra biome

A lot of the questions tested only factual knowledge, e.g. “The plant family Orchidaceae,” but many questions were already asking for comprehension of biological concepts “What do you know about the structure of seeds and germination?” or “The structure and function of the human eye.” Interestingly, some of the questions were cognitively rather advanced and involved elements of analysis, for example, the examinees were presented the following questions: “How do phanerogams and cryptogams compare to each other,” “The structure of the mouthparts of insects and their adaptions,” and “The structure and morphology of mammalian teeth in relation to diet.”

4.3 The 1930s – Genesis of genetics and diverse Darwinism

From the 1930s, 83 questions were asked on various aspects of biology. The emphasis on botany and zoology continued from the previous decade, but more questions were asked on both genetics and evolutionary theory. The botanical and zoological questions were asked from more diverse perspectives compared to the previous decade (Figure 2).

As for the botanical questions, plant systematics had a lesser role than previously, and instead there was a stronger emphasis on plant morphology, physiology and development (Table 5). Moreover, there was also one applied question on the cultivation of coffee, tea and cocoa (Table 5).

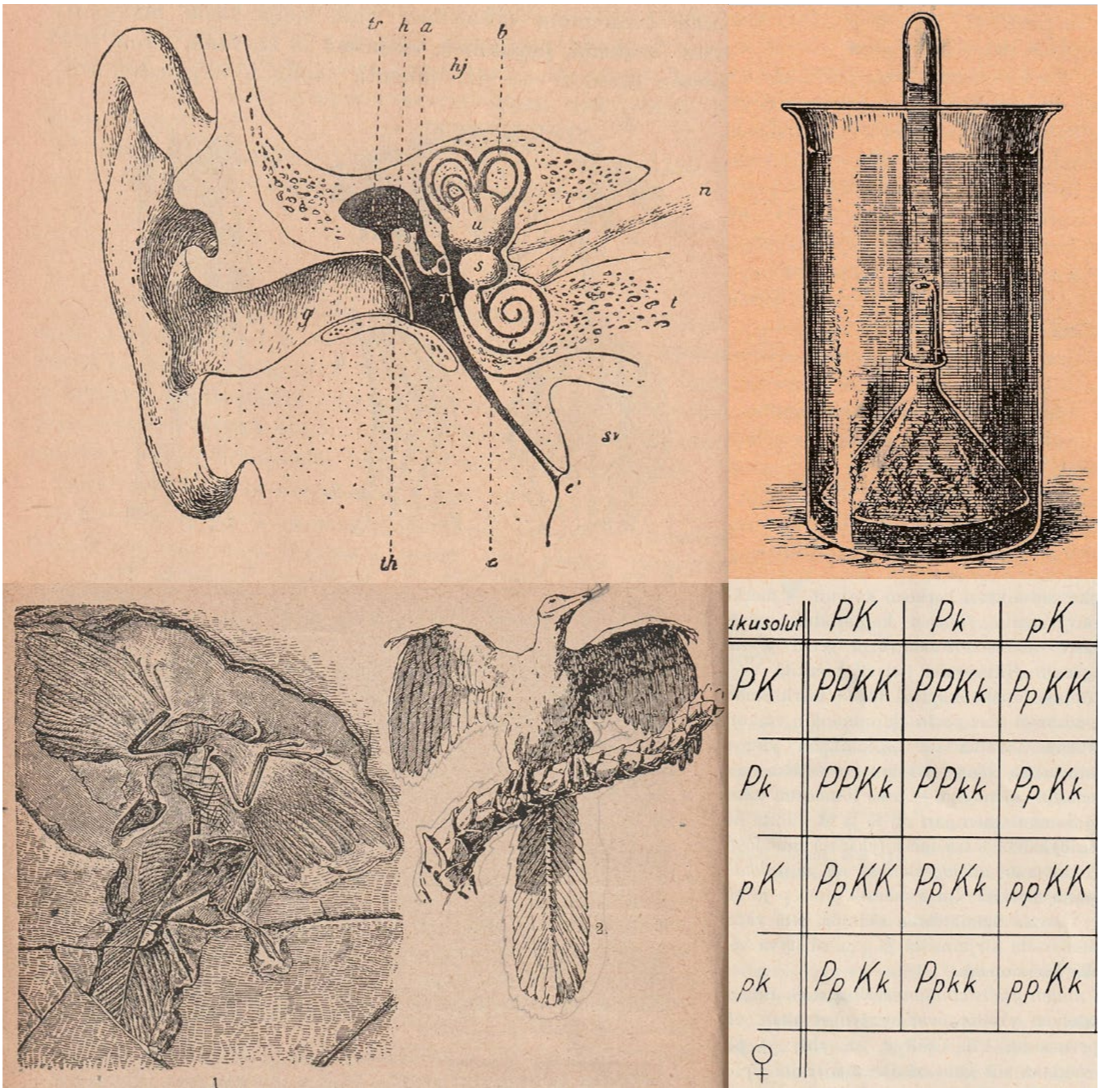


Figure 2. Visual overview of some of the questions in the 1930s as examined in contemporary schoolbooks. (Top left) The structure and function of the human ear. (Top right) Respiration in plants. (Bottom left) The evidence for the theory of evolution. (Bottom right) Mendelism and Punnet squares. (G. Marklund & Jalas, 1933).

Table 5. Plant systematics, morphology, physiology and development in the 1930s.

Plant systematics	Plant morphology	Plant physiology and development	Plants and agriculture
Pine (*Pinus sylvestris*) Spruce (*Picea abies*) Poaceae (the grasses) Diatoms Cacti Potatoes Gymnosperms and angiosperms Thalloid plants	Leaf morphology Morphology of lichens and mosses Plant trichomes Morphology of fungi Root morphology	Water transport Development of the fruit Accessory fruits and flowers Metabolism and respiration Pollination Nitrogen and plant nutrition Secondary growth of trees	Cultivation of coffee, tea and cocoa

In zoology, there were more systematic questions than in the previous decade (Table 6). With respect to physiology, morphology and development, classical zoology still outnumbered human biology in terms of the number of exam questions (Table 6).

Table 6. Animal systematics, morphology, physiology and development along with human anatomy and physiology in the 1930s.

Animal systematics	Animal morphology	Animal physiology and development	Human anatomy and physiology
Ants Finnish reptiles Hawks and owls Finnish aquatic mammals Carnivores and rodents Cartilaginous and bony fish	Rudimentary organs Morphology of human parasites Functional morphology of mammalian teeth Functional morphology of gliding animals Morphology of butterflies Keratin formations of vertebrates Morphology of the platypus	Embryogenesis of the lancelet Metamorphosis of insects Respiration	Ear Muscles Tissue types Digestive system

The decade saw a rise in the number of conceptual questions in ecology in contrast to the biogeographical questions that had been prevalent in the previous decade (Table 7). Also, some behavior-related questions were included (Table 7). In the previous decade, evolutionary issues had been integrated through systematics and comparative morphology, but in the 1930s, the examinees had to analyze the concepts of the evolutionary theory itself (Table 7). The genetics questions tested knowledge on Mendelism and sex determination (Table 7). In addition, the decade witnessed the rise of biochemical, cytological and microbiological questions (Table 7). Lastly, there was one question on human races at the beginning of the decade (Table 7).

Table 7. Microbiology, genetics, evolution, ecology and behavior in the 1930s.

Biochemistry, cell biology and microbiology	Genetics	Evolution	Ecology and behavior
Cell division Cytoplasm Cell nucleus Yeast Enzymes Vitamins Hormones Temperature-dependency of life	Mendelism Sex determination	Artificial selection Fossils Homology and analogy Human evolution Mutations Rudimentary organs Biogeography and evolution Acquired characteristics Human races	Symbiosis Distribution of species Camouflage and mimicry Plankton Boreal forests and rain forests Principles of the ecological community Eusociality of bees Migration of fish Animal herds

In the 1930s, there were still questions testing simply knowledge, but questions testing comprehension and analysis increased in number. For example, the examinees were expected to find answers to analytic questions such as "What is the biological basis of plant and animal breeding and what methods are used for this," "How does parasitism affect the structure of the animal," "Darwinism, natural selection and the modern perceptions of the importance of selection for the origin of species," "Compare homology and analogy," and "Explain Linné's and Darwin's perceptions on the origin of species." In addition, there was one question of an evaluative character: "Plants as the foundation of animal and human existence."

4.4 The 1940s – Mendelism, nutrition and developmental biology

In the 1940s, 83 biological questions were asked. During WWII, the MEB took advantage of any cease-fire and organized several extraordinary exam sessions near the frontline whenever possible. In this decade, crossings established themselves as standard questions in almost all exams, both plant and human physiology concentrated on nutrition, and the zoological questions had an emphasis on developmental biology (Figure 3).

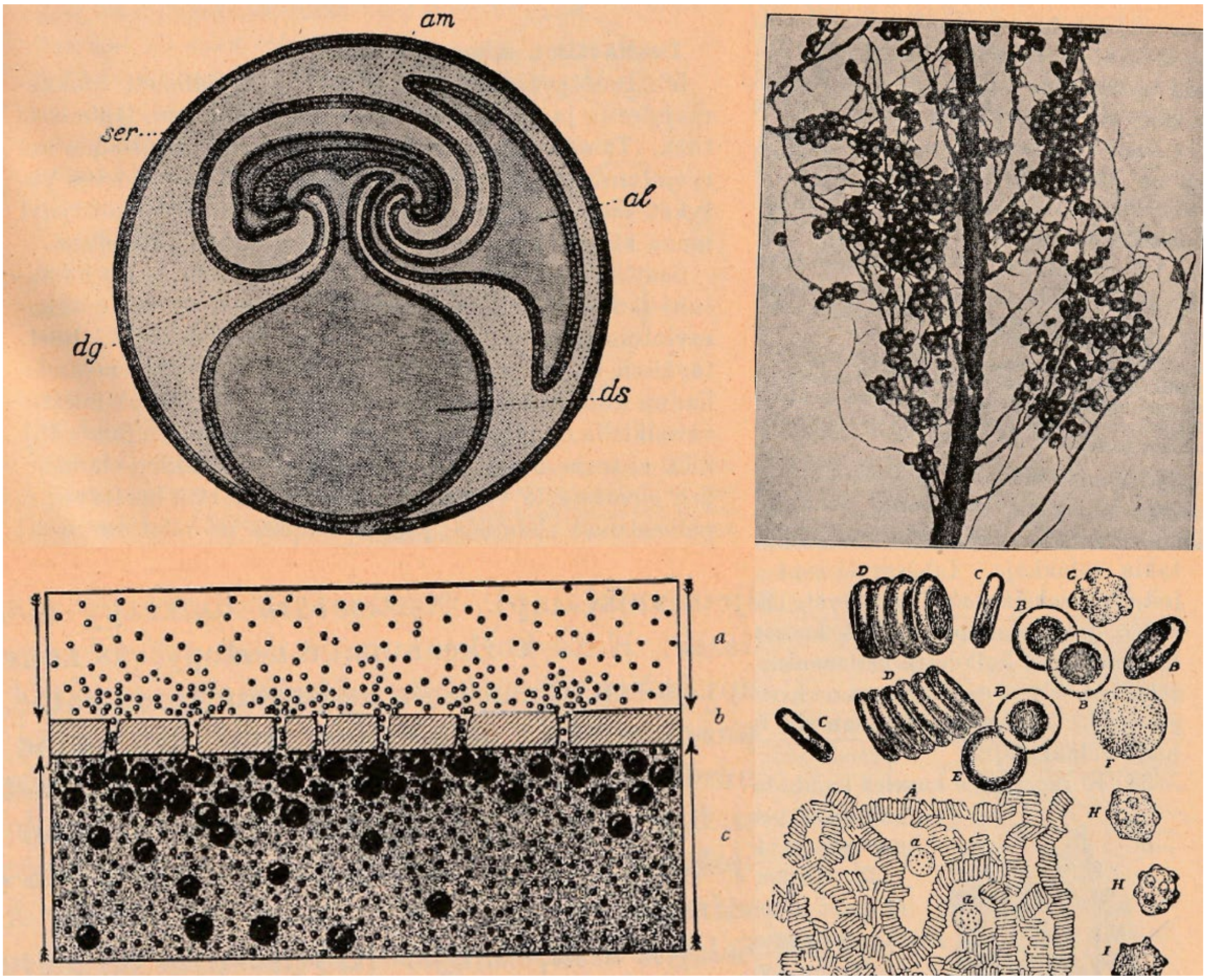


Figure 3. Visual overview of some of the question from the 1940s as illustrated in contemporary schoolbooks. (Top left) The structure of the mammalian embryo. (Top right) Nitrogen and the root nodules of legumes. (Bottom left) Osmosis and water transport in plants. (Bottom right) Blood cells. (G. Marklund & Jalas, 1943).

In contrast to the two precedent decades, there were no systematic questions in botany, and the focus was firmly on plant morphology, physiology and development (Table 8). The decade can be best characterized by the focus on water transport, nitrogen sources and the nutrition of plants, as this theme was inspected several times from both a pure physical-chemical perspective (the mechanism of osmosis) and an applied perspective (the use of fertilizers). Lastly, there were some questions of an ecological character (Table 8).

Table 8. Plant morphology, physiology, development and ecology in the 1940s.

Plant morphology	Plant physiology and development	Plant ecology
Plant tissues	Alternation of generations	Overwintering in plants
Plant connective tissue	Photosynthesis and respiration	Parasitic plants
Cellulose	Fermentation	
Stem morphology	Fertilization in seed plants	
	Asexual reproduction	
	Nutrition and water transport	

Interestingly, all purely zoological questions inspected developmental biology (Table 9). In contrast to previous decades, the physiological questions were all on humans, or mammals and vertebrates in general (Table 9). Several of the physiological questions focused on nutrition and food processing, specifically in the human digestive system.

Table 9. Animal development and human anatomy, histology and physiology in the 1940s.

Animal development	Human anatomy and histology	Human physiology
Nutrition of the embryo	Connective tissues	Digestion
Asexual reproduction	Heart	Hearing
Animal regeneration	Muscles	Connective tissues
Vertebrate morphogenesis	Cartilage and bone	Blood
Extraembryonic membranes	Pancreas	Thermoregulation
	Skin	Excretion

In this decade, the rise of genetics was even more prevalent, and the examinees were facing several questions on different aspects of genetics (Table 10). Also, evolutionary theory, cell biology and biochemistry were well represented (Table 10). Lastly, there were only a few questions on ecological themes (Table 10).

Table 10. Biochemistry, cell biology, microbiology, genetics, evolution and ecology in the 1940s.

Biochemistry, cell biology and microbiology	Genetics	Evolution	Ecology
Protein	Genotype and phenotype	Darwinism	Carbon cycle
Vitamins	Crossing experiments	Lamarckism	Animal migration
Carbohydrates	Gene concept	Natural selection	
Multicellularity	Mendelism	Variation	
	Sex determination	Extinct organisms	
	Mutations		

The general trend was still essays, but some of the crossing experiments were presented as solvable problems. There were few questions testing simply knowledge, but most required comprehension, application and analysis. For instance, the decade included several crossing experiments testing the application of Mendel's laws. The analytically most complex questions were likely “On extinct organisms that combine characters from different systematic groups and their relevance for our view on evolution,” “How is it determined whether the egg cell develops into a boy or girl and how can the equal number of boys and girls be explained?,” and “Compare respiration and fermentation in plants.” Finally, there were a couple of questions where the examinees were asked to evaluate ideas and concepts: “How does modern research view Darwinian selection as the force of evolution?” and “Overview of the cell concept throughout history.”

4.5 The 1950s – Cytogenetics, human physiology and ecology

In the 1950s, 79 biological questions were included in the FME. In this decade, the focus of genetics shifted increasingly from Mendelism to cytogenetics. In zoology, there were few questions on the physiology of animals since most were examining human physiology. Some renaissance of ecological and systematic questions could also be observed, having been more or less absent since the mid-1930s (Figure 4).

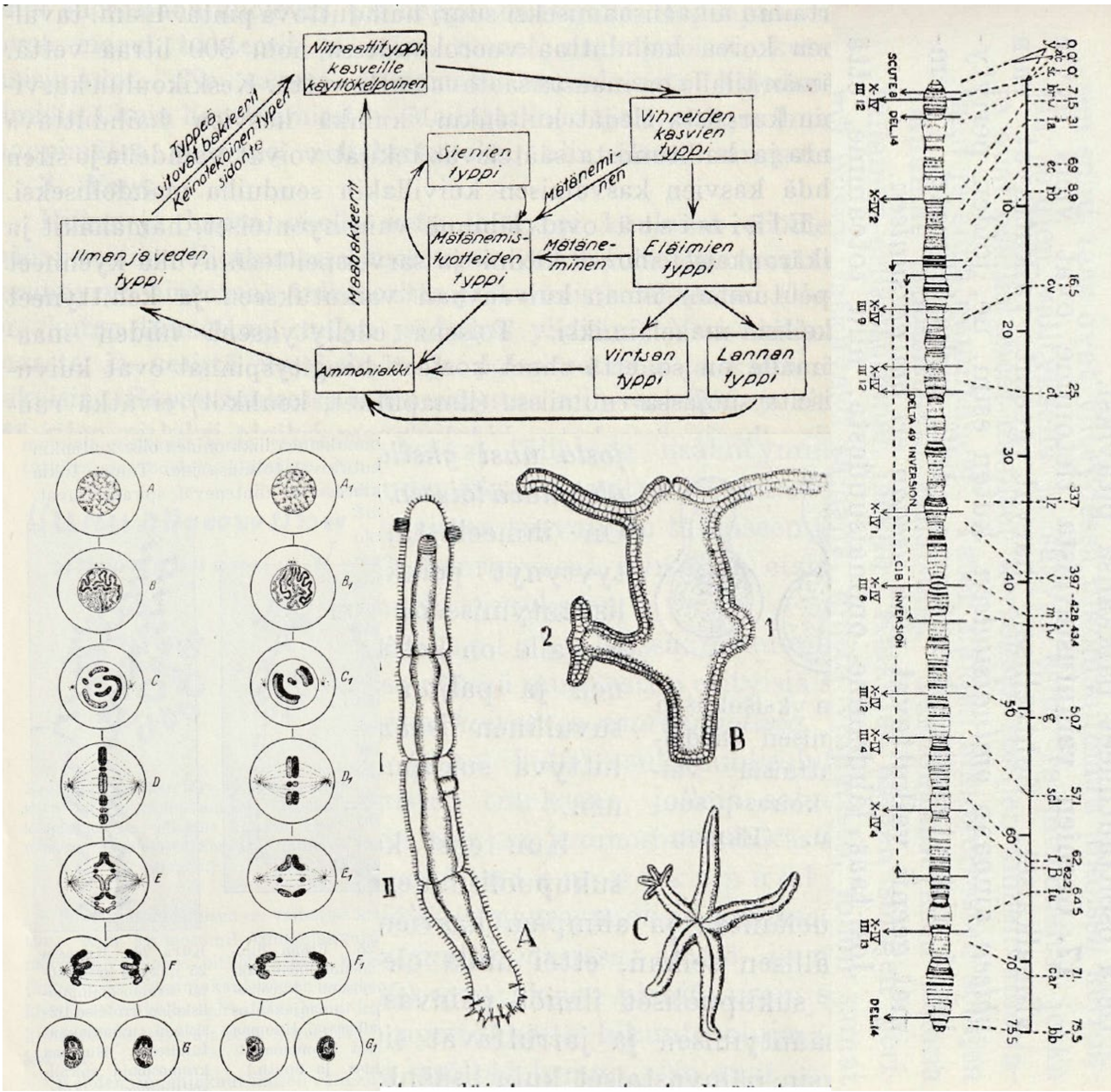


Figure 4. Visual overview of some of the questions from the 1950s as illustrated in contemporary schoolbooks. (Top left) The nitrogen cycle. (Right margin) Linkage and gene maps. (Bottom left) Chromosomes in mitosis and meiosis. (Bottom middle) Asexual reproduction and regeneration in animals. (Suomalainen & Segerstråle, 1953).

In botany, most questions were inspecting plant physiology, although a few ecological questions were also included (Table 11). A new theme was phototropism, which had not been encountered in previous decades (Table 11).

Table 11. Plant physiology, development and ecology in the 1950s

Plant physiology and development	Plant ecology
Asexual and sexual reproduction	Overwintering of plants
Chlorophyll and photosynthesis	Aquatic vegetation
Water transport	
Nitrogen and nutrition	
Respiration	
Phototropism	

During the 1950s, a few systematic questions were asked for the first time since the 1930s (Table 12). In addition, some assignments were on animal physiology and development, but otherwise, all the other assignments were on human physiology (Table 12).

Table 12. Animal systematics, development and physiology, and human anatomy and physiology in the 1950s

Animal systematics	Animal physiology and development	Human anatomy and physiology
Winter birds	Asexual reproduction	Blood
Butterflies	Parthenogenetic reproduction	Endocrinology
	Functional morphology of aquatic mammals	Digestion
		Nervous system
	Thermoregulation	Metabolisms of the fetus and mother
		Muscles

In this decade, the focus of genetics turned increasingly from Mendelism and crossings to cytogenetics (Table 13). Interestingly, the examinees were asked for the first time to evaluate the negative effects of inbreeding and consanguineous marriages (Table 13). As for evolutionary theory, central evolutionary concepts were tested as in previous decades (Table 13). In addition, the decade witnessed a renaissance of ecology, as community ecology, biogeography and ecosystems were examined from different perspectives (Table 13). In terms of biochemistry, cell biology and microbiology, an overarching theme of the decade was energy and the physical and chemical limitations of life on earth (Table 13).

Table 13. Biochemistry, cell biology, microbiology, genetics, evolution and ecology in the 1950s

Biochemistry, cell biology and microbiology	Genetics	Evolution	Ecology
Bacterial cells	Mendelism	Human evolution	Plant communities
Eukaryotic cells	Crossing experiments	Biogeography and evolution	Pest insects
Energy and metabolism	Chromosomes	Homology and analogy	Dispersal
Physical and chemical limitations of life	Mutations	Fossils	Peatlands
	Linkage and crossing-over	Selection	Submarine life
	Mutations	Speciation	Grasslands and savannah
	Gene maps		Nitrogen cycle
	Inbreeding		Producers and consumers
	Consanguineous marriage		

Educationally, the exam did not change from the 1940s, and most questions were essays, although some crossing problems were presented as well. As in the 1940s, only a few questions were testing solely knowledge, as most assignments involved comprehension, application and analysis. The cognitively most challenging questions involving analysis and evaluation were likely “What does genetics say about consanguineous marriages?,” “Compare natural and artificial classification systems,” “How does evolution result in speciation?,” “How do organisms differ from the non-living nature?” and “Biogeography as evidence for the evolutionary theory.” Furthermore, some questions included creative elements such as “Is human breeding possible in the view of genetics?”

4.6 The 1960s – Towards modern biology and establishment

In the 1960s, 92 biological questions were included in the FME. The decade is characterized by further modernization and the inclusion of novel genetic concepts, but otherwise, the biological and educational profile of the exam was similar to the trend established in the 1950s (Figure 5). Here, we define modern biology as the integrative discipline of biology encompassing all the fields from biochemistry to ecology that formed during the latter half of the 20th century.

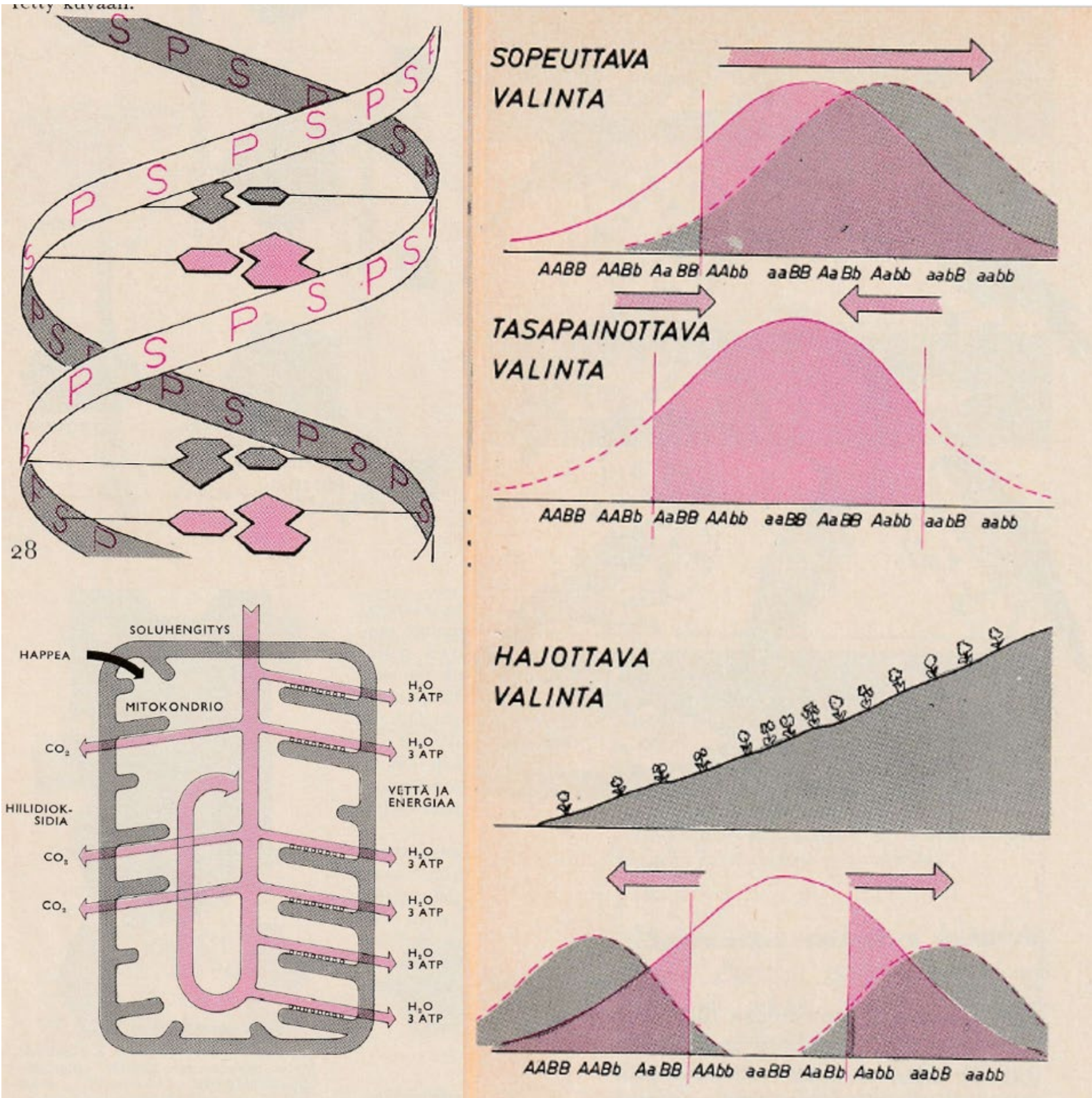


Figure 5. Visual overview of some of the questions of the 1960s. (Top left) The structure of chromosomes, including DNA. (Right margin) The mechanisms of selection. (Left bottom) Cellular metabolism. (Sorsa et al., 1966).

In the 1960s, the significance of botany and plants started to decline in the exam, but the exam nonetheless covered classical concepts of plant physiology (Table 14). Novel elements were plant hormones and the regulation of growth (Table 14). In addition, a few ecological questions were included (Table 14).

In the 1960s, there were only a couple of questions on classical zoology, and otherwise, the questions were testing human anatomy, histology and physiology (Table 15). In addition, there was the first purely clinical question when the examinees were asked to explain transplantations and tissue cultures (Table 15).

Table 14. Plant physiology, development and ecology in the 1960s

Plant physiology and development	**Plant ecology**
Water transport Nutrition and nitrogen Plant hormones Alternation of generations	Overwintering of plants Finnish trees

Table 15. Animal development and human anatomy, histology, physiology and medicine in the 1960s

Animal development	**Human anatomy and histology**	**Human physiology**	**Medicine**
Amphibian development Extraembryonic membranes of birds and mammals Animal regeneration	Germ layers Neural tissue Blood Tissue types Muscles	Digestion Hormones and development Regeneration Vitamins Mechanical senses Hearing	Transplantation and tissue culture

In genetics, there were assignments on classical crossings, cytogenetics and other novel genetic concepts such as polyploidy (Table 16). Interestingly, there were a few questions on eugenics for the first time since the 1930s (Table 16). As for evolution, the questions examined the foundations and evidence for the evolutionary theory as well as the evolutionary history of life on earth (Table 16). Interestingly, there were relatively many questions about the Carboniferous period. In terms of ecology, the test asked for knowledge on ecosystems as well as ecological concepts (Table 16). With respect to cell biology and microbiology, the test asked classical questions on cellular structure, while the biochemical assignments focused on metabolism (Table 16).

Table 16. Biochemistry, cell biology, microbiology, genetics, evolution and ecology in the 1960s.

Biochemistry, cell biology and microbiology	**Genetics**	**Evolution**	**Ecology**
Bacterial cells Eukaryotic cells Energy and metabolism	Mendelism Crossing experiments Sex determination Chromosome structure Meiosis Crossing over Gene maps Polyploidy Research methods in genetics Eugenics	Natural selection Lamarckism vs. Darwinism Rudimentary organs Fossils Evolutionary benefit of sexual reproduction Human evolution Evolution of photosynthesis Mesozoic Era	Boreal forests Peatlands Finnish lakes Carbon cycle Oxygen cycle Nitrogen cycle Plankton Producers and consumers

The educational profile of the exam was similar to the exam from the 1950s. Nonetheless, there were more tasks asking for the comprehension of experimental methods than in previous decades. Some of the more challenging questions were "How can you study the genotype of an individual if it expresses a dominant trait," "Changes in the genotype and its relevance for the evolution of organisms," and "Twins and their role in genetic research."

4.7 Quantitative trends in knowledge content

The kappa statistic of classifying the questions into categories of knowledge content was 0.89, which can be regarded as a strong agreement on the profile of the questions. The cross-tabulation of interrater classifications reveal that there was some disagreement between *Molecules to organisms* and the other categories (Supplementary Material, Figure 1).

As seen from the stacked area graph (Figure 6, Table 17), most questions in the 1920s were in the category *Molecules to organisms* and the second most in *Ecology*. In the 1930s, questions on *Genetics* increased at the expense of *Ecology*, and in the 1940s only a few questions on *Ecology* were asked. In the 1950s and 1960s, the profile stabilized and the percentage of questions in *Molecules to organisms* decreased. In 1944, 1945 and 1946 extraordinary exams were held, which slightly shifts the results in these years, and likely explains the lesser variation in categories during this period.

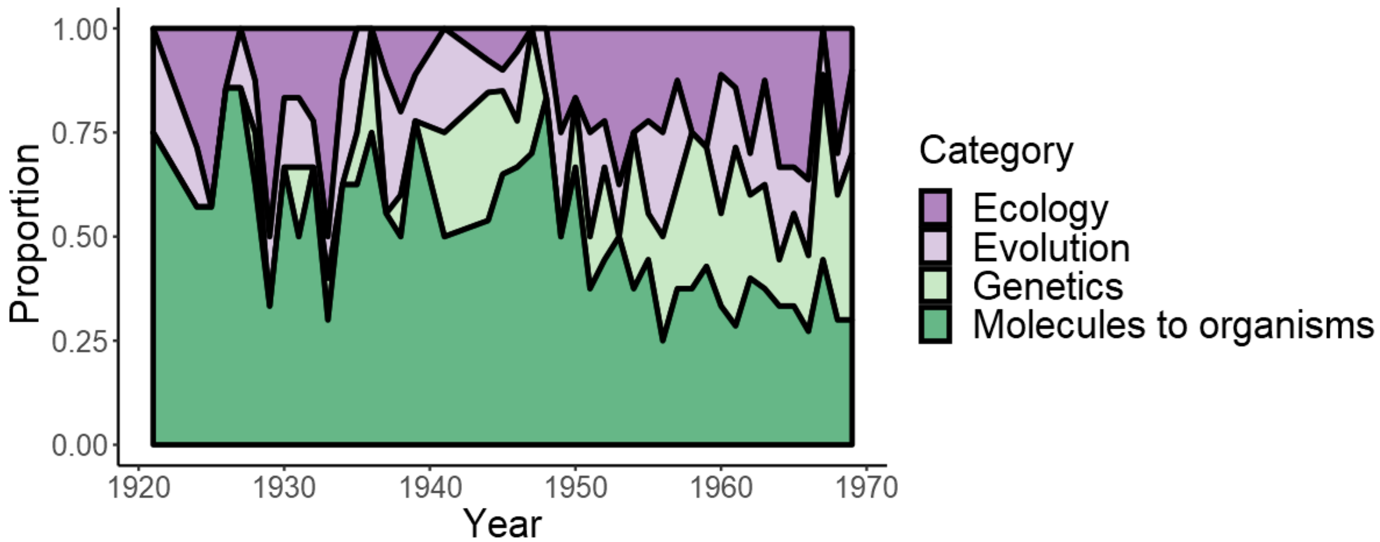


Figure 6. The yearly proportion of questions in different biological categories according to National Research Council (2012), namely Ecology, Evolution, Genetics, and From molecules to organisms. Only the years 1922, 1923, 1940, 1942 and 1943 are missing.

When inspecting frequencies of biological categories across decades, there was no significant change in the proportions between the 1920s and 1930s or between the 1930s and 1940s (Table 17), but as a whole, there was a significant change when moving from the 1920s to 1940s ($X^2 = 11.47$, p = 0.01**, Fisher p = 0.01**). Between the 1920s and 1940s, the increase in genetics and decrease in ecology explained this trend (Table 17). When moving from the 1940s to 1950s, there was a significant change in category proportions, while the 1950s and 1960s were similar in their knowledge content (Table 17). A decrease in *Molecules to organisms* and an increase in *Genetics and Ecology* stood for this result (Table 17).

Table 17. The percentages of different biological categories per decade. The last column shows the chi-square statistic, the p-value of the chi-square test and the p-value of Fisher's exact test. Fisher's exact test was used to compare frequencies between two successive decades, i.e. the interdecadal (ID) change. M & O stands for Molecules to organisms.

	n	Ecology	Evolution	Genetics	M & O	ID X^2 & ID Fisher
1920s	46	22 %	9 %	2 %	67 %	
1930s	83	17 %	17 %	7 %	59 %	3.5 (0.32) & 0.36
1940s	83	7 %	12 %	18 %	63 %	5.1 (0.05) & 0.05
1950s	78	23 %	13 %	22 %	42 %	11.04 (0.01)** & 0.01**
1960s	91	21 %	18 %	27 %	34 %	2.0 (0.57) & 0.58

4.8 Biological novelties

In total, 23 novel biological novelties were found in the exam questions, and the year of the academic establishment was delineated for the novelties (Table 18).

Table 18. Novel biological discoveries in the FME from 1921 to 1969.

Novelty	Type	Year of academic establishment	In FME
Mendelism	Theory	1910 (Gayon, 2016)	1928
Symbiosis	Concept	1880 (Sapp, 1994)	1930
Water transport in plants	Concept	1900 (Pittermann, 2010)	1931
Physiology of hearing	Concept	1930 (Olson et al., 2012)	1932
Eusociality in bees	Discovery	1925 (Couvillon, 2012)	1932
Yeast and fermentation	Discovery	1880 (Barnett, 2000)	1933
Plankton and ecology	Discovery	1910 (Barber & Hilting, 2002)	1933
The cell nucleus and genetics	Theory	1920 (Gayon, 2016)	1936
Genotype and phenotype	Concept	1910 (Gayon, 2016)	1936
Enzymes	Discovery	1930 (Poulsen & Buchholz, 2003a, 2003b)	1937
Hormones	Discovery	1930 (Tata, 2005)	1937
Vitamins	Discovery	1930 (Souganidis, 2012)	1937
Sex determination	Concept	1920 (Stévant et al., 2018)	1937

Mutation	Discovery	1930 (Gayon, 2016)	1938
Modern synthesis and selection	Theory	1940 (Gayon, 2016)	1945
Phototropism	Discovery	1930 (Holland et al., 2009)	1951
Origin of life	Theory	1950 (Fry, 2006)	1953
Neuron physiology	Concept	1952 (Hodgkin & Huxley, 1952)	1955
Mechanisms of speciation	Theory	1950 (Smocovitis, 1992)	1957
Ecosystem	Theory	1950 (Odum & Barrett, 1971)	1959
Gene maps	Concept	1940 (Koszul et al., 2012)	1959
DNA	Discovery	1955 (Gayon, 2016)	1961
Transplantation and tissue culture	Discovery	1955 (Barker & Markmann, 2013)	1966

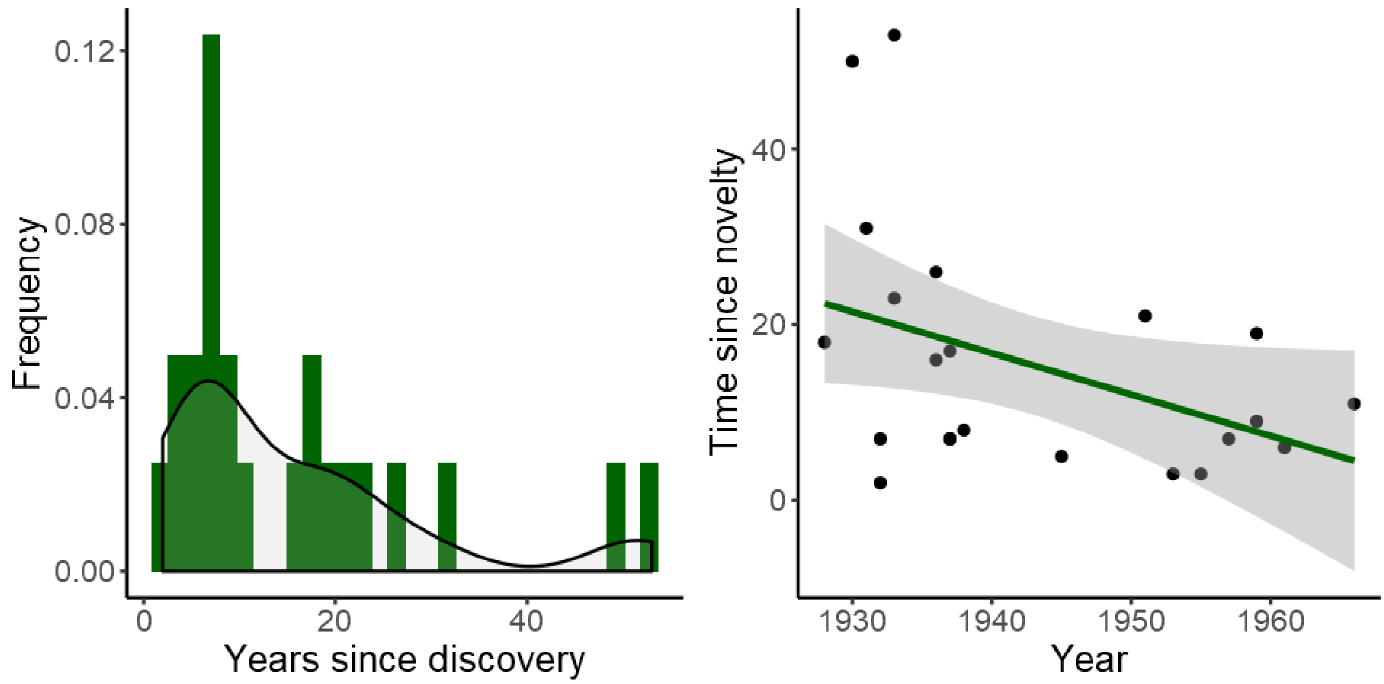


Figure 7. (Right) Histogram and density plot of the time of introduction, i.e. years since the novelty. (Left) Linear regression of the time of introduction as a function of the year when introduced.

The mean time of introduction to the exam was 15-5 years, while the median was 9. The bimodal nature of the density plot of the time of introduction is explained by the fact that approximations were usually made to the closest start of the decade (Figure 7). Otherwise, the density plot and the Poisson test clearly indicate that the rate of introduction is Poisson distributed ($p < 0.0001^{***}$) with the event rate 15.

A linear model could be fit to the yearly-dependence of the time of introduction (T) (Figure 7, Adj. R^2 =0.73, F-statistic = 62, $p < 0.001^{***}$). Moreover, the slope was negative (estimate -0.55, 95 % confidence interval (-0.70, -0.41), $p < 0.001^{***}$), indicating that the time of introduction decreased over the time period.

4.9 Quantitative trends in educational form

The kappa statistic of classifying the questions according to Bloom's taxonomy was 0.83, which can be regarded as a strong agreement on the educational form of the questions. Nonetheless, the cross-tabulation of interrater classifications reveal that there was some disagreement between knowing and comprehending as well as comprehending and applying (Supplementary Material, Figure 2).

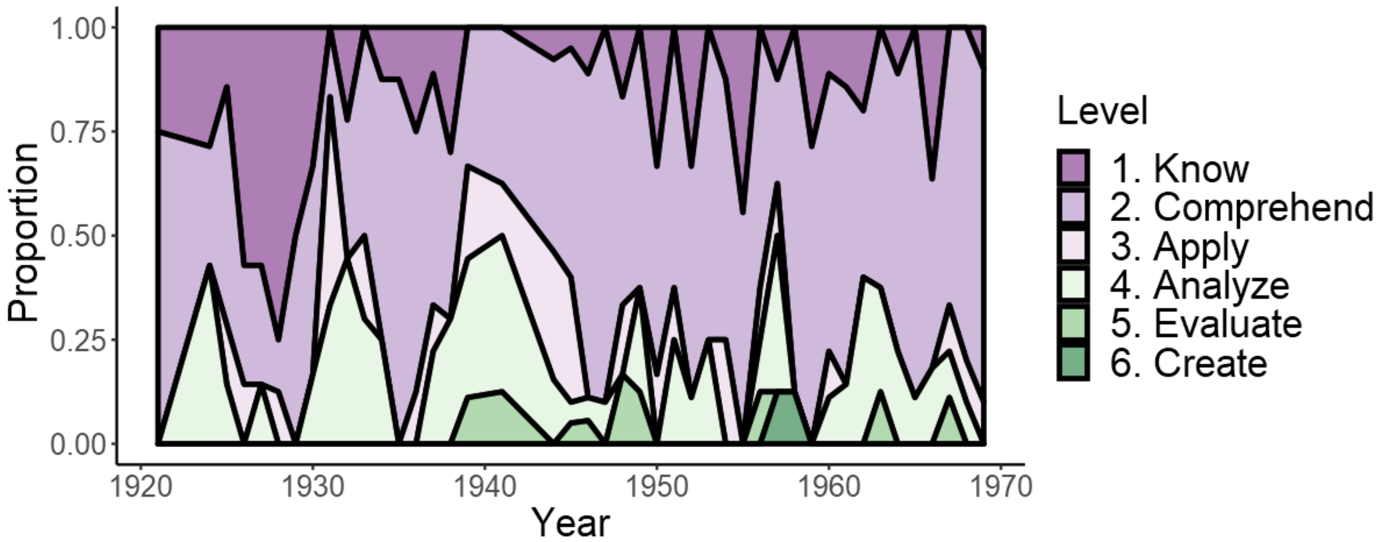


Figure 8. The yearly proportion of questions in different cognitive levels according to Krathwohl and Anderson (2009), namely Know, Comprehend, Apply, Analyze, Evaluate and Create. Only the years 1922, 1923, 1940, 1942 and 1943 are missing.

When counting frequencies for Bloom's taxonomy, most questions represented the *Concept* class, and therefore only the cognitive dimension was chosen for further analysis. As seen from the stacked area graph (Figure 8), the proportion of knowledge-testing questions was high in the 1920s but decreased already in the 1930s. In contrast, the number of comprehensive and analytic questions increased over time, and in the 1940s, the educational profile had settled (Figure 8). Interestingly, there was a peak in the cognitive demand of the questions between 1936 and 1944, when as much as 44% of the questions were ranked to be at level 3 or higher.

As seen from the frequency data, there was a significant change in the educational form between the 1920s and 1930s, and between the 1930s and 1940s, but not after the 1940s anymore (Table 19). The differences are attributable to the change in the number of questions requiring comprehension, application and analysis.

Table 19. The cognitive demand (by Bloom's taxonomy) of assignments in each decade.

	n	Know	Comprehend	Apply	Analyze	Evaluate	Create	ID Fisher
1920s	44	46 %	37 %	7 %	10 %	0 %	0 %	
1930s	83	15 %	49 %	11 %	24 %	1 %	0 %	<0.002**
1940s	83	6 %	61 %	15 %	12 %	6 %	0 %	0.03*
1950s	79	16 %	61 %	8 %	11 %	1 %	3 %	0.07
1960s	92	11 %	66 %	4 %	16 %	2 %	0 %	0.43

Interestingly, the percentage of assignments of different cognitive levels varied between biological categories (Figure 9, Table 20). *Evolution* had more analytic and evaluative questions than the other categories, while *Ecology* and *Genetics* had most applicative tasks. In *Molecules to organisms*, there were a few analytic and applicative tasks, but most were testing comprehension.

Table 20. The percentage of the cognitive demand (by Bloom's taxonomy) in each biological category.

	n	Know	Comprehend	Apply	Analyze	Evaluate	Create
Ecology	69	19 %	55 %	12 %	14 %	0 %	0 %
Evolution	54	15 %	37 %	2 %	35 %	11 %	0 %
Genetics	64	9 %	52 %	19 %	14 %	3 %	3 %
Molecules to organisms	196	17 %	65 %	7 %	10 %	1 %	0 %

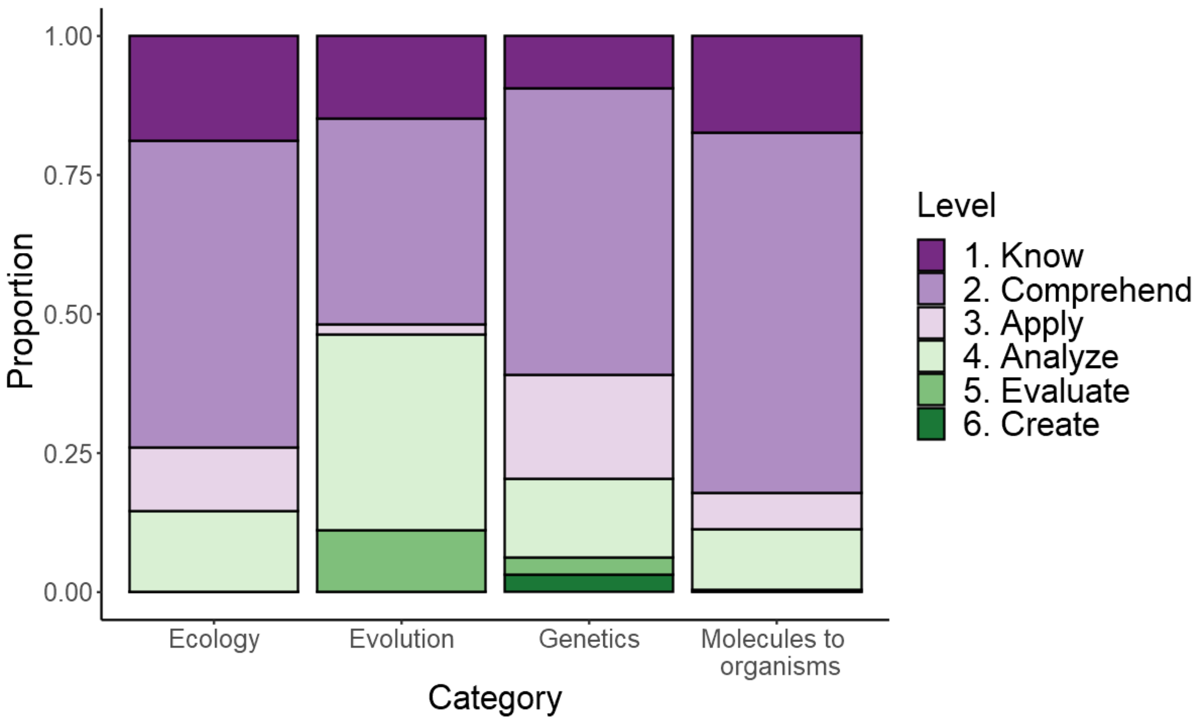


Figure 9. The percentage of the cognitive demand (by Bloom's taxonomy) in each biological category.

Lastly, pairwise comparisons of the frequencies of the four categories show that *Evolution* stands out from the other categories, and *Genetics* differs from *Molecules to organisms*, whereas the difference between *Genetics* and *Ecology* as well as *Ecology* and *Molecules to organisms* is non-significant (Table 21).

Table 21. The results of the chi-squared test of independence and pairwise comparisons.

	Ecology	Evolution	Genetics
Evolution	< 0.001***	-	-
Genetics	0.19	< 0.001***	-
Molecules to organisms	0.46	< 0.001***	0.001**

5. Discussion

5.1 Trends in knowledge content – the FME reflects Finnish academia

The MEB has always consisted of censors from Finnish academia (mostly from the University of Helsinki but later also from other universities), and hence it was assumed that the FME reflects both contemporary national and international academic trends (Kaarninen & Kaarninen, 2002). However, this connection has never been systematically demonstrated for biology. Here, we show that FME mirrors the Finnish history of biology both in Finnish academia and the upper secondary school system. The changes in question content further reflect the major advancements in biology as a field, and a great number of questions concerned novel topics discovered during the study period (Table 18). In addition, also political, social, and economic trends in Finnish history can be seen in the question content.

In the 1920s, the focus on comparative zoology in the FME nicely reflects the emphasis on this subject in Finnish zoology. In the beginning of the 20th century, Finnish zoology was greatly influenced by scholars in Germany, where evolutionary morphology had a strong foothold in the beginning of the century (Levit et al., 2014). However, it is not clear why so few systematic questions were asked in zoology, as zootaxonomy was firmly established in Finnish academia in the 19th century and well presented in contemporary school books (Kivirikko, 1923; Leikola, 2011). As the MEB does not produce protocols or other documents of the exam preparation, the work of the MEB must be interpreted from secondary sources (Kaarninen & Kaarninen, 2002). It seems that there was an agreement in the MEB that the botanical questions focused on systematical aspects, as botanical research in Finnish academia heavily concentrated on taxonomic research rather than plant physiology in the beginning of the 20th century (Morton et al., 1999). This is also reflected by the fact that the professorship of plant physiology at the University of Helsinki was instated no sooner than 1939, while several positions were already devoted to plant systematics (Autio, 2000). In contrast, the professorship of zoophysiology had been instated already in 1910 alongside positions in systematics and ecology (Autio, 2000). In the 1930s, the interest for plant physiology rose in Finnish academia thanks to the works of Fredrik Elfving, which apparently led to more assignments on plant physiology in the FME and likely left room for taxonomic questions in zoology (Autio, 2000; Morton et al., 1999). However, further investigation into the history of both university and secondary school teaching is required to assess whether this focus on plant systematics and comparative zoology was a general trend in Finnish universities and schools or only a peculiarity of the FME.

In the 1930s and 1940s, the increased focus on genetics and the evidence and foundations of the evolutionary theory reflected the ongoing academic debate and establishment of the Modern Synthesis both internationally and in Finland (Gayon, 2016). Interestingly, the only purely racist and eugenic questions were asked in 1929 and 1930, which we see to mirror both the academic and political history of Finland. As for academia, Mattila (1999) reports that eugenic thoughts were introduced and advocated in the 1910s mainly by three leading Swedish-speaking professors: Ossian Schauman, professor of internal medicine, Jarl Hagelstam lecturer in neurology, and Harry Federley, the first professor of genetics, all based at the University of Helsinki. He notes that their eugenic ideas were faced with suspicion by several contemporary physicians at first, although he remarks that the reason was mostly due to unfamiliarity with the new field of genetics.

Towards the 1920s, eugenics became more widely acknowledged in Finnish academia, and the Finnish eugenicists collaborated with colleagues at the State Institute for Racial Biology in Sweden and the Kaiser Wilhelm Institute of Anthropology, Human Heredity, and Eugenics in Germany (Hietala, 2009; Mattila, 1999). Schauman, Hagelstam and Federlay were all involved in leading the committee on sterilization legislation that prepared the Finnish sterilization law passed in 1934 (Hietala, 2009; Mattila, 1999). Furthermore, eugenics was presented as a part of human heredity in Finnish schoolbooks of biology from the 1920s well into the 1940s, as was the case in both Sweden and Germany (Mattila, 1999; Wendt, 2015).

Taken together, eugenic thoughts were not uncommon in Finnish academia or school material from the 1920s to the 1940s, and therefore the lack of eugenics in the

FME after 1930 is interesting. In the 1930s, Väinö Lassila, professor of anatomy, and Erkki Vala, chief editor of the periodical Tulenkantajat, criticized the sterilization law and warned how similar legislation was abused by the Nazi Party in Germany (Mattila, 1999). The right extremist Lapua Movement was quenched in 1932, and therefore we speculate that the Finnish political climate might have influenced the MEB's willingness to ask eugenic questions later in the 1930s. Nonetheless, how eugenics was manifested in Finnish secondary school teaching in the 1930s amidst both academic and political trends would need further clarification.

Interestingly, several of the physiological questions in the 1940s examined nutrition in both plants and humans, which may have to do with academic as well as political and economic factors. As for academic factors, the Finnish Nobelist A.I. Virtanen performed foundational research on nitrogen metabolism and biochemistry in the 1930s and initiated several projects on public nutrition and health together with his colleagues (Heikonen, 1990; Perko, 2014). However, this trend was not unique to Finland as public nutrition and health programs were started and also planned in other Western countries (Mayhew, 1988). As for political and economic factors, one may also speculate whether the scarcity of the wartime affected this trend.

Moreover, the wartime may have contributed to the decline in ecological questions, while biological questions with medical relevance such as genetics and physiology were emphasized. The interrelationship between physical sciences and wartime is widely recognized: science affects weapons and warfare, and warfare steers science in an applied direction to produce better weapons, the typical example being the Manhattan project (Roland, 1985). As for medicine, the relationship is more controversial, with some authors supporting the view that war may also direct and advance medical research (Cooter, 1990). Nonetheless, we find an interesting theme for further research to see whether warfare would affect biological research and teaching by emphasizing themes important for warfare, such as public nutrition and medical aspects.

The new focus on developmental biology may reflect the rise of experimental embryology epitomized by Spemann's induction experiments and followed by several embryologists in Finland (Leikola, 2003). Gunnar Ekman and Sulo Toivonen were both prominent experimental embryologists who were involved in writing school books in biology for upper secondary schools and actively popularized their field of study (Leikola, 2003). Again, further research on secondary school teaching would reveal to what extent developmental biology was also emphasized outside the FME.

In the 1950s, the establishment of the exam's biological content may reflect the higher availability of secondary education to different societal segments, leading to an increase in teachers and academics and less random selection of questions (Kaarninen & Kaarninen, 2002). This would correspond to the progress in the US, where the increasing number of students and a reaction against highly specialized courses in zoology and botany were the leading factors for establishing the modern curriculum in biology in the 1950s and 1960s (Rosenthal, 1990). Moreover, advancements in various fields of ecology of the time likely initiated the renaissance of ecology in the exam in the same way as in the US (McComas, 2002; Odum & Barrett, 1971). One can also speculate whether the increased number of examinees and teachers also forced the MEB to ask more questions in ecology and traditional natural history, as these were considered to be more familiar to both teachers and students (Kaarninen & Kaarninen, 2002). For example, Suomalainen and Segerstråle (1953) had redesigned their school book to start with ecology for this reason, suggesting that these ideas were common within the secondary school of the 1950s.

Interestingly, there was no significant change in the biological content of the exam in the 1960s in contrast to mathematics and the physical sciences (Kaarninen & Kaarninen, 2002). This may be attributable to the fact that the pressure of the technological advancement of the Soviet Union in the beginning of the decade was seen mainly in physical sciences, while no comparable pressure was evident for biology (Graham, 1993). Furthermore, the exam had already been reformed a lot in the previous decade, which was likely deemed to be sufficient.

During the study period, we see a drastic change of assessment content from classical natural history to a more varied selection of topics in evolution, genetics and ecology. This is most evident in botany, as questions relating to plant sciences and especially plant systematics diminished from a major component of the questions in the 1920s to marginal component in the 1950s and 1960s. This is mirrored in school curricula and activities, such as the gathering of student herbaria. Whereas in the 1920s each student was to collect around 200 species of plants to their personal herbarium, the number of species was lowered multiple times, and eventually in 1969, the collection of personal student herbaria was dropped from the Finnish school system (Saarinen et al., 2016; Virtanen & Kankaanrinta, 1989). A similar trend was seen in classical non-human zoology, which gets increasingly replaced by human physiology during our study period. This trend is still evident in modern biology curricula and FME. Some authors have raised concern on the poor species identification skills of contemporary students, which can in part result from this shift away from systematic botany and zoology (Immonen et al., 2006).

The time of introduction of biological novelties decreased during the study period. This illustrates the relationship between the FME and Finnish academia, and the fact that exam developers were not afraid of introducing novelties in exams soon after their academic establishment. The pattern is evident even considering that the estimation of the year of academic establishment of biological novelties is difficult and at times arguably subjective (Supplementary Material). The decrease in the lag of time between academic establishment and inclusion in the FME can in part be explained by improved technology in information distribution and eventual electronic information distribution.

5.2 Trends in educational form – high standard from the beginning

This study contradicts the statement by Kaarninen and Kaarninen (2002) and Virta (2014) that the test battery in humanities and sciences would have tested only knowledge of factual details. Apparently, this may apply to other subjects, but not biology. In contrast, the exam in the 1930s was already rich in comprehensive and analytic components, and the educational standard was established in the 1940s, after which no significant improvements were made. Rostila (2014) and Lindholm (2017) report that about 20% of the questions in the modern FME in biology (2009-2015) were on level 3 or higher in Bloom's taxonomy, indicating that the exam from the 1930s to 1960s was mostly as cognitively demanding as the modern exam. The problem with analyzing historical exam questions is that although the question itself is cognitively demanding, it remains unclear how much cognitive input was required for a given grade in the end. Nonetheless, the inclusion of several applicative, analytic and evaluative questions in the FME proves that the MEB has been subconsciously aware of good forms of assessment before the conceptualization of Bloom's taxonomy.

The most cognitively demanding period of the exam was around 1940, which coincides with the ongoing academic debate on the Modern Synthesis. The most cognitively demanding questions were asked on evolution and genetics, which also reflects the potential influence of the Modern Synthesis on the exam. Furthermore, Lindholm (2017) did not find the cognitive demand of evolution and genetics higher than that of the other categories in contemporary exams, suggesting further that this pattern is specific to the given historical context. The science and concepts of ecology was still in its infancy before the 1950s, and before that ecology was more or less descriptive natural history, upon which it was hard to construct good analytic questions. The lack of applicative and analytic questions in the category Molecules to organisms may be explained by the lack of experimental instrumentation in schools, and probably because of the perceived technicality of the subject (Suomalainen & Segerstråle, 1953).

6. Conclusions

In conclusion, here we summarize for the first time the Finnish matriculation examination from a historical perspective. The FME in biology from 1921 to 1969 followed well both international and national academic trends and transferred them to the exam within 10-20 years. The data shows that the inclusion of biological questions to the exam follows a similar pattern: initial caution, excitement, and stabilization. Contrary to popular stereotypes, the old FME in biology had a high standard of assessment already from the 1930s onwards, comparable to the level of the modern exam. This shows that educators have been aware of good forms of assessment before its theoretical conceptualization. In addition, the cognitively most demanding questions were on evolution, proving that academic excitement in a given discipline may give rise to tasks of a high educational standard. The old FME questions may be used as an inspiration for devising good essay questions even for future generations of students.

References

Ahvenisto, I., Van den Berg, M., Löfström, J., & Virta, A. (2013). Kuka oikeastaan asettaa opetuksen tavoitteet? Yhteiskuntaopin taidolliset tavoitteet ja niiden arviointi opetussuunnitelmien perusteissa ja ylioppilastutkinnossa. *Kasvatus & Aika, 7*(3), 40—55.

Autio, V.-M. (2000). Helsingin yliopiston opettaja- ja virkamiesluettelo 1918—2000. University of Helsinki.

Barber, R. T., & Hilting, A. K. (2002). History of the study of plankton productivity. In P. J. Willaims, D. N. Thimas, & C. S. Reynolds (Eds.), *Phytoplankton Productivity: Carbon assimilation in marine and freshwater ecosystems* (pp. 16—43): Blackwell Science Ltd. doi: https://doi.org/10.1002/9780470995204.ch2

Barker, C. F., & Markmann, J. F. (2013). Historical overview of transplantation. *Cold Spring Harbor perspectives in medicine, 3*(4), a014977. doi:https://doi.org/10.1101/cshperspect.a014977.

Barnett, J. A. (2000). A history of research on yeasts 2: Louis Pasteur and his contemporaries, 1850–1880. *Yeast, 16*(8), 755—771. doi:https://doi.org/10.1002/1097-0061(20000615)16:8

Bloom, B. S. (1956). Taxonomy of educational objectives. Vol. 1: Cognitive domain. *New York: McKay*, 20-24.

Caroli, D. (2019). 'And all our classes turned into a flower garden again'–science education in Soviet schools in the 1920s and 1930s: the case of biology from Darwinism to Lysenkoism. *History of education, 48*(1), 77—98. doi:https://doi.org/10.1080/0046760X.2018.1529252
Cohen, L., Manion, L., & Morrison, K. (2013). *Research methods in education*: Routledge.
Cooter, R. (1990). Medicine and the Goodness of War. *Canadian Bulletin of medical history, 7*(2), 147—159.
Couvillon, M. (2012). The dance legacy of Karl von Frisch. *Insectes sociaux, 59*(3), 297—306. doi:http://dx.doi.org/10.1007/s00040-012-0224-z
Eymard-Simonian, C. (2000). La problématisation méthodologique dans la formation à la recherche en éducation. *Cahiers de la recherche en éducation, 7*(2), 293—312. doi:https://doi.org/10.7202/1016939ar
Faire, L. (2016). *Research methods for history*: Edinburgh University Press.
Fry, I. (2006). The origins of research into the origins of life. *Endeavour, 30*(1), 24—28. doi:https://doi.org/10.1016/j.endeavour.2005.12.002
Gall, M. D., Borg, W. R., & Gall, J. P. (1996). *Educational research: An introduction*: Longman Publishing.
Gayon, J. (2016). From Mendel to epigenetics: History of genetics. *Comptes rendus biologies, 339*(7—8), 225—230. doi:https://doi.org/10.1016/j.crvi.2016.05.009
Goldenfeld, N., & Woese, C. (2007). Biology's next revolution. *Nature, 445*(7126), 369. doi:https://doi.org/10.1038/445369a
Graham, L. R. (1993). *Science in Russia and the Soviet Union: A short history*: Cambridge University Press.
Hallgren, K. A. (2012). Computing inter-rater reliability for observational data: an overview and tutorial. *Tutorials in quantitative methods for psychology, 8*(1), 23.
Happonen, P., Holopainen, M., Sotkas, P., Tihtarinen-Ulmanen, M., & Venäläinen, J. (2016). *Bios 5: Biologian sovellukset (LOPS 2016)*: Sanoma Pro.
Heikonen, M. (1990). *AIV: keksintöjen aika*: Kirjayhtymä.
Hietala, M. (2009). Eugeniikan ja rotuhygienian tausta ja seuraukset. *Tieteessä tapahtuu, 27*(8), 14—19.
Hodgkin, A. L., & Huxley, A. F. (1952). A quantitative description of membrane current and its application to conduction and excitation in nerve. *The Journal of physiology, 117*(4), 500—544.
Holland, J. J., Roberts, D., & Liscum, E. (2009). Understanding phototropism: from Darwin to today. *Journal of experimental botany, 60*(7), 1969—1978. doi:https://doi.org/10.1093/jxb/erp113
Immonen, S., Mehtälä, E., Paasivaara, S., & Suontausta, T. (2006). Valtakunnallinen lähtötasokoe kertoi 7-luokkalaisten biologian osaamisesta. *Natura, 4*, 7—12.
Jenkins, E. W. (1979). The development of school biology 1918—1945. *History of education, 8*(1), 59—73.
Kaarninen, M., & Kaarninen, P. (2002). *Sivistyksen portti: Ylioppilastutkinnon historia*: Otava.
Kinchin, I. M. (2010). Solving Cordelia's dilemma: Threshold concepts within a punctuated model of learning. *Journal of Biological Education, 44*(2), 53—57.
Kivirikko, K. E. (1923). *Biologia oppikoulujamme ylempiä luokkiq sekä itseopiskelua varten* (2nd ed.): Werner Söderström Osakeyhtiö.
Koszul, R., Meselson, M., Van Doninck, K., Vandenhaute, J., & Zickler, D. (2012). The centenary of Janssens's chiasmatype theory. *Genetics, 191*(2), 309—317. doi:https://doi.org/10.1534/genetics.112.139733
Krathwohl, D. R., & Anderson, L. W. (2009). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*: Longman.
Kurzweil, R. (2014). The singularity is near. In *Ethics and emerging technologies* (pp. 393—406): Springer.

Leikola, A. (2003). The Finnish tradition of developmental biology. *International Journal of Developmental Biology, 33*(1), 15—20.
Leikola, A. (2011). *History of Zoology in Finland, 1828—1918*: Societas Scientiarum Fennica.
Levit, G. S., Hossfeld, U., & Olsson, L. (2014). The Darwinian revolution in Germany: from evolutionary morphology to the modern synthesis. *Endeavour, 38*(3—4), 268—278. doi:https://doi.org/10.1016/j.endeavour.2014.10.010
Lindholm, S. (2017). *Biologian ylioppilaskokeiden haasteet: Koetehtävien sisällöt ja vaikeustasot sekä niiden vaikutus todelliseen osaamiseen*. University of Helsinki, Helsinki.
Marklund, G., & Jalas, A. (1933). *Biologia oppikoulujen lukioluokkia varten* (1st ed.): Werner Söderström Osakeyhtiö.
Marklund, G., & Jalas, A. (1943). *Biologia oppikoulujen lukioluokkia varten* (5th ed.): Werner Söderström Osakeyhtiö.
Mattila, M. (1999). *Kansamme parhaaksi*: Suomen historiallinen seura Helsinki.
Mayhew, M. (1988). The 1930s nutrition controversy. *Journal of Contemporary History, 23*(3), 445—464.
Mayr, E. (1982). *The growth of biological thought: Diversity, evolution, and inheritance*: Harvard University Press.
Mayr, E. (1997). *This is biology: The science of the living world*: Universities Press.
McComas, W. F. (2002). The ideal environmental science curriculum: I. history, rationales, misconceptions & standards. *The American Biology Teacher, 64*(9), 665—673.
McHugh, M. L. (2012). Interrater reliability: the kappa statistic. *Biochemia medica, 22*(3), 276—282. doi:https://doi.org/10.11613/bm.2012.031
McTighe, J., & Ferrara, S. (1998). *Assessing Learning in the Classroom. Student Assessment Series*: ERIC.
Morton, A., Kukkonen, I., & Enroth, J. (1999). *Kasvitieteen historia: Kuvaus kasvitieteen vaiheista muinaisajoista nykypäivään*: Gaudeamus.
National Research Council. (2009). *A new biology for the 21st century*: National Academies Press.
National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*: National Academies Press.
Neuendorf, K. A. (2016). *The content analysis guidebook*: Sage.
Odum, E. P., & Barrett, G. W. (1971). *Fundamentals of ecology* (Vol. 3): Saunders Philadelphia.
Olson, E. S., Duifhuis, H., & Steele, C. R. (2012). Von Békésy and cochlear mechanics. *Hearing research, 293*(1—2), 31—43. doi:https://doi.org/10.1016/j.heares.2012.04.017
Perko, T. (2014). *Mies, liekki ja unelma: Nobelisti AI Virtasen elämäntyö*: Otava.
Pittermann, J. (2010). The evolution of water transport in plants: an integrated approach. *Geobiology, 8*(2), 112—139. doi:https://doi.org/10.1111/j.1472-4669.2010.00232.x
Poulsen, P. B., & Buchholz, H. K. (2003a). History of enzymology with emphasis on food production. In J. R. Whitaker, A. G. J. Voragen, & D. W. S. Wong (Eds.), *Handbook of food enzymology* (pp. 11—20): CRC Press.
Poulsen, P. B., & Buchholz, H. K. (2003b). History of enzymology with emphasis on food production. *Handbook of food enzymology*, 11—20.
R Core Team. (2019). R: A language and environment for statistical computing. In. Vienna, Austria: R Foundation for Statistical Computing.
Roland, A. (1985). Science and war. *Osiris, 1*, 247—272.
Rosenthal, D. B. (1990). What's past is prologue: Lessons from the history of biology Education. *The American Biology Teacher, 52*(3), 151—155. doi:https://doi.org/10.2307/4449067
Ross, S. M. (2017). *Introductory statistics*: Academic Press.
Rostila, A. (2014). *Biologian ainereaalin tehtävätyypit, teemat ja tiedolliset haasteet vuosina 2006–2009*. University of Helsinki, Helsinki.
Saarinen, K., Jantunen, J., & Pulli, A. (2016). Vanhojen koululaisherbaarioiden kertomaa – The flora of Eastern Finland as reflected in old school herbaria between 1925 and 1969. *Lutukka, 32*(2), 52—61.

Sáez-Rosenkranz, I. (2016). Historical method applied to educational research. *Revista d'Innovació i Recerca en Educació, 9*(2), 106. doi:https://doi.org/10.1344/reire2016.9.2928
Sapp, J. (1994). *Evolution by association: a history of symbiosis*: Oxford University Press.
Smocovitis, V. B. (1992). Unifying biology: The evolutionary synthesis and evolutionary biology. *Journal of the History of Biology, 25*(1), 1—65.
Sorsa, V., Leikola, A., Mattila, R., & Sorsa, M. (1966). *Lukion biologia* (1st ed.): Werner Söderström Osakeyhtiö.
Souganidis, E. (2012). Nobel laureates in the history of the vitamins. *Annals of Nutrition and Metabolism, 61*(3), 265—269. doi:https://doi.org/10.1159/000343122
Stévant, I., Papaioannou, M. D., & Nef, S. (2018). A brief history of sex determination. *Molecular and cellular endocrinology, 468*, 3-10. doi:https://doir.org/10.1016/j.mce.2018.04.004
Suomalainen, P., & Segerstråle, S. (1953). *Yleisbiologia oppikouluja varten* (2nd ed.): Kustannysosakeyhtiö Otava.
Tata, J. R. (2005). One hundred years of hormones. *EMBO reports, 6*(6), 490—496. doi:https://doi.org/10.1038/sj.embor.7400444
Tikkanen, G. (2010). *Kemian ylioppilaskokeen tehtävät summatiivisen arvioinnin välineenä*. University of Helsinki, Helsinki.
Tuulosniemi, S. (2019). *Elämää kynän ja paperin jälkeen: Ylioppilaskokelaan tekniset valmiudet tuottaa kuvia biologian ensimmäisessä digitaalisessa ylioppilaskokeessa keväällä 2018*. Lahti University of Applied Sciences, Lahti.
Vaskuri, J. (2017). *Oppiennätyksistä opetussuunnitelman perusteisiin: lukion kemian kansallisen opetussuunnitelman kehittyminen Suomessa vuosina 1918-2016*. University of Jyväskylä, Jyväskylä.
Wendt, S. (2015). *Rasbiologisk upplysning: En analys av svenska läroböcker 1930—1950*. Umeå University, Umeå.
Vilhunen, A.-S., & Hopia, A. (2012). *Kehittämistutkimus: Tutkimuksellinen proteiinien opiskelu molekyyligastronomian kontekstissa*. University of Helsinki, Helsinki.
Virta, A. (2014). Historia ja yhteiskuntaoppi reaalikokeessa 1921—1969 – koetehtävien kehitys oppiennätysten ja opetusta koskevan keskustelun näkökulmasta. *Ennen ja Nyt : Historian Tietosanomat, 1*(4).
Virtanen, L., & Kankaanrinta, I. (1989). *Biologia koulussa*. Yliopistopaino.
Vitikainen, R. (2014). *Muistitietoa vai menetelmien soveltamista? Kognitiiviset tiedot ja taidot maailmanuskontojen ylioppilaskoekysymyksissä vuosina 1996–2013*. University of Helsinki, Helsinki.
Vuorio-Lehti, M. (2007). Valkolakin hohde–Keskustelua ylioppilastutkinnon merkityksestä Suomessa toisen maailmansodan jälkeen. *Kasvatus & Aika, 1*(1), 19–33.

Learning Study och kollegial CoRe stimulerar lärares professionella utveckling inom naturvetenskaplig undervisning

Niclas Åhman[1], Gunilla Gunnarsson[2] och Inger Edfors[3]

[1] Institutionen för fysik och elektroteknik, Linnéuniversitetet, Kalmar, Sverige
[2] Institutionen för didaktik och lärares praktik, Linnéuniversitetet, Kalmar, Sverige
[3] Institutionen för kemi och biomedicin, Linnéuniversitetet, Kalmar, Sverige

Syftet med studien är att klargöra hur lärares professionella utveckling stimuleras då de planerar och genomför en Learning Study (LS) kombinerad med verktyget Content Representation (CoRe). Data består av sex erfarna lärares inspelade diskussioner under åtta träffar då de planerar och analyserar en LS bestående av två lektioner i årkurs 6 inom kemi, samt tre CoRe som lärarna skriver. I början av studien talar lärarna mest om undervisning som att fakta ska förmedlas till eleverna. När de sedan planerar första lektionen övergår deras diskussioner till hur de kan stimulera eleverna till diskussion och reflektion. Lärarna planerar både lektion 1 och 2 utifrån ett variationsteoretiskt perspektiv, men lektion 1 genomförs inte i enlighet med vad de planerat. Det är först i lektion 2 som läraren behåller fokus på lärandeobjektet och dess kritiska aspekter. Resultatet av studien visar även att en Learning Study kombinerad med CoRe stimulerar lärares professionella utveckling och ämnesdidaktiska kompetens i form av lärande nätverk enligt Clarkes och Hollingsworths (2002) modell ”interconnected model of professional growth.”

Artikel

LUMAT General Issue
Vol 8 No 1 (2020), 200–228

Mottagen 25 januari 2020
Accepterad 16 augusti 2020
Publicerad 20 augusti 2020

Sidor: 29
Referenser: 31

Kontakt:
niclas.ahman@lnu.se

https://doi.org/10.31129/LUMAT.8.1.1393

Nyckelord: Learning study, lärares professionella utveckling, CoRe, undervisning inom naturvetenskap

Abstract

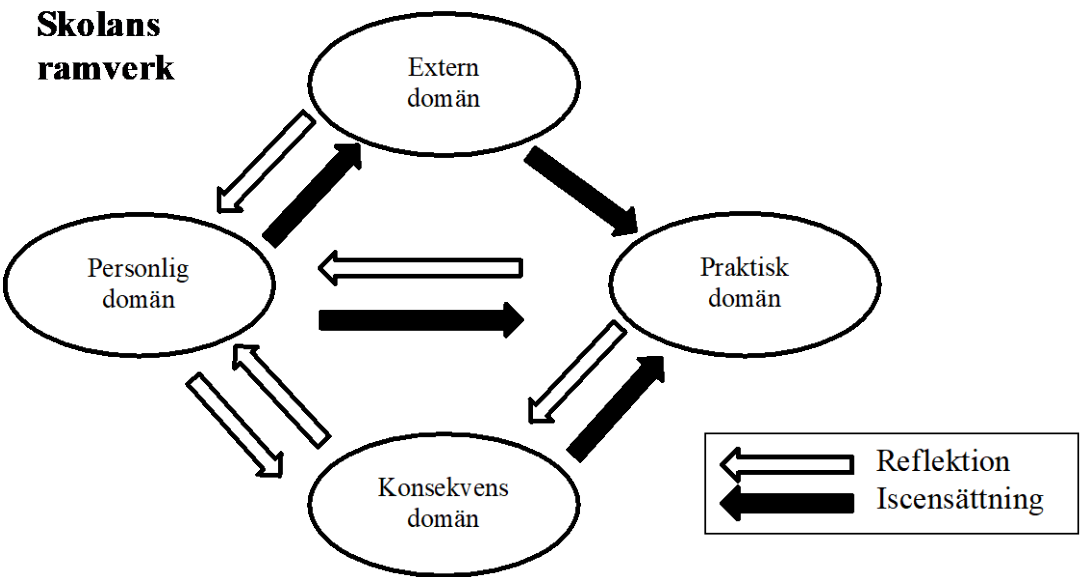
The aim of this study is to explore science teachers' professional development when they perform a Learning Study (LS), using the tool Content Representations (CoRe). The empirical data consists of six experienced teachers' audio recorded discussions during eight meetings when they plan and analyse two lectures in chemistry for year 6 (age 12–13 years), and three written CoRe. In the beginning of the study, the teachers talk about teaching and learning mainly as transformation of facts. However, when they plan the first lecture, they discuss how to stimulate students' discussions and reflections. The teachers planned both lectures according to variation theory. However, only the second lecture is also implemented according to their plan, with a focus on the object of learning. The results show that the combination of CoRe and LS stimulate also experienced teachers' professional development, through growth networks according to the model "interconnected model of professional growth" (Clarke and Hollingsworth, 2002).

Keywords: Learning study, professional development, CoRe, science teaching

 | CC BY 4.0

1 Inledning

Läraren har en central betydelse för elevers lärande, men för att kunna erbjuda en stimulerande lärmiljö behöver lärarens kunskap och kompetens utvecklas kontinuerligt. Lärares professionella utveckling, är precis som elevers lärande, en komplex process där reflektion är central (Schön, 2003). För att de insatser som görs ska få avsedd effekt behöver lärare ha möjlighet att styra innehåll och genomförande av utvecklingsinsatserna så att dessa utgår från deras dagliga yrkesverksamhet (Clarke & Hollingsworth, 2002; Putnam & Borko, 2000; Riveros, Newton, & Burgess, 2012). En modell för att analysera lärares professionella utveckling utifrån växelverkan mellan insats och diskussion om undervisning i den dagliga yrkesverksamheten är Clarke och Hollingsworths (2002) modell "the interconnected model of professional growth" (ICMPG). Lärares professionella utveckling är enligt denna modell individuell och icke-linjär, och sker genom reflektion och iscensättning mellan fyra domäner (se Figur 1). Dessa är: den externa domänen (resurser som föreläsning och diskussion med kollegor), den personliga (lärarens kunskaper och syn på undervisning), den praktiska (lärarens genomförande av undervisning), och konsekvensdomänen (effekter av lärarens agerande). Den professionella utvecklingen påverkas även av skolans ramverk (the change environment) bland annat i form av tid och stöd från skolledning, vilket även betonas i andra studier (Stolk, Bulte, de Jong, & Pilot, 2009a, 2009b).



Figur 1. Interconnected model of professional growth, efter Clarke and Hollingsworth (2002, s. 951).

När det gäller lärares professionella utveckling beskriver Clarke and Hollingsworth (2002) två former, förändringssekvenser (change sequenses) och lärande nätverk (growth networks). En förändringssekvens är tillfällig och leder inte till bestående förändring, till exempel när en lärare vid en studiedag introduceras till en ny undervisningsmetod (extern domän), som prövas (praktisk domän), men sedan överges. Vad som enligt Clarke and Hollingsworth (2002) kännetecknar lärande nätverk är en kedja av reflektion och iscensättning som leder till en mer bestående förändring i lärarens praktik. Läraren överger inte den nya undervisningsmetoden utan reflekterar över dess konsekvenser, exempelvis elevers förståelse (konsekvensdomän), förfinar/utvecklar/anpassar metoden (praktisk domän) samtidigt som lärarens kunskap och inställning ändras (personlig domän).

I vår studie analyseras, med hjälp av ICMPG, vad som sker med lärares professionella kompetens när de genomför en Learning Study (LS) med hjälp av verktyget Content Representations, CoRe. CoRe utvecklades som analysverktyg (Loughran, Berry, & Mulhall, 2012; Loughran, Mulhall, & Berry, 2004) för att beskriva och bedöma lärares ämnesdidaktiska kompetens, av Shulman (1986; 1987) benämnd pedagogical content knowledge, PCK, men kan också användas som stöd för lärares reflektion och utveckling av undervisningen (Hume & Berry, 2011; Loughran et al., 2012; Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000; Nilsson & Loughran, 2012; Skolverket, 2012). Genom att besvara frågorna i CoRe (Bilaga 1) beskriver läraren vad som ska tas upp inom ett specifikt undervisningsområde (”Big Ideas”), samt varför och hur. CoRe ger därmed lärarna stöd vid lektionsplaneringen i en LS att identifiera vilket innehåll som ska tas upp, av Fredlund, Airey, and Linder (2015) benämnt ämnesmässigt relevanta aspekter, samt att diskutera och reflektera över lärandeobjektets kritiska aspekter.

En LS följer en bestämd struktur, där en grupp lärare planerar, genomför och analyserar en eller flera lektioner (Lo, 2012; Pang & Ling, 2012). Den teoretiska utgångspunkten för en LS är variationsteorin (Marton, 2000; Marton & Tsui, 2004), vilken utgår från att variation är en förutsättning för att kunna identifiera kritiska aspekter hos lärandeobjektet. Det innebär att för att veta vad något är måste man veta vad detta inte är, det vill säga att kunna urskilja lärandeobjektet från dess omgivning (Lo, 2014; Marton, 2000). Genom att läraren kontrasterar och ändrar vad som varieras, respektive hålls konstant i lärandeobjektets kritiska aspekter, så stödjer läraren eleven att urskilja aspekter hos lärandeobjektet som möjliggör avsett lärande. För att eleven till exempel ska kunna urskilja att massan inte förändras vid fasövergången från is till flytande vatten, hålls mängden vatten konstant medan aggregationstillstånden varieras från fast till flytande. I arbetet med LS stimuleras lärarna till att diskutera och reflektera över sin undervisning, om vad eleverna lär sig och hur de kan stödja elevernas lärande. De kan då också dela med sig av sina tidigare erfarenheter från undervisning. Genom att genomföra en LS kan undervisningen inom ett område få stöd att förändras så att det lärandeobjekt eleverna erfar överensstämmer med det som lärarna planerat och iscensatt (Anak Andrew, 2011; Holmqvist, 2011; Runesson, Kullberg, & Maunula, 2011). LS i kombination med kollegialt genomförda CoRe har i två studier visat sig gynnsamt för lärares professionella utveckling, en LS-inspirerad aktionsforskningsstudie (biologi och matematik år 1 till 6, Attorps & Kellner, 2017), och en studie med klassisk LS-design (kemisk bindning år 8–9, Bergqvist, 2017).

Vi har tidigare analyserat vad som karaktäriserar lärares förhållningssätt till undervisning och hur detta förändras då de genomför en LS inom området grundläggande kemi år 6 (Åhman, Gunnarsson, & Edfors, 2015). Vi fann att lärarnas förhållningssätt till undervisning successivt förändrades från ett pragmatiskt, där de exempelvis talar om vad de ska göra på en lektion med fokus på praktiska frågor, till ett mer reflekterande förhållningssätt där fokus är på de didaktiska frågorna vad (ämnesinnehåll), hur och varför. I föreliggande studie analyseras samma datamaterial, men utifrån Clarkes och Hollingsworths (2002) modell, ICMPG. Syftet är att klargöra hur kombinationen av CoRe och LS stöder lärare att utveckla sin professionella kompetens inom naturvetenskaplig undervisning genom reflektion och iscensättning mellan de fyra domänerna i modellen ICMPG. Forskningsfrågorna vi söker svar på är:

- Hur resonerar lärarna avseende undervisningsstrategier och elevers lärande när de planerar och genomför en LS kombinerad med CoRe?
- Hur synliggör lärarna lärandeobjektet och dess kritiska aspekter när de genomför en LS?
- Vilka förändringssekvenser och lärande nätverk kan identifieras då lärarna planerar och genomför en LS kombinerad med CoRe?

2 Metod och material

I studien ingick sex lärare i naturvetenskapliga ämnen, årskurs 6 – 9, på en medelstor skola i södra Sverige. Lärarna (L1 – L6) hade alla flera års erfarenhet i yrket (4 – 22 år). De följdes under cirka ett år då de med hjälp av CoRe (Bilaga 1) planerade och genomförde en LS med två lektioner. Tillsammans med skolans övriga lärare introducerades de först till LS och CoRe av en extern föreläsare, väl förtrogen inom området. Under denna studiedag diskuterade och skrev de sex lärarna en gemensam CoRe (CoRe1) inom biologi. Innan studiedagen hade de sex lärarna också en träff då de bland annat diskuterade undervisningsmetoder och lektionsplanering.

Totalt följdes lärarna vid åtta träffar tillsammans med en av författarna, som agerade samtalsledare (Tabell 1). Samtalsledarens roll var att stödja lärarna i deras diskussioner i arbetet med CoRe och LS. Lärarna enades vid träff 3 om ämnesområdet ”grundläggande kemi” i årskurs 6, och diskuterade vid träffarna 3 och 4 utifrån frågeställningarna i CoRe vad de ansåg viktigt att ta upp inom området. Diskussionerna sammanfattades genom att de gemensamt besvarade frågeställningarna i CoRe (CoRe2). Utifrån vad lärarna ansåg var viktigt att fokusera på inom området ”grundläggande kemi” konstruerade de vid träff 5 en förtest beträffande materiens uppbyggnad (Bilaga 2). Förtesten genomfördes i början av höstterminen av eleverna i årskurs 6 (klass A och B, totalt 45 elever). Utifrån elevernas svar på förtesten planerade lärarna vid träff 6 den första lektionen i LS med avseende på lärandeobjektet materia och dess oförstörbarhet (Bilaga 3). Lektion 1 och eftertest genomfördes i klass A, och spelades in med två videokameror placerade längst ned i klassrummet för att säkerställa inspelningen. Vid träff 7 tittade lärarna på den inspelade lektionen och analyserade eftertesten som eleverna genomfört. I eftertesten togs frågorna tre och fyra bort jämfört med förtesten eftersom de inte bedömdes som informativa (fråga tre besvarades korrekt och fråga fyra missförstods av flertalet elever). Utifrån lärarnas analys planerade de lektion 2 (Bilaga 4), som tillsammans med efterföljande eftertest genomfördes i klass B av samma lärare som för lektion 1. Lektion 2 dokumenterades på samma sätt som lektion 1. Vid träff 8 tittade lärarna på inspelningen av lektion 2 och analyserade elevernas eftertest, varefter de utvärderade hela LS. CoRe3 genomfördes individuellt via webbformulär av fyra lärare en tid efter träff 8.

Tabell 1. Översikt av lärarnas aktiviteter och insamlat datamaterial för studien.

Lärarnas aktivitet			**Datamaterial**	
Träff	**Tidpunkt**	**Innehåll**	**Inspelad diskussion**	**Text**
1	Oktober 2012	Lärarna diskuterar på uppmaning av rektor bedömning, undervisningsmetoder, elevstöd, och lektionsplanering	111 min	
2	Januari 2013	Extern föreläsare håller i studiedag om LS och CoRe. Lärarna gör gemensamt en CoRe (CoRe1) inom biologi	96 min	CoRe1
3	Mars 2013	Lärarna väljer ämnesområde för LS, grundläggande kemi år 6, påbörjar gemensamt en andra CoRe (CoRe2)	151 min	
4	April 2013	Lärarna slutför gemensamt CoRe2	136 min	CoRe2
5	Maj 2013	Lärarna konstruerar förtest inom ämnesområdet, fokus på atomer och materias oförstörbarhet	140 min	
6	Augusti 2013	Lärarna analyserar elevernas förtest, planerar lektion 1	122 min	
7	September 2013	Lärarna analyserar lektion 1 (genomförd i klass A med lärare L1) och elevernas eftertest, planerar lektion 2	120 min	
8	September 2013	Lärarna analyserar lektion 2 (genomförd i klass B med lärare L1) och elevernas eftertest, utvärderar hela LS-cykeln	134 min	
	November 2013	Fyra av de sex lärarna gör individuellt via webformulär en tredje CoRe (CoRe3)		CoRe3

Lärarnas åtta träffar dokumenterades med ljudupptagning och utgjorde data för studien, tillsammans med de tre CoRe som lärarna skrev (Tabell 1). Inspelningarna transkriberades ordagrant med hjälp av programvaran NVivoTM (NVivo10, 2012).

För att besvara de tre forskningsfrågorna användes olika angreppssätt. Den första forskningsfrågan sätter fokus på hur lärarna resonerar kring undervisningsstrategier och elevers lärande, vilket ger en beskrivning av den personliga domänen enligt IC-MPG. Genom en iterativ process i enlighet med en tematisk analysmodell (Braun & Clarke, 2006) kodades och kategoriserades data (Tabell 2) för att ge svar på denna forskningsfråga. Koderna utvecklades efter flera genomläsningar av datamaterialet, sorterades och grupperades i två teman, vilka granskades och diskuterades tills konsensus uppnåddes mellan författarna. Representativa och illustrativa citat valdes därefter ut.

Tabell 2. Lärarnas syn på undervisningsstrategier och elevers lärande, identifierade teman och koder.

Tema	Kod
Eleverna lär sig det naturvetenskapliga ämnesinnehållet när läraren förmedlar korrekta fakta	*Lärare ansvarar för att ge korrekt fakta* *Struktur, ordning och repetition*
Eleverna lär sig det naturvetenskapliga innehållet när läraren stimulerar eleverna till reflektion	*Reflektion utifrån lärarledda demonstrationer* *Reflektion utifrån elevdiskussioner*

För att besvara den andra forskningsfrågan (lärarnas synliggörande av lärandeobjektets kritiska aspekter), analyserades hur lärarna planerade, genomförde och diskuterade de två lektionerna utifrån ett variationsteoretiskt perspektiv. Vi tittade således efter hur lärarna lyfte fram lärandeobjektets kritiska aspekter och hur dessa kontrasterades, liksom överenstämmelsen mellan planerad och genomförd lektion. Genom analysen får vi en beskrivning av lärarnas iscensatta undervisning, det vill säga den praktiska domänen enligt ICMPG. Den tredje forskningsfrågan besvaras genom att klargöra samspelet mellan de fyra domänerna i ICMPG, som leder till förändringssekvenser och/eller lärande nätverk.

Lärarna informerades innan träff 1 om studiens syfte, tidsplan och innehåll, samt gav skriftligt samtycke för sin medverkan. Inför videoinspelningarna av lektionerna informerades elever och föräldrar om studien och samtycke inhämtades för elevernas deltagande. Etiska rekommendationer enligt Vetenskapsrådet (2011; 2017) följdes.

3 Resultat

3.1 Lärarnas resonemang avseende undervisningsstrategier och elevers lärande

För att beskriva den personliga domänen analyserades hur lärarna resonerade kring undervisningsstrategier och elevers lärande. Ur dessa diskussioner framkom två teman (Tabell 2).

3.1.1 Eleverna lär sig det naturvetenskapliga ämnesinnehållet när läraren förmedlar korrekta fakta

Lärarna hade i sina diskussioner fokus på att det är deras ansvar att ge korrekta fakta till eleverna, och att struktur, ordning och repetition underlättar lärarens faktaförmedling. Lärarna relaterade ofta till styrdokumenten när de identifierade vilket undervisningsinnehåll som skulle tas upp.

Läraren ansvarar för att ge korrekta fakta

Vid den första träffen diskuterade lärarna vad man kan kräva av eleverna för olika betygskriterier och hur de som lärare kan hjälpa elever som behöver extra stöd. Lärarna tog i diskussionen upp att de har ansvaret för att förmedla information till eleverna. Lärare L5 skulle vilja använda mindre lektionstid för att förmedla baskunskaper än vad hen gör, men uttryckte tveksamhet om hur eleverna då skulle kunna inhämta dessa om inte läraren använder tid till att förmedla fakta, se citat 1.

> ”… att man vill använda lektionstiden mindre till att förmedla dom här baskunskaperna och mer till att göra såna här olika … eh … situationer där man testar kriterierna. Hur får vi då eleverna till att … tillgodogöra sig dom här grundkunskaperna?” (L5 vid träff 1)
>
> (Citat 1)

När lärarna vid träff 2 diskuterade en fråga i CoRe om varför de förordar en viss undervisningsmetod angav de enbart de undervisningsmetoder de skulle välja utan att motivera varför.

> ”Vilka undervisningsmetoder ska du använda för att … av vilken särskild anledning har du valt dessa metoder?” [läser fråga i CoRe]. ”Katederundervisning kommer det att bli. Oavsett. Kommer det garanterat bli.” (L3 vid träff 2)
>
> (Citat 2)

Lärarna framförde olika tolkningar av vad katederundervisning innebär, men var överens om att läraren då förmedlar fakta till eleverna.

> L6: ”Men du kallar det katederundervisning. För mig är kateder att du sitter bakom där och …”
> L3: ”Okej. För mig är det när jag står och föreläser eller berättar någonting framför dem.” (träff 2)
>
> (Citat 3)

Att lärarna i sina diskussioner fokuserade på att det är viktigt att läraren förmedlar korrekt fakta till eleverna styrks av den diskussion som uppstod vid analysen av den genomförda lektion 2 vid träff 8. Lärare L1 skulle under lektion 2 skriva upp på tavlan elevernas förslag på vad som är respektive inte är materia. Avsikten var att eleverna sedan skulle diskutera de två listorna, först i smågrupper och sedan i helklass. När eleverna gav exempel på vad som är ”materia” skrev läraren ned elevernas förslag utan att kommentera dem. När däremot den första elevens förslag på vad som skulle skrivas i kolumnen ”inte materia” var felaktigt så började läraren L1 diskutera om elevens alternativ var korrekt, istället för att skriva upp det på tavlan utan några kommentarer. Citatet nedan illustrerar lärarens frustration över att hen inte klarar av att inför eleverna skriva upp något som är felaktigt på tavlan.

> ”Men just … jag vet inte… jag kände bara … ååå vad fel det blev… och just det att … synd att hon sa nånting som inte var materia … det första … eller som var materia [korrigerar sin felsägning angående elevens svar] … det första. Om det bara hade varit nån som bara hade skrivit … tagit någonting rätt då hade jag skrivit upp det … så hade jag fortsatt liksom även om det hade varit fel tror jag.” (L1 vid träff 8)
>
> (Citat 4)

Vid träff 1 diskuterade lärarna hur de kan möta elever som har det svårt i de naturvetenskapliga ämnena. Lärarna gav som förslag på strategier, att låta eleverna använda lättlästa läromedel, ljudböcker och/eller ge extra tid.

> L6: Sedan är nästa. ”Hur möter vi dom elever som har det svårt i vårt ämne?” [Frågeställning från rektorn.]
> L3: ”Det gör vi … inte” [tyst]
> L6: ”Hur, nu vill jag höra hur. Så vi får med det här. Hur?”
> L2: ”Det är ju genom att… svårigheter i vad.”
> L6: ”Vet inte. Tänk brett. … svårt. Man märker att dom har det svårt.”
> L4: ”Lättläst, inläst.” [ljudbok]
> L6: ”Lättläst, inläst!”
> L3: ”Lättläst, inläst, verkstäder.” [extra tid] (träff 1)
>
> (Citat 5)

Lärarna fokuserade även här på lärarens ansvar att förmedla fakta till eleverna och att förmedlingen underlättas med hjälp av ljudböcker och extra tid.

Struktur, ordning och repetition

Lärarna uttryckte vid flera träffar betydelsen av att lärare genom undervisningen skapar struktur i de fakta som eleverna ska lära sig för att på så sätt stödja deras lärande. Vad som avses med struktur är ibland lite oklart, som i följande citat:

> ”Då måste man ha struktur på detta. Känner jag. Det blir lite glosinlärning.” (L3 vid träff 2)
>
> (Citat 6)

Vid andra tillfällen var det tydligt att lärarna med struktur avsåg att moment ska tas upp i en viss ordning. När lärarna med hjälp av CoRe2 arbetade med att välja område för LS (träff 3) diskuterade de vilken partikelmodell som ska behandlas i årskurs

6 och om begreppen neutroner, protoner och elektroner ska tas upp. De poängterade då att undervisningsinnehållet bör tas upp i en viss ordning. Lärare L3 påpekade vikten av att atomens delar ska vara avklarad innan de kommer till elläran.

> L1: ”Och jag menar sen när man håller på med el. Då pratar man ändå. Det är elektroner som far omkring. SÅ absolut. Så avdramatiserar man det direkt.”
> L3: ”I sjuan så pratar vi joner…”
> L4: ”Då är det bra att ha atomen först va?”
> L3: ”Då måste atomen liksom… den måste va’ behandlad.” (träff 3)
>
> (Citat 7)

Vikten av struktur och ordning av innehållet, men utifrån ordningsföljden mellan teoretiska och praktiska moment togs upp av lärare L5.

> ”Ja precis. Och tajmningen är ofta väldigt viktig. Ibland har man flyt och det stämmer med lektionerna. Sakerna kommer i rätt ordning. Logiskt bra och allt sånt och då kan det bli hur bra som helst.
> …
> Laborationerna tajmar inte den andra delen och ja. Sånt spelar roll.” (L5 vid träff 3)
>
> (Citat 8)

Under träffarna 2–5 diskuterade lärarna utförligt utifrån frågeställningarna i CoRe, men deras nedskrivna svar är kortfattade och delvis ofullständiga. Lärarnas nedtecknade CoRe-svar förstärker dock bilden av att lärarna anser det viktigt att de i undervisningen skapar struktur bland fakta som eleverna ska lära sig och att ge tid för repetition. I CoRe1 angav lärarna som svar på frågan: ”På vilka specifika sätt tänker du dig att du skall underlätta elevernas förståelse beträffande dessa idéer?” att de ska

> ”Ta det lugnt, repetera, ta upp lagom på varje lektion och använda struktur, strukturerat material, tabeller, anteckningar.” (CoRe1)
>
> (Citat 9)

På frågan ”Vilka svårigheter/begränsningar kan förekomma i samband med undervisningen av det specifika ämnesområdet, det vill säga vilka problem kan uppstå i undervisningssituationen?” angav lärarna i CoRe2 att.

> ”Styrning från lärare behövs så att man inte hamnar för långt utanför.” (CoRe2)
>
> (Citat 10)

Lärarna tycks förorda att de i undervisningen ska skapa struktur. De angav dock inte mer detaljerat varför struktur är viktigt, eller vilka svårigheter och problem som kan uppstå.

3.1.2 Eleverna lär sig det naturvetenskapliga innehållet när läraren stimulerar eleverna till reflektion

När lärarna planerade och utvärderade de två lektionerna i LS diskuterade de hur de skulle kunna stimulera eleverna till att reflektera över ämnesinnehållet. De undervisningssätt som lärarna då tog upp var reflektion utifrån lärarledda demonstrationer och reflektion utifrån elevdiskussioner.

Reflektion utifrån lärarledda demonstrationer

När lärarna planerade lektion 1 diskuterade de hur de kan göra för att tydliggöra att all materia, även ”osynlig,” har en massa, så att det blir konkret för eleverna. Genom att använda en balansvåg gjord av rundstav och snöre ville lärarna synliggöra att ballonger som är uppblåsta väger mer än ouppblåsta ballonger. Denna aktivitet genomfördes sedan på båda lektionerna.

> L4: ”… man kanske ska fokusera på diskussionen där. Sedan pratade vi om att hela den grejen, övningen skulle avslutas med att man har en ballong full med luft. Och sen … Väger luft? Alltså har luft vikt? alltså att man kanske släpper ut luften eller nåt sånt.”
> L1: ”Att man väger ballongen flera gånger.”
> L4: ”Vi pratade om L5:s julgran där. Att man skulle ha … att man skulle ha en balansvåg. En sån där pinne. Där man har kanske tio uppblåsta ballonger och tio icke uppblåsta ballonger och då kan man se …” (Träff 6)
>
> (Citat 11)

När lärarna analyserade elevernas resultat på förtesten tolkade de det som att eleverna inte hade förståelse för att massan bevaras när man häller socker i vatten. En av lärarna föreslog då att det kanske blir enklare för eleverna om man använder något som är färgat, och som inte ”försvinner” (blir osynligt) som socker. Lärarna ville genom att ställa två exempel mot varandra stimulera eleverna till att observera likheter och skillnader, samt reflektera över dessa.

> ”Jo jag tänker mest om man tar nåt blått eller om man tar nånting med färg så ser dom att det finns. Då kanske dom inte tvivlar på det. Men är det det som är grejen att om man … får dom att fundera. Tror du verkligen att det här … vita sockret som vi häller i vattnet. Bara för att det försvinner så väger det inget. Än

> om vi tar lika mängd av nåt blått salt till exempel och häller i. Finns det mer för att det syns?” (L2 vid träff 6)
>
> (Citat 12)

Reflektion utifrån elevdiskussioner

Lärarnas analys vid träff 7 av första lektionen och dess eftertest visade att eleverna hade utvecklat sin förståelse om materia. Eleverna var dock fortfarande osäkra på massans bevarande och fick sämre resultat på eftertesten än vad de hade på förtesten. När lärarna analyserade den inspelade lektionen kom de fram till att det var för mycket som hände på lektionen. Utifrån lärarnas analys av lektion 1 och elevernas eftertest diskuterade de hur undervisningen skulle kunna förändras och planerade därefter lektion 2. De poängterade att de ska vara mer lyhörda för elevernas resonemang och föreställningar om materia. En lärare föreslog att läraren under lektion 2 ska ha en diskussion med eleverna om vad man kan väga och inte väga. Genom att eleverna först fick tänka enskilt, därefter diskutera i par och till sist alla i en helklassdiskussion, förändrades undervisningen så att eleverna fick tid både för diskussion och reflektion. Genom att låta eleverna diskutera vad som väger och vad som inte väger, hoppades lärarna att det ska bli synligt för eleverna att materia har massa.

> L5: ”Här. I en sån här situation också. Enskilt tänkt liksom … först tänk efter är det materia? Tycker du att det är materia? Tänker var och en och sen så …”
> L1: ”Alltså att man väntar …”
> L5: ”Snackar man med grannen lite grann om dom och sen tar man ett resonemang med allihopa. Det skulle kunna funka här också.”
> L2: ”Ja absolut … ja i det mesta eller hur?”
> L5: ”Mm.” (Träff 7)
>
> (Citat 13)

Lärarna planerade att i uppgiften för lektion 2 inte berätta vad som är eller inte är materia, utan syftet var att detta ska komma fram successivt genom elevernas diskussioner.

> L5: ”Efter det att du har samlat in dom här olika förslagen på materia och icke materia och sen så skicka ut dom igen så att var och en fick tänka och hålla med om att det där är materia och det där är inte materia och så vidare och diskutera.”
> L4: ”Just att hålla med om den här fördelningen.”
> ….
> L4: ”Ja precis så. Att dom själva kanske får fundera på vad som är rätt och fel.” (Träff 7)
>
> (Citat 14)

Lärarnas planering att inte berätta fakta för eleverna utan låta dem själva komma fram till vad som är respektive inte är materia genom diskussion tolkar vi som att lärarna ser det som viktigt för elevernas lärande att de reflekterar över och diskuterar begreppet, och att enbart faktaförmedling från läraren inte är tillräckligt för ett lärande.

Vid den sista träffen diskuterade lärarna vad som gjorde undervisningen tydligare för eleverna under lektion 2 jämfört med lektion 1. Lärare L2 poängterade att det faktum att eleverna hade gjort en lista med förslag och att de fick tid att diskutera förslagen, utan att läraren gav dem rätt svar, stimulerade deras lärande.

> ”Jag tror listan ... Bara den här listan ... Att man hade den gemensam. Att man diskuterade kring listan och det tror jag gjorde mycket ... Just materia, icke materia.” (L2 vid träff 8)
>
> (Citat 15)

Av lärarnas diskussioner framgick att de ville skapa möjligheter till reflektion över ämnesinnehållet för eleverna i de olika aktiviteterna. Detta återspeglades dock inte i de skrivna CoRe som lärarna gjorde, varken i grupp eller enskilt.

3.2 Lärarnas synliggörande av lärandeobjektet och dess kritiska aspekter

För att besvara den andra forskningsfrågan och därmed beskriva den praktiska domänen studerade vi hur lärarna synliggjorde lärandeobjektet och dess kritiska aspekter. Vi fann att lärarna planerade lektionernas aktiviteter i enlighet med ett variationsteoretiskt perspektiv. De bestämde vad de skulle lyfta fram i lärandeobjektet ”materia och dess oförstörbarhet,” och hur de skulle kontrastera, det vill säga synliggöra likheter och skillnader för att tydliggöra lärandeobjektets kritiska aspekter (Tabell 3). I sina diskussioner under planeringen av lektionerna använde lärarna sig dock inte explicit av variationsteorins begrepp.

Tabell 3. Analys av planerade och genomförda aktiviteter under lektion 1 och 2.

Lärandeobjekt: Materia och dess oförstörbarhet				
Aktivitet	**Analys av planerad aktivitet**		**Analys av genomförd aktivitet**	
	Kritisk aspekt	**Vad som hålls konstant (K) respektive varieras (V)**	**Lektion 1**	**Lektion 2**
Väga olika saker	All materia har massa	K: Väga materia V: Vad som vägs	Läraren fokuserar inte på den kritiska aspekten utan tar upp andra frågor, vilket gör att eleverna inte fokuserar på lärandeobjektet.	Läraren fokuserar på den kritiska aspekten, styr samtalet när eleverna kommer in på andra områden. Avslutar så att aktiviteten pekar på nästa aktivitet.
Balansvåg och ballonger	All materia har massa	K: Antal ballonger på varje sida av balansvågen. V: Luftmängden i ballongerna.	Läraren fokuserar på den kritiska aspekten under aktiviteten, men behåller därefter inte fokus på lärandeobjektet.	Läraren fokuserar på den kritiska aspekten, även när uppblåsningen av ballongerna distraherar eleverna
Lektion 1: Smälta tenn Lektion 2: Is i vatten	Materias massa, fasövergång och aggregations-tillstånd	K: Mängden materia (massa) V: Temperatur och aggregations-tillstånd	Läraren fokuserar inte på de kritiska aspekterna, utan på tenn och andra metaller och dess smältpunkter.	Läraren fokuserar på de kritiska aspekterna, uppmanar eleverna att diskutera och reflektera över vad som händer. Går igenom förväntat resultat när aktiviteten inte går som planerat, leder diskussionen så att de kritiska aspekterna tydliggörs.
Brustablett i vatten	Materias massa, fasövergång och aggregations-tillstånd	K: Mängden materia (massa) V: Ämnen före och efter upplösning	Läraren fokuserar inte på de kritiska aspekterna då aktiviteten misslyckas på grund av fel vald utrustning.	Ingick inte i lektion 2.
O'boy i vatten	Materias massa, fasövergång och aggregations-tillstånd	K: Mängden materia (massa) V: Ämnen före och efter upplösning	Läraren fokuserar inte på de kritiska aspekterna utan diskuterar även andra närliggande frågor.	Ingick inte i lektion 2.

Utifrån resultatet på förtesten konkretiserade lärarna inför lektion 1 de kritiska aspekter som de ville att eleverna skulle erfara för att förstå lärandeobjektet. Det vill säga att all materia har massa, att även materia som inte syns (exempelvis luft) har massa och att den är oförändrad vid blandningar, reaktioner och fasövergångar (materians oförstörbarhet), se citat 13 och 14. Planeringen för den första lektionen fullföljdes dock inte i genomförandet av lektionen (Tabell 3). I sin analys av lektion 1 och av elevernas resultat på tillhörande eftertest drog lärarna slutsatsen att eleverna hade utvecklat sin förståelse med avseende på att materia som inte syns har massa. De fann dock att eleverna inte utvecklat förståelsen kring massans bevarande, utan fick sämre resultat på eftertesten än vad de hade på förtesten. En anledning till detta var enligt lärarna, att det var för många moment under lektionen, likaså att läraren inte gjorde anteckningar som eleverna kunde skriva av. Lärarnas bedömning var också att genomgångarna var för långa för elever i årskurs 6, samt att eleverna fokuserade på fel saker eftersom demonstrationerna var för svåra och att den valda utrustningen inte var lämplig.

> L1: ”Sen var det att vi hade ganska många såna här visningsdelar kan man säga. Så det var så att jag stod och pratade nästan hela tiden … och jag kände nog att man kan prata lite och sen kan man göra nånting annat. Så att dom får göra något.”
> L3: ”Variera.”
> L1: ”Variera lite mer. Vi sa att det blev inte så tradigt men till slut så blev ju många lite trötta på att lyssna.” (Träff 7)
>
> (Citat 16)

Lärarna drog slutsatsen att det måste vara mer omväxling, med flera olika undervisningssätt och elevaktiva moment för att ta bort fokus från läraren. Förslag som gavs var att eleverna skulle kunna arbeta med text och eventuellt svara på frågor eller att göra ett eget experiment.

Vi fann att lärarna under planeringen av lektion 1 använde sig av kontrastering i de fem aktiviteterna (Tabell 3), det vill säga att något hålls konstant medan något annat varieras i aktiviteten. Samtidigt visar vår analys av aktiviteterna under lektion 1, att läraren i sin undervisning inte hade fokus på lärandeobjektet och dess kritiska aspekter. Detta kan vara en anledning till att elevernas resultat vid eftertestet i vissa fall var sämre än i förtestet.

Vid lärarnas planering av lektion 2 konstaterade de att eleverna behövde vara mer aktiva så att diskussion och reflektion stimuleras. De ändrade därför i första aktiviteten så att eleverna gavs tid för reflektion och diskussion (Bilaga 4). De minskade också på antalet aktiviteter, från fem till tre. Den andra aktiviteten var densamma som vid lektion 1, medan den tredje var ny (Bilaga 4). Aktiviteterna fokuserade på att all materia har massa, samt att materians massa bevaras vid fasövergångar. Lektion 2 avslutades med att läraren gav en sammanfattning varefter eleverna genomförde eftertestet. Lärarnas analys av lektionen och eftertestet visade att eleverna hade utvecklat sin förståelse av lärandeobjektet materia och dess oförstörbarhet. Orsaken till detta var, enligt lärarna, att lektion 2 hade färre moment än lektion 1 och att eleverna fick tid till reflektion och diskussion.

> L1: ”Ja. Men jag tror att om man hade haft det här upplägget på första lektionen så hade det blivit bättre.”
> L4: ”Liknande.”
> L1: ”Just det här att man ska inte ha för många moment.”
> …
> L1: ”Då fick dom aldrig tid att sitta själva och fundera utan det gick bara på.” [lektion 1]
> …
> L1: ”Det var mera … fråga hit och dit och …” [lektion 1]
> …
> L1: ”Det var mycket högre tempo.” [lektion 1] (Träff 8)
>
> (Citat 17)

Att läraren hade erfarenhet från första lektionen vid genomförandet av lektion 2, lyftes även fram som orsak till det bättre utfallet. Lärare L1, som genomförde båda lektionerna, poängterade att lektion 2 genomfördes på ett sätt så att elevernas fokus låg mer på undervisningens innehåll än på läraren och att detta skilde sig från lection 1.

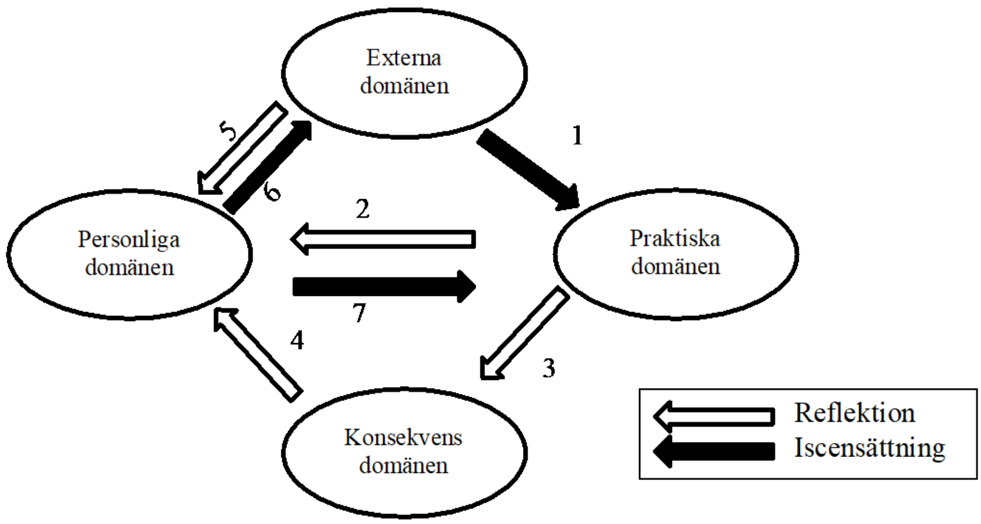
Vi fann att lärarna både i planering och i genomförande av lektion 2, agerade i enlighet med ett variationsteoretiskt perspektiv genom att lyfta fram lärandeobjektet och uppmärksamma eleverna på de kritiska aspekterna genom kontrastering (Tabell 3). Lärarna diskuterade dock inte explicit vid genomgången av lektionen och tillhörande eftertest hur de som lärare kunde synliggöra de kritiska aspekterna för eleverna. Vid den första aktiviteten lät läraren eleverna få tid till att reflektera över vad som är materia respektive inte materia. Jämfört med första lektionen, där samma aktivitet genomfördes, hade läraren under andra lektionen större fokus på lärandeobjektets kritiska aspekter, så att inte ovidkommande frågor medförde att eleverna tappade fokus. Läraren knöt också ihop aktiviteterna så att avslutningen av en aktivitet ledde fram till nästa. Även vid den andra aktiviteten hade läraren större fokus på lärandeobjektet, än när den genomfördes under lektion 1 (Tabell 3). Läraren satte på detta vis den kritiska aspekten, att all materia har massa även om det inte syns, i centrum för elevernas uppmärksamhet. Den tredje aktiviteten, som skulle illustrera materians oförstörbarhet och som var ny jämfört med lektion 1, fungerade inte som tänkt. Detta berodde på att den bägare som användes för att hälla upp is och vatten med redan innehöll lite vatten, vilket läraren upptäckte försent. Detta innebar att massan inte hölls konstant i experimentet. Eleverna uppmanades därför att diskutera och reflektera över det förväntade resultatet av försöket. I diskussionen fokuserade läraren på den kritiska aspekten, det vill säga att massan är konstant även om aggregationstillståndet varierar. Den erfarenhet som läraren fick av första lektionen och analysen av den gjorde troligtvis att hen behöll fokus på lärandeobjektet, även när den planerade aktiviteten under lektion 2 inte fungerade som planerat.

3.3 Förändringssekvenser och lärande nätverk

Enligt modellen ICMPG leder förändring i någon av de fyra domänerna till förändring i de andra domänerna vilket benämns som förändringssekvenser och/eller lärande nätverk. Lärarna i studien fick stöd genom föreläsning och workshop av en extern föreläsare och textmaterial om CoRe, LS och elevföreställningar, vilket i denna studie inkluderas i den externa domänen. Denna domän inkluderar även lärarnas diskussioner med kollegor under de regelbundna träffarna då de planerade och genomförde en LS med hjälp av verktyget CoRe. Genom insatserna i den externa domänen gavs lärarna möjlighet att reflektera över sina egna kunskaper och föreställningar kring undervisningsstrategier och elevers lärande, vilket gav förändring i den personliga domänen. När lärarna beskrev sin syn på undervisning och lärande påverkade de varandra, det vill säga en lärares uppfattningar och kunskaper (personlig domän) påverkade och utgjorde därmed del av den externa domänen för de andra lärarna. Insatserna i den externa domänen (workshop, textmaterial, kollegiala diskussioner), påverkade hur de två lektionerna planerades och genomfördes (praktisk domän). Då det endast var en lärare som genomförde lektionerna, så var lärarnas erfarande av den praktiska domänen med stor sannolikhet olika och därmed också inverkan på den personliga domänen, även om övriga lärare upplevde undervisningen genom att se på den inspelade filmen (citat 4, 16 & 17).

I den praktiska domänen ingår förutom genomförandet av de två lektionerna, även lärarnas erfarande av det gemensamma arbetet med CoRe och planeringen av lektionerna, vilket också påverkas av lärarnas syn på undervisning och lärande (personlig domän). Lärarnas reflektioner över den första genomförda lektionen och elevers resultat på eftertest, påverkade också den personliga domänen (citat 13–17). Utifrån lärarnas reflektioner (personlig domän) och diskussioner (extern domän) planerades och iscensattes nästa lektion. Lärarnas reflektion över och analys av resultaten på elevernas förtest och eftertest (konsekvensdomän) påverkade hur lektionerna genomfördes (praktisk domän), men påverkade även den personliga domänen (citat 11 och 15). Resultaten ovan visar på förändringssekvenser, reflektion och iscensättning mellan olika domäner, vilket tyder på en professionell utveckling hos lärarna.

Hos läraren (L1) som genomförde de planerade lektionerna fann vi indikationer på att reflektion och iscensättning skedde mellan flera av domänerna, vilket därmed kan ses som ett lärande nätverk (Figur 2).



Figur 2. Lärande nätverk hos lärare L1.

Genom förslag (steg 1) från kollegor på innehållet (citat 11, 13–14), de praktiska erfarenheterna i undervisningen (steg 2) och elevers resultat på eftertest (steg 3, 4) pekar detta på att L1 har förändrat sitt sätt att undervisa om det valda ämnesinnehållet (steg 7). Genom lärarnas diskussion och reflektion (steg 5, 6) vid analys av lektion 1 (citat 13, 14, 16) skedde förändringar av upplägget av lektion 2 (steg 7). Ser vi på hur lärare L1 genomförde lektion 2 i jämförelse med lektion 1 med avseende på hur lärande objektet och dess kritiska aspekter synliggjordes, pekar detta på att det skedde en kedja av reflektion och iscensättning mellan de olika domänerna (citat 17). Även hos de andra lärarna skedde reflektion och iscensättning mellan de olika domänerna, men då de inte genomförde några lektioner utan endast deltog i att planera och analysera dessa fick de inte egen undervisningserfarenhet såsom lärare L1. Då den praktiska domänen inte enbart innefattar de fysiska klassrumserfarenheterna, kan det ha skett professionellt lärande även hos de andra lärarna utifrån undervisningserfarenheter de fick via analysen av de genomförda lektionerna och diskussionerna kring undervisningsstrategier under träffarna (citat 11–14). Detta illustreras även i citat 15, som visar på reflektion hos lärare L2 baserat på de genomförda lektionerna, även om denne lärare inte genomförde lektionen.

Vi finner att det hos lärarna skedde professionell utveckling i form av förändringssekvenser och lärande nätverk. Möjligheterna till professionell utveckling påverkas av de ramverk som är aktuella för lärarna. I den aktuella studien hade lärarna stöd av en intresserad rektor, som avsatt tid för lärarna att genomföra en LS. Flera av lärarna påpekar vid sista träffen att tid är en begränsande faktor när samtalsledaren frågar om de tror att de kommer genomföra CoRe och/eller LS fler gånger.

> L6: ”Det här kräver ju tid.”
> Flera lärare: ”Ja.”
> L6: ”Det tror jag är det som mest stoppar.” (träff 8)
>
> (Citat 18)

4 Diskussion och slutsatser

Fokus i studien ligger på lärares professionella utveckling utifrån hur deras ämnesdidaktiska kompetens kommer till uttryck när de planerar och genomför en LS. Tidigare studier har visat att lärares ämnesdidaktiska kompetens utvecklas av den diskussion som sker när de använder CoRe vid planering av undervisning (Nilsson & Loughran, 2012), likaså att tillvägagångssättet som används vid LS stimulerar lärares professionella utveckling (Anak Andrew, 2011; Holmqvist, 2011; Nilsson, 2014). I vår studie har vi, i likhet med Attorps och Kellner (2017) och Bergqvist (2017), kombinerat CoRe med LS, men vår analys av lärares professionella utveckling sker utifrån ICMPG (Clarke & Hollingsworth, 2002). Enligt denna modell utvecklas läraren i sin profession genom iscensättning och reflektion mellan fyra interagerande domäner.

Vi har tidigare visat (Åhman et al., 2015) att arbetet med CoRe och LS kan ge en förändring av hur lärarna talar om sin undervisning, från ett pragmatiskt till ett reflekterande sätt. Detta indikerar förändringar i det som Clarke and Hollingsworth (2002) benämner den personliga domänen. Resultatet i föreliggande studie indikerar att lärarnas arbete med att tydliggöra lärandeobjektet och de kritiska aspekterna får konsekvenser både i den personliga och i den praktiska domänen. Vi ser förändring i lärarnas val av undervisningsstrategier, deras tal om hur elever lär sig naturvetenskap, och hur lektion 2 genomförs, vilket indikerar reflektion och iscensättning mellan de olika domänerna.

Vi finner att det kollegiala arbetet att genomföra CoRe ger stöd för att stimulera lärarna till att diskutera och reflektera utifrån ett ämnesdidaktiskt perspektiv. Diskussionen under det kollegiala arbetet med CoRe underlättar för lärarna att identifiera ämnesrelaterade aspekter som är viktiga för eleverna att fokusera på inom ämnesområdet ”grundläggande kemi.” Under genomförandet av LS diskuterar de även vad som är relevant att variera ur ett ämnesmässigt perspektiv, vilket Fredlund et al. (2015) framhåller som värdefullt för att underlätta elevers lärande. Vi kunde dock inte se någon utveckling i de skriftliga svar lärarna gav i de tre CoRe de genomförde, till skillnad från Bergqvist (2017) som fann att lärarnas svar i en andra CoRe, gjord efter lektion 3, var mer utvecklade än de i en CoRe gjord före lektion 1. Attorps och Kellner (2017) trycker på betydelsen av CoRe för den kollegiala diskussionen, men redovisar inga data avseende lärarnas svar i CoRe. Lärarnas skriftliga svar i de tre genomförda CoRe var kortfattade och våra resultat visar på svårigheten att bedöma en lärares professionella utveckling endast utifrån de skriftliga svaren i en CoRe. Dock visar resultaten att frågeställningarna i CoRe stimulerar till diskussioner mellan lärarna då de genomför kollegiala CoRe. Jämfört med att göra enskilda CoRe ger kollegialt gjorda CoRe utrymme för erfarenhetsutbyte mellan lärarna, vilket enligt Riveros et al. (2012) och Clarke and Hollingsworth (2002) gynnar deras reflektion och professionella utveckling. Vi finner att det stöd som CoRe ger under arbetet med LS stimulerar lärarnas reflektion och diskussion, vilket bidrar till professionell utveckling, vilket stämmer överens med tidigare forskning (Hume & Berry, 2011; Loughran et al., 2012; Loughran et al., 2000; Loughran et al., 2004; Nilsson & Loughran, 2012).

När lärarna tillsammans planerade, genomförde och analyserade lektionerna i LS, så diskuterade de hur och varför elever lär sig, samt hur de kan underlätta för elevers lärande. Även om de variationsteoretiska begreppen och teorin som en LS utgår från hade introducerats och också diskuterats vid mötena så använde lärarna inte den variationsteoretiska terminologin explicit när de analyserade lektionerna. Vi drar slutsatsen att för att lärarna ska kunna använda de variationsteoretiska begreppen när de diskuterar och reflekterar över sin undervisning behöver de mer tid och stöd i form av fler LS cykler tillsammans med teoretisk fördjupning (Holmqvist, 2011; Runesson et al., 2011).

Kombinationen av CoRe och LS stimulerar den professionella utvecklingen även hos erfarna lärare enligt våra resultat. Arbetet med CoRe underlättar för lärarna att identifiera ämnesrelaterade aspekter som är viktiga för eleverna att fokusera på inom ämnesområdet ”grundläggande kemi.” Under planering och genomförandet av lektionerna 1 och 2 resonerade lärarna även om vilka artefakter som var lämpliga att använda, samt vad som är relevant att variera ur ett ämnesmässigt perspektiv. Under studien förändrar lärarna sina resonemang om undervisningsstrategier och om hur eleverna lär sig naturvetenskap. Resultatet indikerar att arbetssättet har potential att stimulera professionell utveckling och skulle därför kunna vara en modell för skolor att använda för att långsiktigt utveckla lärares kompetens. För detta behövs dock att ramverket, i form av stödjande organisation och tid, ger lärarna möjlighet för professionell utveckling, vilket citat 18 och tidigare studier tar upp som viktigt (Clarke & Hollingsworth, 2002; Putnam & Borko, 2000; Riveros et al., 2012; Stolk et al., 2009a, 2009b). Fler studier med kombinationen CoRe och LS som följer en lärargrupp under längre tid, med fler LS-cykler och uppföljning en tid efter att LS genomförts, behövs. Detta för att få fördjupad förståelse av lärares professionella utveckling, utifrån hur lärande nätverk hos enskild lärare kan stimuleras. I studien ser vi hur lärarna använder artefakter för att hjälpa elever att uppmärksamma lärandeobjektet. Det skulle därför också vara intressant att studera hur användandet av artefakter i undervisningen kan stödja lärares och elevers samtal om fenomen, samt vilken betydelse detta har för lärares professionella utveckling.

5 Tack

Författarna tackar de deltagande lärarna och kollegor vid Linnéuniversitetet för värdefulla insatser och diskussioner. Studien finansierades av forskarskola LicFontD2 och Linnéuniversitetet.

Referenser

Anak Andrew, V. (2011). Using Learning Study to improve the teaching and learning of accounting in a school in Brunei Darussalam. *International Journal for Lesson and Learning Studies, 1*(1), 23–40. doi:10.1108/20468251211179687

Attorps, I., & Kellner, E. (2017). School–University action research: Impacts on teaching practices and pupil learning. *International Journal of Science and Mathematics Education, 15*(2), 313–330. doi:10.1007/s10763-015-9686-6

Bergqvist, A. (2017). *Teaching and learning of chemical bonding models: Aspects of textbooks, students' understanding and teachers' professional knowledge.* (Dissertation). Karlstad Universitet, Karlstad.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. doi: 10.1191/1478088706qp063oa

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education, 18*(8), 947–967. doi: 10.1016/S0742-051X(02)00053-7

Fredlund, T., Airey, J., & Linder, C. (2015). Enhancing the possibilities for learning: variation of disciplinary-relevant aspects in physics representations. *European Journal of Physics*(5). doi:10.1088/0143-0807/36/5/055001

Holmqvist, M. (2011). Teachers' learning in a learning study. *Instructional Science, 39*(4), 497–511. doi:10.1007/s11251-010-9138-1

Hume, A., & Berry, A. (2011). Constructing CoRes—a strategy for building PCK in pre-service science teacher education. *Research in Science Education, 41*(3), 341–355. doi: 10.1007/s11165-010-9168-3

Lo, M. L. (2012). Towards a science of the art of teaching. *International Journal for Lesson and Learning Studies, 1*(1), 7–22. doi: 10.1108/20468251211179678

Lo, M. L. (2014). *Variationsteori : för bättre undervisning och lärande* (1 ed.). Lund: Studentlitteratur.

Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and developing science teachers' pedagogical content knowledge* (2 ed.). Rotterdam: Sense publishers.

Loughran, J., Gunstone, R., Berry, A., Milroy, P., & Mulhall, P. (2000). *Science cases in action: Developing an understanding of science teachers' pedagogical content knowledge.* Paper presented at the The National Asociation for Research in Science Teaching, New Orleans.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370. doi: 10.1002/tea.20007

Marton, F. (2000). *Om lärande.* Lund: Studentlitteratur.

Marton, F., & Tsui, A. r. (2004). *Classroom discourse and the space of learning.* Mahwah, N.J.: Lawrence Erlbaum.

Nilsson, P. (2014). When teaching makes a difference: Developing science teachers' pedagogical content knowledge through learning study. *International Journal of Science Education, 36*(11), 1–21. doi: 10.1080/09500693.2013.879621

Nilsson, P., & Loughran, J. (2012). Exploring the development of pre-service science elementary teachers' pedagogical content knowledge. *Journal of Science Teacher Education, 23*(7), 699–721. doi: 10.1007/s10972-011-9239-y

NVivo10. (2012). QSR International, http://qsrinternational.com.

Pang, M. F., & Ling, L. M. (2012). Learning Study: Helping teachers to use theory, develop professionally, and produce new knowledge to be shared. *Instructional Science: An International Journal of the Learning Sciences, 40*(3), 589–606. doi: 10.1007/s11251-011-9191-4

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4–15.

Riveros, A., Newton, P., & Burgess, D. (2012). A situated account of teacher agency and learning: Critical reflections on professional learning communities. *Canadian Journal of Education, 35*(1), 202–216.

Runesson, U., Kullberg, A., & Maunula, T. (2011). Sensitivity to student learning: A possible way to enhance teachers' and students' learning? In, O. Zaslavsky, & P. Sullivan (Eds.), *Constructing knowledge for teaching secondary mathematics tasks to enhance prospective and practicing teacher learning* (pp. 263-278). New York: Springer.

Schön, D. A. (2003). *The reflective practitioner : how professionals think in action*. Repr. Aldershot: Ashgate.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14. doi: 10.3102/0013189X015002004

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–22.

Skolverket. (2012). *Att se helheter i undervisningen*. Stockholm: Fritzes

Stolk, M. J., Bulte, A. M. W., de Jong, O., & Pilot, A. (2009a). Strategies for a professional development programme: Empowering teachers for context-based chemistry education. *Chemistry Education Research and Practice, 10*(2), 154–163.

Stolk, M. J., Bulte, A. M. W., de Jong, O., & Pilot, A. (2009b). Towards a framework for a professional development programme: Empowering teachers for context-based chemistry education. *Chemistry Education Research and Practice, 10*(2), 164–175.

Vetenskapsrådet. (2011). *God forskningssed*. Stockholm: Vetenskapsrådet.

Vetenskapsrådet. (2017). *God Forskningssed [Elektronisk resurs]*. Stockholm: Vetenskapsrådet.

Åhman, N., Gunnarsson, G., & Edfors, I. (2015). In-service science teacher professional development. *Nordic Studies in Science Education, 11*(2), 207. doi: 10.5617/nordina.2048

Bilaga 1

CoRe (enligt Skolverket, 2012)

Ämnesområde:	Big Idea	Big Idea
Vad förväntar du dig att eleverna ska lära sig om just denna specifika kunskap?		
Varför är det viktigt att eleverna vet just detta?		
Vad vet du mer om just denna Idé (som du inte anser att eleverna behöver lära sig nu)?		
Vilka svårigheter/begränsningar kan förekomma i samband med undervisningen av det specifika ämnesområdet, d.v.s. vilka problem kan uppstå i undervisningssituationen?		
Vilken är din kunskap om elevers begreppsuppfattningar/missuppfattningar i ämnet och hur påverkar dessa din undervisning?		
Andra faktorer som kan påverka din undervisning i det här området?		
Vilka undervisnings-metoder ska du använda och av vilken särskild anledning har du valt just dessa metoder?		
På vilka specifika sätt tänker du dig att du ska underlätta elevernas förståelse beträffande dess idéer?		
Vilka specifika sätt tänker du dig att du ska använda för att ta reda på att eleverna har lärt sig det du förväntat dig att de ska ha gjort?		

Bilaga 2

Förtest och eftertest: Materiens uppbyggnad

1. **Vad är materia?**
Om du anser att en kastrull *är* materia, så kryssar du i JA. Om du anser att en kastrull *inte* är materia, så kryssar du i NEJ. Fortsätt sedan med resten av listan.

	JA	NEJ	JA	NEJ
Atom Människa	☐	☐	☐	☐
Dammkorn Nervcell	☐	☐	☐	☐
Kastrull Olja	☐	☐	☐	☐
Ljus Skugga	☐	☐	☐	☐
Luft Tulpan	☐	☐	☐	☐
Magnetfält Vakuum	☐	☐	☐	☐
Molekyl Värme	☐	☐	☐	☐

2. **Vad har vikt?**
Om du anser att kastrull har vikt, så kryssar du i *JA*. Om du anser att en kastrull inte har vikt, så kryssar du *NEJ*. Fortsätt sedan med resten av listan.

	JA	NEJ	JA	NEJ
Atom Människa	☐	☐	☐	☐
Dammkorn Nervcell	☐	☐	☐	☐
Kastrull Olja	☐	☐	☐	☐
Ljus Skugga	☐	☐	☐	☐
Luft Tulpan	☐	☐	☐	☐
Magnetfält Vakuum	☐	☐	☐	☐
Molekyl Värme	☐	☐	☐	☐

3. **Minsta delen**
   I en lärobok kan man *läsa ”Om man tänker sig att man delar ett stycke järn i mindre och mindre delar, så kommer man till en minsta del som inte går att dela. Denna minsta del är en atom.”* Några elever diskuterar vad detta betyder.

   Sven säger: *Atomerna finns i järnstycket från början.*
   Stina säger: *Atomernas storlek beror på hur bra verktyg man har då man delar.*
   Olle säger: *Formen på en atommåste bero på hur man delar.*
   Lisa säger: *Formen på en atom beror inte på hur man delar.*
   Ulla säger: *Atomerna uppstår då man delar.*

   Vilken eller vilka elever har rätt? ____

   Vilken eller vilka elever har fel? ____

   Förklara ditt svar!

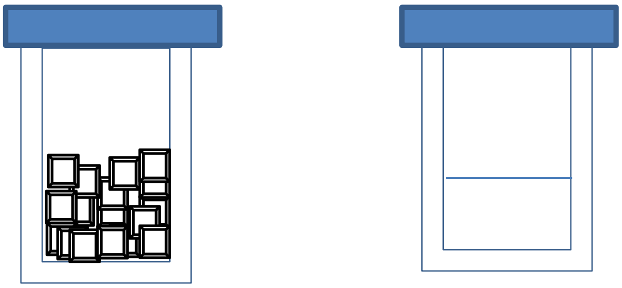
4. **Brinnande papper**

Du har en flaska med luft i. Du lägger ner en bit brinnande papper och sätter snabbt på korken. Vad kommer innehållet i flaskan att väga efter försöket jämfört med före försöket?

Lika mycket ☐
Mindre ☐
Mer ☐
Förklara ditt svar!

5. Isen som smälter i burken

En burk fylls med iskuber. Ett tättslutande lock sätts på, varefter burken med innehåll vägs. Resultatet är 630 gram. Burken får sedan stå tills all is har smällt. Vi väger den igen. Vad blir resultatet?



Mycket mer än 630 gram ☐
Lite mer än 630 gram ☐
Fortfarande 630 gram ☐
Lite mindre än 630 gram ☐
Mycket mindre än 630 gram ☐
Förklara ditt svar!

6. Socker i vatten

I en kastrull finns 1000 gram vatten. Eva häller 200 gram socker i vattnet och vickar sakta på kastrullen tills allt sockret har löst sig. Vad väger nu innehållet i kastrullen?

Mindre än 1000 gram ☐
Precis 1000 gram ☐
Mellan 1000 gram och 1200 gram ☐
Precis 1200 gram ☐
Mer än 1200 gram ☐
Förklara ditt svar!

Bilaga 3

Aktiviteter vid lektion 1

Aktivitet	**Beskrivning av aktivitet**
1. Väga olika saker	Läraren diskuterar med eleverna om saker som väger utifrån elevernas och lärarens förslag. Utifrån förslagen försöker läraren väga föremålet, diskuterar om det går att väga väldigt små föremål, och om ljus, ljud, skugga och magnetfält väger något.
2. Balansvåg och ballonger	Läraren väger tre tomma ballonger och gör om proceduren för tre andra tomma ballonger. Läraren konstaterar att de två vägningarna ger samma resultat. Ballongerna från första vägningen hängs upp på ena sidan av en balansvåg. De tre övriga ballonger blåses upp och hängs upp på andra sidan av balansvågen.
3. Smälta tenn	Läraren väger en bit tenn i en aluminiumform. Därefter smälts tennbiten över en brännare. Det smälta tennet vägs.
4. Brustablett i vatten	Läraren väger och skriver upp totalvikten av brustablett, vattenmängd, E-kolv och kork. Därefter stoppas brustabletten i E-kolven med vatten och korken sätts på. När brustabletten är upplöst vägs kolven igen.
5. O'boy i vatten	Läraren väger totalvikten av O'boy, vattenmängd och bägare. Därefter hälls O'boy i vatten, blandas och vägs.

Bilaga 4

Aktiviteter vid lektion 2

Aktivitet	**Beskrivning av aktivitet**
1. *Väga olika saker*	Läraren har en diskussion med eleverna om vad som man kan väga och inte väga. Utifrån denna diskussion berättar läraren att det som man kan väga kallas materia. Därefter skriver läraren upp två kolumner på tavlan, en för materia och en för inte materia. Därefter får eleverna ge förslag på vad de anser är materia och sedan på vad de anser inte är materia. Dessa förslag reflekterar eleverna sedan över, först enskilt och sedan med bänkkamraten. Som avslutning har man en gemensam diskussion i klassen där man går igenom de olika elevförslagen
2. *Balansvåg och ballonger*	Läraren väger tre tomma ballonger och gör om proceduren för tre andra tomma ballonger. Läraren konstaterar att de två vägningarna ger samma resultat. Ballongerna från första vägningen hängs upp på ena sidan av en balansvåg. De tre övriga ballonger blåses upp och hängs upp på andra sidan av balansvågen.
3. Is i vatten	Läraren väger först en bägare med is och därefter en bägare med vattnen. Därefter läggs isen och vatten i en ny bägare och när isen har smält vägs bägaren med vatten igen.

Promoting learning with understanding: Introducing languaging exercises in calculus course for engineering students at the university level

Helen Alfaro[1,2] and Jorma Joutsenlahti[1]

[1] Tampere University, Faculty of Education and Culture, Finland
[2] University of Costa Rica, School of Mathematics, Department of Mathematics Education, Costa Rica

The study of mathematics at the university level requires logical thinking and strong mathematical skills. Contemporary first-year students are not prepared for these demands and end up failing their courses. This study aims to present an instrument for enhancing mathematics teaching and promoting learning with understanding in higher education by a combination of symbolic, natural, and pictorial languages in different tasks. We analyze the 17 solutions of four languaging exercises administered in a basic calculus course for engineering students at the University of Costa Rica. The results suggest that these exercises promote the acquisition of skills necessary to be mathematically proficient and are a useful tool for revealing students' mathematical thinking and misconceptions.

Keywords: languaging, university mathematics teaching, mathematical proficiency derivatives

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 229–251

Received 21 February 2020
Accepted 17 September 2020
Published 24 September 2020

Pages: 23
References: 35

Correspondence:
jorma.joutsenlahti@tuni.fi

https://doi.org/10.31129/LUMAT.8.1.1412

1 Introduction

In the last years, research in university mathematics education has increased substantially (Biza et al., 2016; Goodchild & Rønning, 2014), and the transition from high school mathematics to university mathematics has been intensely discussed (Winsløw et al., 2018; Varsavsky, 2010). There is a general concern about first-year students' unpreparedness to face university level mathematics. A significant portion of students enrolled in non-mathematics majors experience the consequences of this knowledge gap, which are seen in the alarming rates of failure and dropout presented in the mathematics courses taken (Biza et al., 2016; Fox et al., 2017).

Several researchers (e.g., Artigue, 1995; Kilpatrick et al., 2001; Winsløw et al., 2018) point out that students enter the university without strong mathematics knowledge. This problem was already identified in 1972, as presented by Hoyles, Newman, and Noss (2001) in this excerpt that points out that:

> "[students] do not understand the mathematical ideas which university teachers consider basic to their subject; they are not skillful in the manipulative processes of even elementary mathematics; they cannot grasp new ideas quickly or at all; ... and, particularly, they have no sense of purpose that is, they

Published by the University of Helsinki, Finland / LUMA Centre Finland | CC BY-NC 4.0

> do not seem to realize that in order to study mathematics intensively they must work hard on their own trying to sort out ideas new and old, trying to solve test problems, and so on." (Thwaites, 1972, as cited in Hoyles et al., 2001, p.831)

Contemporary students continue to present the same difficulties. They have deficiencies in problem-solving skills, conceptual understanding, and the thinking and reasoning skills needed for the university level (Kempen & Biehler, 2014; Er, 2018; Gruenwald et al., 2004; Luk, 2005). Although they are successful in tasks of mechanical calculation, the practical and theoretical meaning of the lessons' contents is not clear to them. It is evident that there is a knowledge gap between high school and university mathematics that influences the students' performance.

Biza et al. (2016) and Hong et al. (2009) associate students' low performance in the first courses of university mathematics with changes in teaching styles, required study and learning strategies, and the nature of the mathematics that is taught.

This knowledge and the cultural gaps should be addressed by institutions of higher education by promoting conceptual understanding (Engelbrecht & Harding, 2015). These initiatives must convey the connections between concepts (Nardi, 1996), the abstract nature of mathematical notions, and the complexity of mathematical thinking (Biza et al., 2016).

Some universities have taken measures to fill in the gaps in first-year university students' knowledge of mathematics, such as peer work, bridging courses, and mathematical support centers (Mustoe & Lawson, 2002). Initiatives that work on improving conceptual understanding have been introduced in some engineering courses at the University of Tampere. In this institution, they have used languaging exercises as a tool for improving students' understanding of concepts (e.g., Rundgrén et al., 2016). This strategy showed favorable results not only for improving students' understanding but for promoting learning and improving the students' grades.

As in other countries, in Costa Rica, the knowledge gap between high school and university mathematics is a significant problem. This situation led the University of Costa Rica to introduce, in 2015, a mandatory precalculus course for students in non-mathematics majors with severe mathematical deficiencies. However, the course has had a pass rate of only 40% (Blanco, 2019). A significant problem with the math courses for engineering students has been that the teaching methods and objectives of the course are not focused on improving students' conceptual understanding but on reinforcing the mechanical solution of equations such as limits, derivatives, and integrals. According to the course syllabus, the approach is not formal, focused on proofs, but is instead focused on applications and practicing calculation techniques

(University of Costa Rica, 2019). Classes consist mainly of lectures in which the teacher explains the concepts and solves examples. The role of the student is more of a receiver and less of a participant.

The present research aims to improve university mathematics teaching at the University of Costa Rica through the use of languaging exercises in classes. The exercises integrate the use of natural, symbolic, and pictorial language and aim to improve students' mathematical understanding, mathematical communication, and justification skills, as well as help students to be aware of their mathematical thinking. This proposal intends to move from the traditional teaching method commonly used in the university's calculus courses towards an alternative in which students participate in their learning process. In the same way, it aligns with the need for initiatives that deal with the difficulties in the transition from high school to university mathematics, addressing the abstract character of the mathematical concepts and the complexity of the mathematical thinking (Biza et al., 2016).

2 Theoretical framework

2.1 Mathematical proficiency

In the field of mathematical education, how mathematics learning is conceived of has changed over the years. According to Boesen (2014), these changes have focused on highlighting that *knowing* mathematics implies more than knowing how to perform procedures; it is about *doing* mathematics from a broader perspective. The model of mathematical proficiency (Kilpatrick et al., 2001) aligns with this perspective and provides an outline for the competencies needed to achieve mathematical understanding.

Kilpatrick et al. (2001) consider five main competencies that are necessary for learning mathematics: conceptual understanding, procedural fluency, adaptive reasoning, strategic competence, and productive disposition. This model intends for students to learn with understanding, since "learning with understanding is more powerful than simply memorizing because the organization improves retention, promotes fluency and facilitates learning related material" (Kilpatrick et al., 2001, p. 118). For the authors, deep understanding requires the connection of individual pieces of knowledge. They emphasize that their five main competencies are intertwined; in other words, each depends on the others to fully develop and be useful for solving mathematical problems. Consequently, each competency should receive the same importance in the educational context. Table 1 shows the skills of each competence that are important at the university level, and for the interests of this research.

Table 1. Specific skills for each competence

Conceptual Understanding	- Understand why a mathematical idea is important - Understand when and where an idea is useful - Understand, identify, and verbalize connections between concepts - Remember and reconstruct methods - Monitor students' work - Represent mathematical situations in different ways - Explain why some facts are a consequence of others - Understand and use mathematical concepts in various contexts properly
Procedural Fluency	- Know when and how to use procedures appropriately, flexibly, accurately, and efficiently - Performing mental methods - Mechanical counting, solving procedures, simplifying
Strategic Competence	- Know a variety of solution strategies - Select strategies for solving problems - Formulate problems - Know different representations of problems and select the most useful - Flexibility of approach, solve novel situations
Adaptive Reasoning	- Knowledge of how to justify conclusions - Give informal explanations and justifications
Productive Disposition	- Students' beliefs about the importance and utility of learning mathematics

Source: Based on Kilpatrick et al. (2001).

This model has been used before in research related to improving students' understanding of mathematics at the university level (e.g., Silius et al., 2011; Joutsenlahti et al., 2016). Working on the development of these competencies could increase the chances of learning with understanding, which would be beneficial for students in terms of advancing in their studies successfully.

2.2 Languaging for expressing mathematical thinking

Language has been proved to play a significant role in teaching and learning mathematics. From a social-semiotic point of view, it is not only a powerful tool for communication and representation but also for thinking and meaning-making (Schleppegrell, 2010). According to Prediger and Wessel (2013), the construction of new mathematical concepts requires the acquisition of new means for expressing them. It is in this sense that Joutsenlahti and Kulju (2017) present languaging as a multimodal approach for developing students' meaning-making processes in mathematics.

Languaging is defined as the student's expression of their mathematical thinking across different modes. Seen in terms of languaging, mathematical thinking is "an information process monitored by one's metacognition" (Joutsenlahti & Kulju, 2017, p. 3). The expression of the students' mathematical thinking is observed through oral or written languaging exercises, involving three languages: mathematical symbolic (SL), natural (NL), and pictorial (PL) (see Figure 1). The combination of different languages promotes the construction of connections and aims to support the student's meaning-making process (Joutsenlahti et al., 2016), since they access three different meaning potentials (i.e., SL, NL, and PL) to construct mathematical reality. Each language shows specific properties and connotations of the mathematical concepts (O'Halloran, 2015).

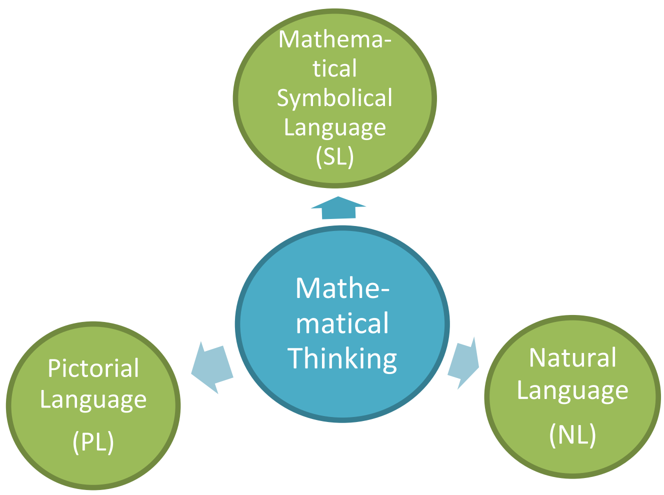


Figure 1. Languages used for expressing mathematical thinking.
Adapted from Joutsenlahti & Kulju (2017).

Moreover, the literature suggests that, through writing, students try to express their thinking process clearly and concretely so that readers can understand (Morgan, 2002). Students must sort out their thoughts and review and clarify their mental processes to explain them to others orally or in writing. This practice will improve their understanding of mathematical concepts (Kline & Ishii, 2008; Silius et al., 2011). Having the answers written and explained in the students' own words helps teachers to follow the mathematical thinking of students, and it is also useful for students to understand the solution processes afterward (Morgan, 2002; Silius et al., 2011).

At this point, it would be valuable to clarify the link between languaging theory and the mathematical-proficiency model. On the one hand, the use of NL and students' own words relate to adaptive-reasoning skills when giving explanations and justifications, as well as to conceptual understanding when verbalizing connections between concepts. On the other hand, SL and the PL are present in strategic competency when knowing and selecting different solution strategies, in procedural fluency when solving procedures accurately and efficiently, and in conceptual understanding when representing mathematical situations in different ways.

In this article, we use languaging theory to address the study of derivatives in a calculus course. Derivatives are essential content for non-mathematics majors in any basic calculus course because of their many applications in fields such as economics, engineering, and biology. Derivatives can be represented in different ways according to the interpretation given to them. For example, it can be understood geometrically with pictorial representation as the slope of the line tangent to a curve at a given point, an interpretation that will be strictly linked to the algebraic-symbolic representation of the equation of a line (Kaplan et al., 2015). A complete understanding of derivatives concept requires understanding each of its interpretations and representations, including the connections between them.

Considering the multi-representational characteristics of the concept of derivatives, languaging theory offers an appropriate way to approach its study.

2.3 The study of derivatives: The Costa Rican context

In Costa Rica, the topic of derivatives is not included in the mathematics curriculum in high school, although it might be studied in some private high schools, scientific high schools, or special optional programs in advanced mathematics that public universities offer in secondary school. Therefore, when students get to university and take their first mathematics courses, they have no or only a little knowledge about derivatives and their applications. At the University of Costa Rica, this topic is covered for engineering majors in the Calculus I course, after the study of limits. The course contents include (a) the definition of derivatives as a limit; (b) differentiation rules, relationship between continuity and differentiability; (c) derivatives as the slope of tangent lines; (d) derivatives as rates of change; (e) optimization problems; (f) minimum and maximum; and (g) graphing. However, all these topics are studied from a procedural point of view; that is, the focus is on learning and practicing calculation techniques (Universidad de Costa Rica, 2019). Some content, such as optimization problems, requires problem-solving skills, but the emphasis is still on the calculations. Consequently, students are trained in procedural fluency but do not develop the rest of the mathematical-proficiency model skills.

Considering the evidence presented above, in this study, we aim to answer the following research questions:

1. How are mathematical-proficiency features shown in answers to the languaging exercises?
2. How do answers to the languaging exercises reveal students' mathematical thinking about derivatives?

3 Methodology

3.1 Data collection and analysis

The exercises analyzed in this article are part of the instruments used in one study about students' perspectives on the use of languaging exercises developed in the University of Costa Rica in 2017 (Alfaro, 2018). Initially, 17 languaging exercises covering derivatives were designed and applied in a course for first-year engineering majors in Calculus I at the University of Costa Rica. The exercises were reviewed by the collaborating teachers' previous implementations to ensure consistency of language and context. For this study, we chose four languaging exercises that exemplify the usefulness of this tool in developing mathematical-proficiency skills and reveal the students' mathematical thinking. We analyzed the solutions of 17 engineering majors from the University of Costa Rica. The participants voluntarily agreed to participate and were informed that their performance in the exercises would not affect their course grade and that the data would be treated confidentially.

The collaborating teachers received information about the languaging theory and the desired objective of the exercises. However, they were free to decide when to implement the exercises as they progressed through the program. In the same way, they decided at what point in the class to use the exercises, for example, to introduce the topic, as an example, or as homework. Students did not receive any special language training before solving the exercises other than references to the various representations that teachers used when giving lectures. Therefore, the use of languaging exercises in this study intents to introduce the students to a way of solving exercises where they have to make more connections. They are a methodological tool more than a methodology itself.

From the languaging exercises, we received answers in NL, PL, and SL that led us to a direct qualitative content analysis (Hsieh & Shannon, 2005) based on the mathematical-proficiency model, using the concepts in Table 1 as a guide and with the specific aspects of each strand as described by Kilpatrick et al. (2001). This analysis addresses the first research question. The productive-disposition strand was not considered, as it was difficult to observe through students' written solutions. In order to answer the second research question, we performed a conventional content analysis considering the mathematical contents included in the course syllabus about derivatives.

3.2 Description of the exercises

The following is a description of Languaging Exercises 3, 14, 16, and 17: Exercise 3, shown in Figure 2, studies three cases in which a function is not differentiable. Each case is represented in the table using a different language. The students' task is to fill in the empty boxes with the representations in the missing languages. This exercise includes knowledge of the definition of derivatives (geometric, analytical), conditions of derivability and continuity, understanding and calculation of limits, and basic notions of graphing functions. The purpose of the exercise is to observe whether students have clarity about the concepts and rules involved so that they can use them with any of the representations given and express them in different ways. This exercise focuses on conceptual understanding and adaptive reasoning, as described in Table 1. Additionally, it supports the use of the three languages suggested by languaging theory.

What are the possible cases in which a function is not derivable?
Give examples of each of them using the three types of languages.

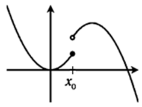
	Mathematical symbolic language: numbers, symbols.	**Natural language: written words.**	**Pictorial language: drawings, graphs, etc.**
I		At points where the curve presents peaks since the lateral derivatives would be different.	
II	$f(x) = \sqrt[3]{x}, in\ x = 0$		
III			

Figure 2. Languaging Exercise 3, from Alfaro (2018).

In Exercise 14, the analytic characteristics of a function are given using mathematical symbolic language (see Figure 3). The information involves intersections with the axes, maximum and minimum points, intervals of monotony and concavity, and details about the behavior of the function in the infinities. The students' task is to explain, in their own words, the graphical implication of each given statement and make a sketch of a graph that meets the given conditions. This exercise is similar to the one used by Baker et al. (2000) in their study, "A calculus graphing schema." As the authors point out, this is a non-routine exercise about graphing, which aims to evaluate if the students can interpret the given characteristics by providing accurate explanations and visualizations of the graphical implications of the features. This exercise promotes adaptive-reasoning skills connected to the use of NL when asking for explanations and justifications and besides it supports strategic competence (see Table 1).

Consider the following information which is fulfilled for a function f

- $f\ is\ continuous$
- $f(-1) = -1,\ f(2) = -1,\ f(-3) = 4, f(0) = 0$
- $f'(-1) = 0, f'(2) = 0$
- $f'(x) = 0\ if\ x < -3$
- $f'(x) < 0\ in\ the\ intervals\ ]-3,-1[\ and\ ]0,2[$
- $f'(x) > 0\ in\ the\ intervals\ ]-1,0[\ and\ ]2,+\infty[$
- $f''(x) > 0\ in\ the\ intervals\ ]-3,0[\ and\ ]0,5[$
- $f'(x) < 0\ in\ the\ intervals\ ]5,+\infty[$
- $\lim_{x\to+\infty} f(x) = 6$

Explain in your own words the graphic implication of each of the above points. Then make an outline of the chart that meets the conditions.

Figure 3. Languaging Exercise 14, from Alfaro (2018).

Exercise 16 is an optimization problem in which students must find the measures that minimize the amount of material needed to build a cylinder, that is, its area, knowing its volume. Students are asked to assume that they have to explain how to solve the problem to one of their classmates and write that explanation in their own words, justifying the statements used and including the symbolic or pictorial elements they consider necessary. However, they do not need to solve the problem, that is, to perform the calculations. This exercise aims to identify if students understand how to solve this type of problem in a way that they can explain to others. While writing, students must revise the mental process they used for solving the problem. In this way, they become aware of the mathematical ideas, the connection between concepts and the strategies involved in the resolution of the optimization problems. In other words, it stimulates adaptive-reasoning skills and the use of NL together with the use of conceptual understanding (see Table 1).

Finally, Exercise 17 concerns the chain rule for deriving composite functions. The exercise shows a composite function and three attempts at solutions by three solvers. Two attempts show the steps of the solution in symbolic language, and the other shows a calculator's result. Students have to decide who got the right answer, determine the errors in the wrong answers, and present the correct solution. The objective of this exercise is to apply students' knowledge of the basic derivation rules, as well as the chain rule for composite functions, to identify the correct answer. The exercise is designed so that the correct answer is the calculators. Therefore, the students must construct the solution for the derivatives. The two incorrect solutions present errors that students frequently commit in this type of exercise, with the intention that, by identifying errors in the work of others, they will not commit them in the future. The skills from Table 1 promoted in this exercise are procedural fluency, conceptual understanding, and adaptive reasoning.

We had $h(x) = g\big(f(x)\big), f(x) = e^x$ and $g(x) = 2x^2 + 1$. Daniel and Josué derivate $h'(x)$ as follows:

Daniel's answer	Josué's answer
$f(x) = e^x$ $g'(x) = 4x$ so $h'(x) = g'\big(f(x)\big) = 4e^x$	$h(x) = g\big(f(x)\big) = 2(e^x)^2 + 1 = 2e^{x^2} + 1$ $h'(x) = 2e^{x^2} \cdot (2x)$ so $h'(x) = 4xe^{x^2}$

María got the answer $4e^{2x}$ in the calculator. Who had the right answer? Find the errors in the wrong answers and present the correct solution.

Source: Finnish Board of Matriculation Examination, Finland, Spring, 2017.

Figure 4. Languaging Exercise 17.

4 Results

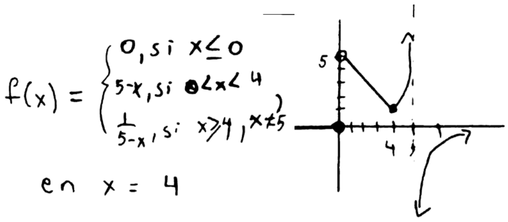
4.1 Evidence of mathematical-proficiency strands in students' answers

By means the model of mathematical proficiency, it was possible to identify various characteristics that relate to the strands in the students' answers: conceptual understanding, procedural fluency, adaptive reasoning, and strategic competence.

Conceptual understanding

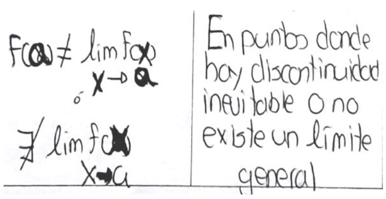
Examples of specific skills of conceptual understanding were present in the students' answers. The dominant skill was the one that makes connections between concepts. This makes sense because the study of derivatives requires students to understand and be able to apply definitions and prior concepts, such as limits and continuity. Students must be able to understand the relationship between those concepts and derivatives. The connections were shown when the students related the symbolic form of a function with its respective graphic representation (Table 2A) by using previous knowledge to make conclusions (Table 2B) and when justifying the choice of strategies (Table 2C).

Table 2. Connections between concepts in students' answers

 (S10, E3)	$f'(x) = 0\ if\ x < -3$ means that "for all numbers less than 3 the function is constant."  (S4, E14)	"Derive the formula of the function of the area to determine the relative maximums or minimums that will solve the problem." (S1, E16)
A	**B**	**C**

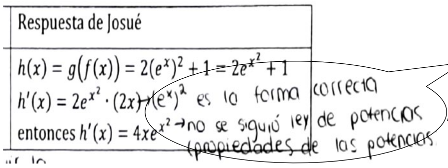
The students also proved to be able to represent mathematical situations in different ways, as seen in Exercise 3's answers, when they used the three languages for representing each case (Table 3A). The competences of understanding why a mathematical idea is important, and when and where to use it, are also shown. For instance, in Table 3B, the student had to recognize that the idea of the relative maximum and minimum gave him more useful information than the fact that the derivative was zero at those points. Likewise, in Table 3C, the student explains why he decided to derivate the area, considering the given problem.

Table 3. Using different representations and understanding why and when mathematical ideas are useful.

 *"At points where there is inevitable discontinuity or there is no general limit."* (S4, E3)	*"The points x = -1 and x = 2 are critical, that is, the graph changes monotony (the slope is zero), it is a peak (a relative max or min)."* (S4, E14)	*"It is necessary to minimize the area of the cylinder, which would be equivalent to the amount of material needed. This area is given by* $A = 2\pi r^2 + 2\pi rh$*."* (S10, E16)
A	**B**	**C**

The ability to monitor their work and the ability to know when and how a procedure is correct are closely related. Students expressed how they used tools such as the sign chart to review their work: "A sign chart of the first derivative is made to see which critical number is the minimum" (S15, E 16). The chart was used in Exercises 14 and 16. Moreover, the solutions also showed that the students were able to identify and name the misapplied rules in Exercises 17: "In the case of Daniel, the error is that he derived a composition of functions without using the chain rule" (S10, E17). They were also able to correct those errors, as shown in Table 4.

Table 4. Knowing when a procedure is correct in a student's answer



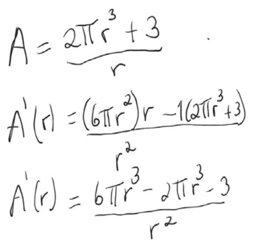
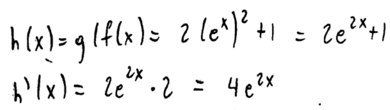
→ $(e^x)^2$ *is the correct way*
→ *The power rule was not followed (power properties)*

(S2, E17)

Procedural fluency

Procedural fluency is perhaps the most-practiced skill in mathematics classes. Many exercises, for example, those concerning limits and derivatives, consist of doing calculations and procedures. However, in the languaging exercises presented in this article, there was no need to repeatedly perform calculations or procedures. Therefore, the procedural fluency ability was reflected in the students' responses as calculations supporting the explanations and solutions (Table 5A) or in their evaluations of procedures developed by others and in showing the correct way to perform a procedure (Table 5B).

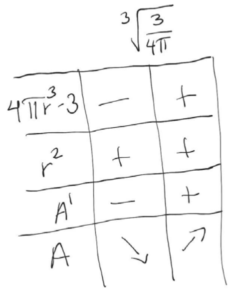
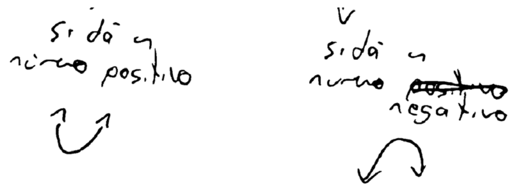
Table 5. Procedural fluency in students' answers

 "5) substitute the data of the auxiliary [equation] and derive the equation 6) obtain the critical numbers and confirm with the sing table." (S14, E16)	 (S10, E17)
A	**B**

Strategic competence

Strategic competence was visible when students used strategies to prove that a point was a maximum or minimum using the first derivative test (Table 6A) or the concavity test (Table 6B). This shows that they know multiple solution strategies and can select the best one or the one they feel most confident using; it means they are flexible about which approach to follow

Table 6. Examples of different solution strategies in the students' answers

"Obtain the critical numbers and confirm with the sign chart. The derivative is useful for finding relative maximum and minimum points".  (S14, E16)	"If we derive once again, the second derivative allows us to analyze whether the function is minimized or maximized depending on what the statement asked for."  "If it is positive" "If it is negative" (S13, E16)
A	B

On a questionnaire given to the students (see Alfaro, 2018 for more details), they said that they were not used to providing explanations and justifications, meaning that those tasks were novel situations for them. Still, they were able to accomplish them, as shown in Table 3C and Table 6B.

Adaptive reasoning

Adaptive reasoning was exemplified in the ability to give informal explanations or justifications. The students provided explanations for the cases in which the function was not differentiable (Table 7A) when they interpreted the characteristics of a function (Table 7B), and in processes, they used to solve the optimization problem (Table 7C). In addition to explaining, the students resorted to theory, using definitions and rules to add validity to their claims (Table 7D).

Table 7. Adaptive reasoning skills in students' answers

A	*"In the points where the derivative tends to $+\infty$since this would mean a perpendicular tangent line, which does not exist."* (S10, Exercise 3)	
B	*f is continuous*	- *"It does not have vertical asymptotes"* (S4) - *"The graph does not have gaps or peaks; it is a continuous function"* (S1) - *"f is continuous if it has no gaps in its graph and there are no numbers that do not have an image"* (S16) - *"Any value that is used will serve to find values"* (S13) - *"Differentiable function"* (S3) (E14)
C	*"Understand that when talking about cylinder dimensions we relate it to the area of this"* (S12, E14)	
D	*"María, Daniel failed to derive f (x) and substitute it in g '(x), on the other hand, Josué lacked to resolve the property of the exponents, when power is raised to another power the exponents multiply"* (S13, Exercise 17)	

In the previous sections, the students' answers to the languaging exercises reveal some of the mathematical-proficiency features described by Kilpatrick et al. (2001). By using skills from the different strands in a variety of tasks, students improve their performance in competencies essential to successful mathematical learning.

4.2 Evidence of students' mathematical thinking about derivatives

To analyze the students' mathematical thinking when solving the exercises, we considered the derivative-related content in the curriculum for Calculus I at the University of Costa Rica. We identify the knowledge about derivatives that students understood and the misconceptions they had about some mathematical concepts.

Students' knowledge about derivatives

There were mathematical concepts that the students understood and explained correctly. For the topic of differentiability, 5 out of 17 students showed that they were able to identify that a derivative does not exist in $f(x) = \sqrt[3]{x}, in\ x = 0$ because the tangent line at that point is vertical: "At the points where the tangent line is vertical so the slope is undefined" (S4, E3). Another five students identified the situation correctly but had some conceptual errors when explaining it. In another case, 16 of 17 participants correctly explained that a reason for the function not being differentiable was the discontinuity, as explained by S10, "at points where the derivative is not continuous, because if it is not continuous it is not derivable" (E3), or in other words, when "the lateral limits do not coincide" (S2, E3). These examples suggest that the students can express, in NL, the cases where a function is not differentiable. Later, we will see that they had some misconceptions regarding the same topic when using SL.

In addition, 9 out of 17 students were able to recognize, in NL and PL, how the derivative affects the shape of a graph. They correctly interpreted six or more of the features given in SL, including the $\lim_{x \to +\infty} f(x)$ and the intervals of monotony and concavity.

On the other hand, students were also successful at interpreting a statement of the optimization problem. They were able to recognize the variables and formulas as well as understanding the aim of the exercise. Fourteen out of seventeen students identified the area as the function to be minimized (see Table 3C) and the volume as the auxiliary equation used to clear a variable and replace it in the original equation so that it is stated in terms of a single variable, as shown in Table 5A.

Finally, the students showed the ability to identify and explain errors in the solution of a derivative that involved the composition of two functions, one exponential and the other quadratic, through a combination of NL and SL. One of the errors was related to the performance of the chain rule. For that, students wrote "$h'(x) \neq g'(f(x))$" (S4, E17) or "Daniel forgot to multiply by $f'(x)$" (S14, E17). Other students (5 out of 17) attributed the error to how the composition of functions had been performed, remarking that first one must compose and then derive. In this way, they showed they were aware of the order of the composition despite it not being the source of the mistake. The other error was about the power rule, and it was also explained in both NL and SL. Answers like "the same base is left, and because it is multiplication, the exponents are added" (S6, E17) or "Josué's error is found in that $(e^x)^2$ is not e^{x^2}, but e^{2x}" (S10,E17) are examples of the ways students explained the error, showing that they recognized the mistake and also knew the way to solve it.

Misconceptions about mathematical concepts

Analyzing the students' answers, we found misconceptions related to the use of symbols, conceptual understanding, and procedure. Regarding the use of symbols, the students' solutions showed a lack of rigor when writing mathematical symbols, for example, omitting "$f(x)$" before the formula of a function or when writing a limit. The lack of rigor could also be found in the items left out of the optimization problem. The students did not consider the domain of the optimization function as necessary and omitted the prove that the point found was effectively a minimum point, as established by the problem. Another aspect left aside by 10 of 17 students was to determine both dimensions (height and radius) as requested in the statement; they only found the value of one variable. This demonstrates that the students did not read carefully or were only solving the problem mechanically.

More profound misconceptions related to the understanding of functions, algebra, derivatives, and continuity are also evident. For instance, in Example A in Table 8, there is an algebraic mistake: Because the second fraction is not defined, the denominator will be zero. The example in Table 8B shows a mistake related to the definition of a function: The expressions $x = x^2$ and $x = -x^2 + 8$ are equations and do not define an association rule of a function. Additionally, the choice of the point $x = x_0$ does not indicate a specific value, so it could be assumed that the discontinuity would be fulfilled in any value that is assigned to x_0. However, for $x = 2$ and $x = -2$, the given piecewise function would be continuous, contradicting what they intended to exemplify. S16 and S2 both gave a function continuous in all its domain as an example of a discontinuous function in Figure 4C. Other misinterpretations were related to considering the possibility of a function with vertical segments, writing "vertical function" (S5, E3), or "the function will be a vertical line" (S17, E3).

Additionally, there were errors such as the direct association of derivatives with the tangent line, where the students use phrases like "the derivative was vertical" (S9) when actually the line was the one that was vertical at the point $x = 0$, not the derivative.

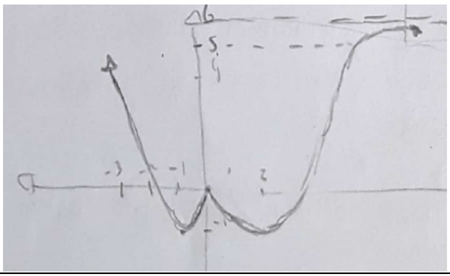
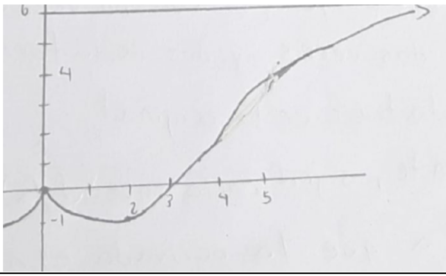
Table 8. Students' mistakes in SL

$h(x)\begin{cases}\frac{x_0}{1}\\ \frac{x^2+3x}{x_0-x_0}\end{cases}$ (S7, E3)	$f(x)\begin{cases}x=x^2, \text{ si } x<x_0\\ x=-x^2+8, \text{ si } x\geq x_0\end{cases}$ en $x=x_0$ (S14, E3)	$f(x)=\begin{cases}x^2, \text{ s. } x_0\leq 0\\ -x^2, \text{ s. } x>0\end{cases}$ (S16 S2, E3)
A	**B**	**C**

On the topic of differentiable functions, there were students who used the contrapositive of the rule "if a function is differentiable, then it is continuous" correctly, using NL in Exercise 3. However, when using or interpreting SL in Exercise 14, they made the false assumption that if the function is continuous, then it is differentiable. They also wrongly assumed that a continuous function does not have peaks, which could be influenced by the previous idea related to differentiability.

There were also misconceptions associated with the false assumption that all the points where the derivative is zero are maximum or minimal points before verifying the change in monotony. For instance, in E14 S16 wrote, "all the numbers less than -3 are minimums because the derivative is zero," and in this case, the interval $]-\infty, -3[$ corresponds to a constant segment. It is interesting how the student could decide that those points were minimums and not maximums when actually the function was constant. This constant section of the graph was also the most challenging feature for the students to draw. Six out of seventeen were not able to represent it correctly, drawing the segment as growing (S14, E14) or ending the sketch in $x = -3$. On the other hand, plotting the concavity changes in the cases where there were no changes of monotony, as, in point $x = 5$ shown in Table 9B, was also difficult for the participants.

Table 9. Students' difficulties in sketching the function (A: S14, B: S10)

	
A	**B**

These examples show that students were not conscious of the consequences of misusing SL, that they had trouble using it for representing functions with specific characteristics, and had difficulty translating this language into NL. Also, they did not differentiate between mathematical objects, such as between a function correspondence rule and an equation or the derivative and the tangent line. They did not consider the basic rules for defining a fraction or connect the expressions in SL to an accurate graphical representation.

5 Discussion

The first university courses in mathematics, such as calculus, represent one of the most significant challenges for students. Learning at the university level requires the students to have conceptual understanding, skills to perform algebraic procedures, the ability to establish connections between concepts, and complex mathematical thinking. Previous studies suggest that representing mathematical concepts in different modes is essential in the meaning-making process (Schleppegrell, 2010). A concept such as the derivative, which can be defined from its analytical form as a limit, geometrically as the slope of the tangent line to a curve, or in physics as the rate of change at which a particle moves (Kaplan et al., 2015), must be studied using different representations.

The analysis of the languaging exercises answers presented in this paper made it possible to observe that the use of NL, PL, and SL favored the practice of four of the skills defined by Kilpatrick et al. (2001) as needed for learning mathematics. Conceptual understanding was the skill with the most features identified in the students' answers, namely, identifying, making, and verbalizing connections between concepts and understanding why a mathematical idea is important and why and where to use it. Procedural fluency was mostly seen supporting explanations given in NL or PL. Providing explanations and justifications in NL were the principal form in which adaptive reasoning was shown. The students needed to provide them in all the exercises despite the fact they were not used to doing so, which in fact relates to the strategic competence skill of solving novel situations.

The results also demonstrated students' thinking about the mathematical concepts involved and revealed some difficulties and misconceptions they made. Considering the strategies that they used to solve the tasks, the use of the variation tables stands out. They were used as an auxiliary resource in Exercise 14 as a summary table of the characteristics of the function for graphing and in Exercise 16 to perform the test of the first derivative. Another resource used by most of the students in Exercise 16 was the auxiliary equation. In this same exercise, most students were able to understand the problem and to identify the respective formulas of area and volume to differentiate. This result differs that of from Klymchuk et al. (2010), who categorized students' difficulties of in this type of problem as difficulties related to understanding the problem and difficulties related to the identification and usage of the formula. A possible explanation for this is that the students at the University of Costa Rica were already familiar with geometric optimization problems.

Regarding the difficulties and misconceptions observed, some were consistent with previous studies, such as an incorrect association of derivatives with the tangent line (Park, 2015), difficulties with the chain rule (Maharaj, 2013), and problems understanding the vertical tangent line and graphing an increasing upside-down function (Baker et al., 2000). Moreover, there were other problems identified, for instance, the lack of rigor with which students wrote mathematical expressions, which caused them to write mathematically ill-defined statements. Furthermore, phrases like “vertical function” indicated conceptual errors related to the definition function. On the other hand, the assertions that continuous functions have no peaks and that all points where the derivative becomes zero are minimal suggest that students were not aware of the conditions necessary to make such conclusions.

The experience of introducing languaging exercises in a calculus course for engineering students aimed to give them the opportunity to participate in the construction of their knowledge, for example, by asking for explanations using their own words. The exercises forced them to think instead of mechanically solving. Furthermore, the discussions and doubts that arose from the exercises provided valuable information about general misconceptions and the way students thought, for the teachers and the students themselves. These are not always possible to obtain when the class only focuses on developing procedural skills. The use of different languages was crucial to promoting the different competences, since each language plays a role in the conceptualization of problems (Schleppegrell, 2010) and the construction of meanings.

The results of this research highlight the importance of using different languages in the study of mathematical concepts. This is because it promotes essential competencies for learning mathematics and is a powerful instrument to observe students’ thinking and identify misconceptions and gaps in their knowledge. Additionally, this study proved that it is possible to use this approach at the university level and in this way, address the problems of transition from school to university mathematics. Due to the small sample used in this study, it is not possible to generalize the results. However, they provide a valuable panorama of how this kind of exercise can be implemented and its utility in understanding and promoting students’ comprehension of mathematical concepts. Further research could be conducted to investigate how or if the use of different languages affects students’ performance in mathematics and study other possible ways of including this kind of exercise in evaluations.

Acknowledgments

We thank the University of Costa Rica for the study grant that supported this research, and all individuals that kindly agreed to collaborate.

References

Alfaro, H. (2018). *Appealing multimodal languages to access first year university students' understanding of mathematical concepts in Costa Rica* [Master's thesis]. Tampere University. http://urn.fi/URN:NBN:fi:uta-201805041636

Artigue, M. (1995). La enseñanza de los principios del Cálculo: problemas epistemológicos, cognitivos y didácticos. In M. Artigue, R. Douady, L. Moreno, & P. Gómez (Eds.), *Ingeniería didáctica en educación matemática* (pp. 97-140). Grupo Editorial Iberoamérica.

Baker, B., Cooley, L., & Trigueros, M. (2000). A calculus graphing schema. *Journal for Research in Mathematics Education*, *31*(5), 557–578. https://doi.org/10.2307/749887

Biza, I., Giraldo, V., Hochmuth, R., Khakbaz, A., & Rasmussen, C. (2016). *Research on teaching and learning mathematics at the tertiary level: State-of-the-art and looking ahead.* Springer. https://doi.org/10.1007/978-3-319-41814-8

Blanco, P. (2019). *La mayoría de estudiantes de primer ingreso reprueban examen de diagnóstico de matemática en la UCR*.Universidad de Costa Rica. https://www.ucr.ac.cr/noticias/2019/04/02/la-mayoria-de-estudiantes-de-primer-ingreso-reprueban-examen-de-diagnostico-de-matematica-en-la-ucr.html

Boesen, J., Helenius, O., Bergqvist, E., Bergqvist, T., Lithner, J., Palm, T., & Palmberg, B. (2014). Developing mathematical competence: From the intended to the enacted curriculum. *Journal of Mathematical Behavior*, *33*(1), 72–87. htps://doi.org/10.1016/j.jmathb.2013.10.001

Engelbrecht, J., & Harding, A. (2015). Interventions to Improve teaching and learning mathematics in first year courses. *International Journal of Mathematical Education in Science and Technology*, *46*(7), 1046–1060. https://doi.org/10.1080/0020739X.2015.1070441

Er, S. N. (2018). Mathematics readiness of first-year college students and missing necessary skills: perspectives of mathematics faculty. *Journal of Further and Higher Education*, *42*(7), 937–952. https://doi.org/10.1080/0309877X.2017.1332354

Fox, G., Campbell, S., Grinshpan, A., Xu, X., Holcomb, J., Bnteau, C., Lewis, J. & Ramachandran, K. (2017). Implementing projects in calculus on a large scale at the University of South Florida. *Journal of STEM Education, 18*(3). https://www.learntechlib.org/p/180987

Goodchild, S., & Rønning, F. (2014). Teaching mathematics at higher education. In H. Silfverberg, T. Kärki, & M. S. Hannula (Eds.), *Proceedings of NORMA14* (pp. 396-400). Finnish Research Association for Subject Didactics.

Gruenwald, N., Klymchuk, S., & Jovanoski, Z. (2004). Reducing the gap between the school and university mathematics: University lecturers' perspective. *The New Zealand Mathematics Magazine*, *41*(3), 12–24. http://hdl.handle.net/10292/8391

Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, *15*(9), 1277–1288. https://doi.org/10.1177/1049732305276687

Hong, Y. Y., Kerr, S., Klymchuk, S., McHardy, J., Murphy, P., Spencer, S., Thomas, M., & Watson, P. (2009). A comparison of teacher and lecturer perspectives on the transition from secondary to tertiary mathematics education. *International Journal of Mathematical Education in Science and Technology*, *40*(7), 877–889. https://doi.org/10.1080/00207390903223754

Hoyles, C., Newman, K., & Noss, R. (2001). Changing patterns of transition from school to university mathematics. *International Journal of Mathematical Education in Science and Technology*, *32*(6), 829–845. https://doi.org/10.1080/00207390110067635

Joutsenlahti, J., Ali-Löytty, S., & Pohjolainen, S. (2016). Developing learning and teaching in engineering mathematics with and without technology. In *Proceedings of the 44th SEFI Annual Conference*.

Joutsenlahti, J., & Kulju, P. (2017). Multimodal languaging as a pedagogical model—A case study of the concept of division in school mathematics. *Education Sciences*, *7*(1), 9. https://doi.org/10.3390/educsci7010009

Kaplan, A., Ozturk, M., & Ocal, M. (2015). Relieving of misconceptions of derivative concept with derive. *International Journal of Research in Education and Science*, *1*(1), 64–74. https://doi.org/10.46328/ijres.v1i1.18

Kempen, L., & Biehler, R. (2014). The quality of argumentations of first-year pre-service teachers. In P. Liljedahl, C. Nicol, S. Oesterle, & D. Allan (Eds.), *Proceedings of the joint meeting of PME38 and PME-NA36*. 3, (pp. 425–432). PME.

Kilpatrick, J., Swafford, J., & Findell, B. (2001). *Adding it up: Helping children learn mathematics*. National Academy Press.

Kline, S. L., & Ishii, D. K. (2008). Procedural explanations in mathematics writing: a framework for understanding college students' effective communication practices. *Written Communication*, *25*(4), 441–461. https://doi.org/10.1177/0741088308322343

Klymchuk, S., Zverkova, T., Gruenwald, N., & Sauerbier, G. (2010). University students' difficulties in solving application problems in calculus: student perspectives. Mathematics Education Research Journal, 22(2), 81–91. https://doi.org/10.1007/BF03217567

Luk, H. S. (2005). The gap between secondary school and university mathematics. *International Journal of Mathematical Education in Science and Technology*, *36*(2-3), 161–174. https://doi.org/10.1080/00207390412331316988

Maharaj, A. (2013). An APOS analysis of natural science students' understanding of derivatives. *South African Journal of Education*, *33*(1), 1–19. https://doi.org/10.15700/saje.v33n1a458

Morgan, C. (2002). The place of pupil writing in learning, teaching and assessing mathematics. In P. Gates, *Issues in mathematics teaching* (pp. 232-244). Routledge.

Mustoe, L., & Lawson, D. (2002). Mathematics for the European engineer. A *Curriculum for the twenty-first century*. SEFI.

Nardi, E. (1996). *The novice mathematician's encounter with mathematical abstraction: tensions in concept-image construction and formalization* [Ph.D. thesis, University of Oxford].

O'Halloran, K. L. (2015). The language of learning mathematics: A multimodal perspective. *The Journal of Mathematical Behavior*, *40*, 63–74. https://doi.org/10.1016/j.jmathb.2014.09.002

Park, J. (2015). Is the derivative a function? If so, how do we teach it? *Educational Studies in Mathematics*, *89*(2), 233–250. https://doi.org/10.1007/s10649-015-9601-7

Prediger, S., & Wessel, L. (2013). Fostering German-language learners' constructions of meanings for fractions—Design and effects of a language-and mathematics-integrated intervention. *Mathematics Education Research Journal*, *25*(3), 435–456. https://doi.org/10.1007/s13394-013-0079-2

Rundgrén, A.; Joutsenlahti, J., & Mäkinen, J. (2016) Is languaging experienced to improve understanding of structural mechanics? In *Proceedings of the 44th SEFI Annual Conference* (12-15).

Schleppegrell, M. J. (2010). Language in mathematics teaching and learning: A research review. In J. N. Moschkovich (Ed.), *Language and mathematics education: Multiple perspectives and directions for research* (pp. 73-112). Information Age Pub.

Silius, K., Pohjolainen, S., Kangas, J., Miilumäki, T., & Joutsenlahti, J. (2011). What can be done to bridge the competency gap between upper-secondary school and university mathematics?

In *2011 IEEE Global Engineering Education Conference EDUCON* (pp. 428-436). IEEE. https://doi.org/10.1109/EDUCON.2011.5773172

Universidad de Costa Rica, (2019) MA1001: Cálculo 1[Course syllabus]. www.emate.ucr.ac.cr

Varsavsky, C. (2010). Chances of success in and engagement with mathematics for students who enter university with a weak mathematics background. *International Journal of Mathematical Education in Science and Technology*, *41*(8), 1037–1049. https://doi.org/10.1080/0020739X.2010.493238

Winsløw, C., Gueudet, G., Hochmuth, R., & Nardi, E. (2018). Research on university mathematics education. In T.Dreyfus, M. Artigue, D. Potari, S. Prediger, & K. Ruthven (Eds.), *Developing research in mathematics education* (pp. 82-96). Routledge.

University mathematics students' study habits and use of learning materials

Timo Tossavainen[1], Janne Gröhn[2], Lasse Heikkinen[3], Anna Kaasinen[3] and Antti Viholainen[2]

[1] Department of Arts, Communication and Education, Lulea University of Technology, Sweden
[2] Department of Physics and Mathematics, University of Eastern Finland
[3] Department of Applied Physics, University of Eastern Finland

In this article, we report from a group (*N*=98) of students from two campuses of one Finnish university, on their study habits, and to what extent they use different kinds of learning materials in university mathematics courses. Our results show that the older students are more communicative with their teachers, whereas the younger students ask for help more often from fellow students. The sociomathematical norms that constitute the local study culture have a significant impact on the study habits and on the use of learning materials. For example, the use of videos and studying lecture materials before the lectures were clearly more usual at one campus than at the other. We also found some significant differences between the groups that are based on the study programmes. The students of mathematics without an intention to become a teacher were most traditional in their study habits, whereas the students of applied physics were most active to participate in teaching. The student teachers most often lie in the middle in the issues where the other groups differ from one another. Quite unexpectedly, students' previous performance in upper secondary school does not explain the differences in the study habits in the university.

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 252–270

Received 27 March 2020
Accepted 30 September 2020
Published 5 October 2020

Pages: 19
References: 26

Correspondence:
timo.tossavainen@ltu.se

https://doi.org/10.31129/LUMAT.8.1.1317

Keywords: learning material, mathematics, student, university

1 Introduction

The Finnish universities that offer courses and programmes in mathematics are facing a new kind of challenge in 2019–2020, as they for the first time meet a whole student generation that, in upper secondary school, has continuously studied mathematics in a digital learning environment and taken the national matriculation exam in such a milieu instead of using paper and pen. This raises the question: what kind of methods and media we should use for delivering mathematical knowledge to these students in university mathematics courses.

This article aims at providing some facts for this discussion by investigating mathematics students' study habits at one Finnish university and, especially, how actively students use various learning materials available to them. Further, we survey how variation in these issues relates to variation in the students' previous study

Published by the University of Helsinki, Finland / LUMA Centre Finland | CC BY 4.0

performance. In Finland, the grades in the national matriculation exams are generally assumed to summarise the performance in upper secondary school well. Hence, they play a fundamental role in admission to university; a good overview of Finnish upper secondary education, the matriculation examination, and how they are related to admission to university is given by Kupiainen, Marjanen, and Hautamäki (2016). We also explore whether one can notice some differences in the study habits and use of learning materials between different student generations.

There are obviously many factors that influence students' study habits and use of learning materials. For example, self-efficacy in mathematics and views of the nature of mathematics is related to the general motivation and performance in mathematics (e.g., Stevens, Olivárez, Lan, & Tallent-Runnels, 2004; Tossavainen, Rensaa, & Johansson, 2019) which in turn affect how actively students participate in teaching and use learning materials. On the other hand, individuals' motivation and self-efficacy in mathematics vary quite a lot during the years (e.g., Tossavainen & Juvonen, 2015). Yet there are longitudinal studies showing that students' performance at the end of upper secondary school can be quite well predicted from their achievement in the earlier years, cf. Metsämuuronen (2017). Moreover, parents' educational background also plays a significant role here and the effect is seen already in primary and lower secondary school (ibid.). In other words, there are also more permanent elements in a student's educational history that have a significant impact on his/her study habits and thereby on the achievement.

Sociomathematical norms (Yackel & Cobb, 1996) have a dynamic impact on students' activities in the teaching and learning of mathematics. It has been reported that these norms and their effects may vary even between single courses at the same institution (e.g. Roy, Tobias, Safi, & Dixon, 2014). One reason for that is that the norms in the classroom are formed and develop in interaction with a teacher and students, and teachers of a different kind steer this process in different directions.

Further, a student's personal properties such as sociality also play a significant role when it comes to study habits and, e.g., using social platforms for searching for mathematical knowledge.

The present study is a part of a larger investigation on the university mathematics students' study habits. In this article, we focus on the effects that are related to a student's educational background, study programme, and the differences between the sociomathematical norms on the involved campuses. Further, we divide the respondents into two groups (which we call the younger and older students) according to that whether they have taken the national matriculation exam in mathematics under the most recent national core curriculum or not. The new core curriculum was implemented in August 2016 and it necessitates the use of digital learning environments also in mathematics. Our specific research questions are as follows.

1. How do the national matriculation exam grades in mathematics and mother tongue explain the variation in the respondents' study habits and use of learning materials in university?
2. Do the older and younger university students differ from one another with respect to their study habits or use of learning materials?
3. How do the students of different programmes or campuses differ from one another as users of learning materials and in their study habits?

The first question may look somewhat strange at first sight as we do not try to explain students' performance with the aid of study habits or use of learning materials, but we do in the opposite way. A motivation for this is as follows. As we already mentioned, in Finland, the grades in the national matriculation exams in mathematics and mother tongue are used as central indicators of the expected success in academic studies at the admission to higher education (Kupiainen, Marjanen, & Hautamäki, 2016; Kupiainen, 2017). Therefore, we want to survey to what extent these grades are really related to the variation in study habits in university. An implicit hypothesis here is that, for example, versatile use of learning materials and social study habits are beneficial and productive for studying mathematics in university, cf. Holzinger, Kickmeier-Rust, & Albert (2008) and Blasco-Arcas, Buil, Hernández-Ortega, & Sese (2013).

In order to answer the third question, we make a comparison of three groups: 1) the student teachers, 2) the students of pure or applied mathematics, and 3) the students of applied physics with mathematics as a minor subject. The first and second groups study at one campus, the third group at the other. For further information, see the method section.

The overview of students' study habits and use of learning materials will be contained in answer to the last question.

2 Theoretical framework

In this study, we consider the participants' expressed study habits in the framework of sociomathematical norms. Yackel and Cobb (1996, p. 460) build their theory on the well-known fact that a mathematical learning process bases both on an active individual construction of knowledge and on acculturation into the mathematical practices of some society such as a classroom, a group of mathematicians working on the same field etc. The aim of this theory is to provide tools for discussing teachers' and students' activity in learning situations. The fundamental idea of the theory is that, in distinction to general social norms that sustain classroom microcultures, there also are norms that are specific to the mathematical activities. A concrete example of this is the common phenomenon that students who are active and social in science or language classes may turn passive and antisocial in the mathematics classroom since they do not find an appropriate way to express their mathematical thinking or to communicate with a teacher.

Originally, Yackel and Cobb concentrated on analysing mathematical discussions – for example, explanation, justification, and argumentation – but the sociomathematical norms also guide learners' other mathematical activities such as participation in small-group interactions (Yackel, Cobb, & Wood, 1991). An example of the sociomathematical norm is the one that instructs a student when and how it is suitable for him/her to contribute to a discussion during the lecture. These norms are not solely defined by a teacher; the notion of mathematical difference is used to illustrate that the sociomathematical norms are interactively constituted more or less by all participants.

As our research questions show, we do not study any cognitive processes related to study habits or using learning materials but focus only on relative frequencies between various habits and material types and on finding variables that may explain the observed variation in these frequencies. In other words, we do not study any latent variables related to study habits or learning materials. However, we recall shortly the fact that the notion of learning material is far from being trivial. The following two examples demonstrate that there are several schools or traditions defining what learning materials, and especially, digital learning materials are exactly.

Lewis (2019) writes about teaching and learning materials: "the term refers to a spectrum of educational materials that teachers use in the classroom to support specific learning objectives, as set out in lesson plans", whereas for Nokelainen (2006, p. 179), learning material can be any material that is designed for educational purposes. When digital learning materials are concerned, he adds a requirement that the material is published in a digital form and intended to be accessed by a computer. A significant difference between these traditions is the following. The former definition focuses on the teacher perspective and is contextualised to a (physical or virtual) classroom. Moreover, it also assumes that a specific learning object has been determined in advance by the authors of the material. The latter definition also speaks about the educational purposes but leaves the learning objects and the principal user unspecified. Moreover, the use of such material is not restricted to any place or time, only accessibility by a computer is required from a digital learning material. A common feature in these definitions is that the format and the platform of learning materials can be diverse. Nowadays, the same applies also to the hardware, many students prefer a mobile phone or a tablet instead of a computer.

In this study, we base on the latter definition and accept, for example, any social media as a learning material (or a platform for accessing relevant mathematical knowledge) if a student him-/herself has considered it relevant. For a wider discussion about digital curriculum materials, i.e., the organised systems of digital resources in electronic formats that articulate a scope and sequence of curricular content, we refer to Pepin, Choppin, Ruthven and Sinclair (2017).

3 Previous research

Study habits are a traditional topic for research in mathematics education. In addition to international surveys such as PISA and TIMSS – where the study habits are considered most often as explanatory factors for learning results – in the 2000s, this tradition however seems to have been most actively cultivated outside Europe and in Africa especially. In Africa, for example, Akinsola, Tella, and Tella (2007) have studied how students' achievement in university mathematics depends on their skills to manage time in studying. Not surprisingly, procrastination in studies weakens the achievement.

On the other hand, the rise of ICT in mathematics education has made study habits a more actual topic for educational research also in western countries. For example, the importance of being able to self-regulate one's learning strategies becomes even greater when studying becomes more independent of time and space in digital learning environments. Broadbent's and Poon's (2015) systematic review of the topic shows that time management, metacognition, effort regulation, and critical thinking skills all are important factors in predicting achievement in online higher education learning environments. The identification of the significant indicators and predictors of achievement using the learning management data from digital learning environments is indeed a hot topic for the system developers. For example, You (2016) reports on the measures of self-regulated learning that are significant to achievement. Most often, such measures are time-based, yet the achievement can be predicted better by focusing on studying qualitatively what activities a learner focuses on in a learning environment.

PISA and TIMSS also explore the use of learning materials in mathematics education in secondary school. In short, printed textbooks are still most often used materials in the Finnish secondary mathematics education, and they are used regularly. However, textbooks are not used up to their full potential. Lepik, Grevholm and Viholainen (2015) and Viholainen, Partanen, Piiroinen, Asikainen and Hirvonen (2015) have reported from a survey of mathematics teachers' self-reported practices of textbook use in upper secondary schools in Finland, Estonia, and Norway. The authors of the former, large-scale study summarise their findings concerning Finland by saying that textbooks are a crucial resource for exercises, but about 45 % of the Finnish teachers use them merely as a source of exercises. There are also studies showing that both the character of a teacher – e.g., the work experience, age, beliefs, etc. – and the character of the learning materials influence how a teacher interacts with the material (e.g. Remillard & Bryans, 2004). A consequence is that many students do not get guidance for using textbooks as multifaceted learning resources. On the other hand, it is well-known that many mathematics teachers prepare themselves material that they use versatilely instead of printed books. Anyway, the latter study shows that mathematics teachers themselves may use the printed textbooks extensively in planning and conducting their teaching, but from the students' perspective, these are first and foremost a source of exercises.

To sum up, our literature review indicates that mathematics students' and teachers' intentions and views of the use of learning material may be more different from one another than one might expect. It is not at all evident that all students have learnt to make good use of learning resources in mathematics by the end of secondary education.

4 Method

4.1 Questionnaire and data collection

The collection of data was conducted using a questionnaire which was originally designed by two authors. The design was based on the theoretical framework and the questionnaire used in the previous study by Tossavainen, Rensaa, and Johansson (2019). All authors analysed and revised the first and following versions of the questionnaire before the final version was completed.

In addition to a section surveying a respondent's educational background, the questionnaire contains three sets of five-point Likert scales related to study habits, the use of different learning materials and knowledge sources, and the respondent's views of the nature of mathematics and him-/herself as a learner of mathematics. The last set is excluded from this study because it will be used in another study. The English translations of the items in the other two sets and the coding of the Likert scales are given in the Appendix.

Data for this study were collected during an ordinary lecture on three courses, without giving any information about the study in advance, at two campuses of one Finnish university. The courses are intended to be taken in the first and third year. The students participated on a voluntary basis, and the data contains almost all students from the involved courses. The participants (N=98) are 1) student teachers (i.e., subject teachers or primary school teachers with 60 ETCS minor studies in mathematics), 2) the students of mathematics without intention to become a teacher, 3) the students of applied physics with 39–60 ETCS minor studies in mathematics, or 4) the students of other subjects. The number of students in the lastly mentioned group is eight, and they are excluded from the analyses that concern the third research question (due to the small group size). All participants are Finnish.

The university courses related to this study are traditional lecture courses or flipped classroom courses. The traditional lecture courses consist of classroom lectures and practicals. In practicals, correct solutions to homework exercises are looked through in a teacher-led whole class discussion. There is also an improved approach to practicals in use, where students first have a small group discussion about the exercises they have solved, and then the solutions are revised in a teacher-led whole class discussion. Learning material in traditional lecture courses depends on the subject and the teacher, including for example lecture slides, lecture notes, a course book and exercises. In the flipped classroom approach, classroom lectures are replaced with pre-material, typically online videos, which students study individually. After studying the pre-material, students attend face-to-face meetings that are devoted to student-centered learning activities allowing students to utilize the expertise of the teacher in their learning process. Furthermore, the implementation of practicals in flipped classroom courses is like the traditional lecture course case. The principal learning material in flipped classroom courses is comprises of videos, slides and notes written by the teacher, a course book, and exercises. For information on the flipped classroom approach in physics, we refer to Saarelainen and Heikkinen (2013) and Mäkitalo-Siegl, Kankaanpää, Heikkinen, and Saarelainen (2016).

4.2. Analyses

The data were analysed using SPSS 25 software. The analyses are based on, e.g., the use of Student's t-tests, One-way ANOVA, Spearman correlations, the effect sizes (Cohen's d) and the computation of the usual descriptive statistics. For the limit values of the effect sizes, we refer to Sawilowsky (2009).

4.3 Limitations

In this research, we have concentrated on studying how much students use different kinds of learning materials in university mathematics courses. Considering also in what ways students use the material would enable us to study, for example, student achievement in relation to learning materials. Further, it is plausible that the way how teachers themselves use learning materials in these courses also affects the students' use of learning materials, cf. Remillard & Bryans (2004). In our questionnaire, this effect was not separately measured but imbedded in the sociomathematical norms.

The questionnaire was conducted among groups of students whose learning environments differ in some key aspects. A concrete example of this is that the flipped learning methodology is more widely used at one of the campuses. In other words, at this campus, students get more support for taking video-based learning materials in use. Again, the role of this kind of support was not measured separately but taken into account as a part of the sociomathematical norms.

Finally, we also point out that the research data were collected during classroom lectures. Therefore, students who prefer to study without attending lectures probably are underrepresented in our data.

5 Results

Before answering our first research question, we recall that the Likert scales surveying students' study habits and use of learning materials are given in the Appendix. The number of items surveying the study habits is fifteen and eleven items focus on the use of learning materials. Further, to show that there is enough variation in the grades for conducting meaningful correlation analyses, we record the distributions of the respondents' grades in the national matriculation exams in Table 1. For the readers, who do not know the assessment scale of these exams, we refer to Ylioppilastutkinto (2020).

Table 1. Distributions of the respondents' grades in the matriculation exams

Grade	Mathematics (*N*=97)	Mother tongue (*N*=96)
I	0	1
A	0	4
B	2	11
C	17	18
M	33	30
E	31	19
L	14	13

In light of the above facts, the results from the Spearman correlation analysis may be considered quite surprising: only one item (1.15) related to study habits correlates with the grade in the mathematics matriculation exam ($\rho = 0.22, p < 0.05$) and none of them with the grade in the mother tongue matriculation exam. Further, none of the items related to the use of learning materials correlates with the grade in mathematics, but three items (2.6, 2.7, and 2.10) correlate with the grade in mother tongue. The correlation coefficients are $\rho = -0.25, p < 0.05$; $\rho = -0.21, p < 0.05$; and $\rho = -0.21, p < 0.05$, respectively.

In other words, the higher grade in the mathematics matriculation exam is related only to higher interest in mathematical hobbies also in one's spare time. The negative correlations between the grade in mother tongue and Items 2.6, 2.7, and 2.10 means that the students with a higher grade use both printed and electronical textbooks somewhat less than students with a lower grade. We discuss these findings and why they are surprising more thoroughly in Section 6.

Our second research question examines the effect of the national core curricula. Here we have divided the participants into two groups according to the year of their exam. There is a natural choice for the cut point because the new national curricula for upper secondary schools were implemented in 2016. Consequently, those who have taken their exam 2017 or later have also studied mathematics in upper secondary school under the curriculum that assumes the use of digital learning environments in mathematics.

Table 2 shows only those items where the mean difference is significant with $p < 0.05$ in the Student's independent samples t-test. The items where the mean difference is significant at the level $p < 0.01$ are denoted with the asterisk (*). The students in Group Y ("the younger") have taken the exam in 2017–2019, the students in Group O ("the older") in 2001–2016. Note also that the number of the respondents varies slightly across the items; the intervals are shown in the table.

Table 2. The significant differences in study habits and in the use of learning materials between the younger and older students

Item	**Group Y** (*N*=54–55)		**Group O** (*N*=37–40)	
	Mean	Std. dev.	Mean	Std. dev.
1.6	2.11	1.03	2.58	1.11
1.7*	4.11	0.96	3.48	1.04
1.10	3.52	1.36	4.10	1.03
1.12	2.85	1.25	3.48	0.99
1.13	4.00	1.12	3.49	0.96
2.5*	1.55	1.03	2.54	1.55
2.6	1.54	1.08	2.05	1.40
2.7*	1.37	1.00	2.05	1.28

* = $p < .01$

Table 2 reveals some interesting differences in study habits between the younger and the older students: the older are braver to ask the lecturer (1.6) whereas the younger more often turn to their fellow students (1.7) when they need help with understanding the content of a lecture. Further, the older are more active to communicate with the teacher of the practicals (1.12) and edit their own solutions during the session (1.10) than the younger who communicate more with the other students in issues related to the practicals (1.13). The differences in Items 2.5–7 also speak for the fact that the older are more independent and self-directed and read more literature. What may be a little less expected is the outcome of 2.7, i.e., that this finding concerns also electronical books and journals. Moreover, it is worth mentioning that the group means are lower in 2.7 than in 2.5–6 (yet the mean differences are not significant at the level $p < 0.05$). In other words, electronical materials are not more popular than printed materials in either group.

Table 3 shows the means and standard deviations of the study habit items in three groups that represent three different study programmes. The items where there are significant mean differences in the Bonferroni post hoc test of One-way ANOVA are indicated with the asterisks. As already said, the first two groups study at the same campus, whereas the third group at the other campus. Therefore, in the comparisons of the last group with other groups, we have no possibilities to separate the effect that is due to the local sociomathematical norms from the effect that is due to the fact that these students study in a different programme. Thus, the effect of the study programme can be studied only between the first two groups who study the same courses. This applies to Table 4, too.

Table 3. The descriptive measures of study habits across the study programmes

Item	Teachers (*N*=39)		Mathematicians (*N*=18)		Physicists (*N*=33)		Total (*N*=94–98)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
1.1	4.67	0.62	4.50	0.79	4.76	0.61	4.66	0.64
1.2**	4.72	0.61	4.39	0.85	4.94	0.24	4.71	0.61
1.3*	4.44	0.72	4.39	0.85	4.81	0.40	4.56	0.68
1.4**	1.79	0.70	1.83	0.86	2.76	1.03	2.14	0.95
1.5	3.31	1.00	3.50	1.15	3.73	0.91	3.50	0.98
1.6	2.18	0.97	2.00	1.09	2.76	1.12	2.35	1.10
1.7	3.82	0.94	3.50	1.20	4.15	0.97	3.86	1.04
1.8	1,36	0.87	1.88	1.41	1.42	0.94	1.52	1.08
1.9	3.05	1.08	3.61	1.20	3.15	0.97	3.21	1.07
1.10	3.74	1.25	3.22	1.56	4.06	1.09	3.75	1.24
1.11	2.37	1.30	2.89	1.61	2.88	1.19	2.70	1.33
1.12**	3.00	1.03	2.56	1.50	3.58	1.03	3.15	1.19
1.13	3.82	1.04	3.39	1.29	4.06	0.96	3.80	1.09
1.14	1.49	1.05	1.78	1.22	1.36	0.93	1.51	1.05
1.15**	1.54	0.68	2.33	1.14	2.09	1.07	1.90	1.02

$* = p < .05$; $** = p < .01$

In Items 1.2 and 1.3, there are statistically significant differences and even the effect size is large between Mathematicians and Physicists in 1.2 ($d = 0.88$), and medium in 1.3 ($d = 0{,}63$). In practice, one must, however, interpret these items so that students in all groups are active to participate in small-group practicals, and they actively do their exercises in advance, yet the students of applied physics are the most active with respect to both issues. From a practical point of view, a more remarkable difference is seen in 1.4. Physicists are clearly more active to study the lecture material before the lecture. Here the effect size between Teachers and Physicists is large, almost very large ($d = 1.10$), and large between Mathematicians and Physicists ($d = 0.95$). Further, there is no difference between Teachers and Mathematicians. We hypothesize that these findings are more due to differences in local study cultures than due to different study programmes.

It is interesting to also review the mean differences between the items. The high means in 1.1–3 indicate that the students in general are active to participate in lectures and practicals. The means in 1.5, 1.9, 1.10 are already somewhat lower, yet in the interval 3–4, which show that the students are quite active also in studying the learning material after lectures and during the practicals. Further, they are quite active to ask for help from the fellow students (1.7 and 1.13) but not as active to ask for help from the lecturer or the small-group teacher (1.6 and 1.12); the respective mean differences in Student's paired samples t-test are significant in both cases (1.7 vs. 1.6: $\mathrm{t}(97) = 11.48$, $p < 0.001$; 1.13 vs. 1.12: $t(93) = 4.58$, $p < 0.001$). In the first pair, the effect size is large, almost very large ($d = 1.16$). The low means but large standard deviations in 1.8 and 1.14 reveal that only a few students seek support for their mathematical studies on the social media.

Table 4 contains three items where the mean differences are statistically significant. Item 2.4 shows that Mathematicians are most active to study the given solutions to exercises in the small group practicals, whereas there is no difference between Teachers and Physicists in this issue. Hence, we can conclude that the difference is mostly due to different study programmes; the students of (pure) mathematics are probably more motivated to study also the alternative solutions given at the practicals and have more mathematical hobbies in their spare time, cf. Items 1.9 and 1.15 in Table 3.

Table 4. The descriptive measures of the use of learning materials across the study programmes

Item	Teachers (*N*=39)		Mathematicians (*N*=18)		Physicists (*N*=33)		Total (*N*=96–98)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev
2.1	4.26	1.07	3.89	1.61	4.61	1.00	4.32	1.20
2.2	4.56	0.88	4.61	0.78	4.76	0.75	4.62	0.82
2.3	4.23	1.01	4.39	0.85	4.30	0.88	4.32	0.90
2.4*	3.56	1.27	4.29	1.05	3.58	1.23	3.75	1.21
2.5*	1.58	1.08	2.00	1.57	2.27	1.49	1.95	1.35
2.6	1.71	1.35	2.00	1.37	1.72	1.11	1.75	1.23
2.7	1.45	1.03	1.56	1.15	1.97	1.33	1.66	1.16
2.8**	3.11	1.43	2.33	1.50	3.79	1.22	3.26	1.45
2.9	2.97	1.33	2.78	1.44	3.09	1.31	2.99	1.30
2.10	2.78	1.40	2.89	1.64	3.48	1.12	3.11	1.35
2.11	1.77	1.22	1.71	1.26	1.64	1.22	1.72	1.23

$* = p < .10$; $** = p < .01$

By Item 2.5, Teachers are less active to use the course literature. Again, one may interpret that this difference is mostly due to different study programmes; the student teachers focus on the material discussed during the lectures; the other students seek also the background knowledge. On the other hand, the means for all groups are rather low in this item and the standard deviations are quite large. The observed mean differences are thus due to a relatively small number of students.

Item 2.8 reveals an interesting difference that seems to be due to both differences in local study cultures and different study programmes: Mathematicians are clearly less active to use videos than other students, whereas physicists are quite active to use them. We discuss this finding in more detail in Section 6.

The comparison of means between the items reveals some interesting differences in the use of learning materials. That all students are active to use their own lecture notes is not surprising, but that the solutions for the exercises are not actively used is. Indeed, the mean difference between Items 2.2 ($\bar{x} = 4.65$) and 2.4 ($\bar{x} = 3.75$) is significant ($t(96) = 6.87$, $p < 0.001$) with almost large effect size ($d = 0.70$). The use of complementary literature is however only rare (2.6–7) except for material to be found on the Internet (2.10). In 2.10, the mean differences are actually quite large but so are also the standard deviations, therefore the mean differences are not significant at level $p < 0.05$. Item 2.11 confirms the finding which we already have mentioned; the social media are not important sources of mathematical knowledge for a majority of students.

6 Discussion and conclusions

In our data, the higher grade in the mathematics matriculation exam is related only to higher interest in mathematical hobbies also in one's spare time, not to any specific study habits. This finding is surprising and, perhaps, of a greater value, from the following perspective. There are studies showing that the grade in mathematics matriculation exam is a strong predictor of achievement in almost any other subject (e.g., Kupiainen, Marjanen, & Hautamäki, 2016). Our finding does not conflict the previous research or challenge the practice related to admission to university but merely suggests that the better achievement is based more on students' personal features and the quality of studying than on the versatility of study habits and used learning materials. As also Tossavainen's and Juvonen's (2015) study shows, the higher intrinsic motivation in mathematics and having an interest in mathematics also outside school are related to one another. Our finding can thus be explained by saying that the correlation between the grade and Item 1.15 is due to a variation in the students' intrinsic motivation in mathematics. An interesting question for future research is, of course, what is the mechanism behind the correlation of the grade in the mathematics matriculation exam and achievement in further studies if the effect of higher grades is not observable in the study habits.

The negative correlations between the grade in mother tongue and Items 2.6, 2.7, and 2.10 is somewhat more difficult to explain since also the grade in mother tongue is a good predictor of achievement in many subjects (Kupiainen, 2017). Our finding was that the students with a higher grade use both printed and electronical textbooks less than students with a lower grade. The effect sizes in the correlations are not large, yet remarkable to some extent. Our interpretation is that linguistically talented students may benefit from the materials distributed by the lecturer and the teacher of the practicals better than those students who are not equally competent in languages. A very recent study by Prat et al. (2020) shows that students with good ability to learn languages are also good at learning programming languages. In their study, linguistic competence was even more significant than the mathematical competence.

The differences between the younger and older students that are shown in Table 2 probably have not much to do with the revision of the national core curriculum but are more due to the fact that the older students simply are more advanced in the transition to adulthood. In other words, the older students are more independent and self-directed and, therefore, they also read more literature. They can also meet the lecturer and the teacher of the practicals at a more equal level and hence they are more active to communicate with them when they want to have help with the content of teaching. What may be a little less expected is the outcome of 2.7, i.e., that the older students also use more often electronical books and journals. Once again, the large standard deviations however indicate that this is mostly due to a smaller group of students; many students do not use these sources regardless of their age.

Our answer to the last research question reveals several differences between the student groups. As we have pointed out, our data do not allow us to separate in all cases whether the difference is due to differences in the local sociomathematical norms or that the groups represent different study programmes. An overall view however is that the students of applied physics differ from the other two groups more than the student teachers and the students of (pure) mathematics from one another.

A plausible explanation for the difference between the applied physics students and the other students is the fact that, at the campus where the applied physics students study, cooperative learning plays an important role. The students at the campus are strongly encouraged to work together from the beginning of their studies. For example, they typically solve the exercises in small groups before the practicals, cf. Item 1.3. Furthermore, various measures to support the integration of students into the academic community as early as possible are used, and the students' role as active members of the community is highlighted. Thus, these students actively participate in small group practicals and are used to asking help from the teacher of the practicals which also Items 1.2 and 1.12 show. As already mentioned in Section 4.3, a lot of effort has also been invested in using the flipped classroom approach. Items 1.4 and 2.8 give illustrative evidence for the results of using the flipped classroom approach: the students of applied physics study lecture material in advance and use videos while studying more often than the other students; not only in the flipped classroom courses but also in the traditional lecture courses.

A finding that can be interpreted to demonstrate the other end of sociomathematical norms is related to Items 1.6 and 1.12. The students of (pure) mathematics were least active to communicate with the lecturer and the teacher of the practicals (yet the mean difference is significant at the level $p<0.05$ only in the latter issue). A possible explanation is that these students appreciate individual and self-sufficient working methods more than other students. Whether this is good or bad, we leave this topic open for a further debate. We mention only that we did not find any evidence in our data that these students were less satisfied with their studies in mathematics. For example, although their mean in 1.2 is lower than that of the other groups, they still participate in the practicals actively.

An interesting finding is also that the students in general are not active users of social media when they study mathematics. Perhaps, this tells about the sociomathematical norms at both campuses. Although the use of videos is already encouraged and supported (at least, at one of the campuses), the role of social media is considered less important. One reason for this may be that many university teachers are not used to distribute their materials via social media but as downloads (or videos) at the homepage of the course. A crucial difference between these distribution formats is that, in social media, you are expected to be available at least every now and then, whereas, at the homepage of a course, it is sufficient that the documents are found there.

The most significant result in Table 4 becomes visible as we recall the findings of Lepik, Grevholm, and Viholainen (2015) and Viholainen, Partanen, Piiroinen, Asikainen, and Hirvonen (2015): the transition from upper secondary school mathematics to university mathematics also contains a transition from the heavy use of (printed) text books to studying mostly with the help of lecture notes, handouts and material for and from the practicals. The shift seems to be comprehensive when one compares the means, for example, in Items 2.1 and 2.5 with the results of the above-mentioned articles. For a learner with some kind of dyslexia, this change can be insurmountable in spite of other relevant competences. Indeed, many handouts do not make use of colours, varying font-size or other layout tools for highlighting the central definitions and theorems, giving concrete examples, etc. This topic would clearly deserve more attention.

References

Akinsola, M.K., Tella, A., & Tella, A. (2007). Correlates of academic procrastination and mathematics achievement of university undergraduate students. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(4), 363-370. DOI 10.12973/ejmste/75415

Blasco-Arcas, L., Buil, I., Hernández-Ortega, B., & Sese, F. J. (2013). Using clickers in class. The role of interactivity, active collaborative learning and engagement in learning performance. *Computers & Education, 62*, 102–110. DOI 10.1016/j.compedu.2012.10.019

Broadbent, J. & Poon, W. L. (2015). Self-regulated learning strategies & academic achiement in online higher education learning environments: A systematic review. *The Internet and Higher Education, 27*(October), 1–13. DOI 10.1016/j.iheduc.2015.04.007

Fan, L. Zhu, Y., & Miao, Z. (2013). Textbook research in mathematics education: development status and directions. *ZDM Mathematics Education, 45*, 633-646. DOI 10.1007/s11858-013-0539-x

Holzinger, A., Kickmeier-Rust, M., & Albert, D. (2008). Dynamic Media in Computer Science Education; Content Complexity and Learning Performance: Is Less More? *Educational Technology & Society, 11*(1), 279–290.

Kupiainen, S. (2017). Ylioppilas opiskelijavalintojen pyörteessä. Seminaari opiskelijavalintojen kehittämisestä Haaga-Helia 7.11.2017. Retrieved from https://minedu.fi/documents/1410845/5626566/Sirkku+Kupiainen+Opiskelijavalinta.pdf/03baa728-4f02-4b76-a515-e67a5ecb0139/Sirkku+Kupiainen+Opiskelijavalinta.pdf

Kupiainen, S., Marjanen, J., & Hautamäki, J. (2016). The problem posed by exam choice on the comparability of results in the Finnish matriculation examination. J*ournal for educational research online, 8*(2), 87–106.

Lepik, M., Grevholm, B. & Viholainen, A. (2015). Using textbooks in the mathematics classroom – the teachers' view. *Nordic Studies in Mathematics Education, 20*(3-4), 129–156.

Lewis, B. (2019). TLM: Teaching/Learning Materials. Retrieved from https://www.thoughtco.com/tlm-teaching-learning-materials-2081658

Metsämuuronen, J. (2017). *Oppia ikä kaikki – matemaattinen osaaminen toisen asteen koulutuksen lopussa 2015. Julkaisut 1:2017.* Helsinki, Finland: Kansallinen koulutuksen arviointikeskus.

Mäkitalo-Siegl, K., Kankaanpää, J., Heikkinen, L., & Saarelainen, M. (2016). Higher education students' experiences on flipped classroom in physics. *The European Association for Practitioner Research on Improving Learning (EAPRIL) 2016 conference, Porto, Portugal.*

Nokelainen, P. (2006). An empirical assessment of pedagogical usability criteria for digital learning material with elementary school students. *Journal of Educational Technology & Society, 9*(2), 178–197.

Pepin, B., Choppin, J., Ruthven, K., & Sinclair, N. (2017). Digital curriculum resources in mathematics education: foundations for change. *ZDM Mathematics Education, 49*(5), 645-661. DOI 10.1007/s11858-017-0879-z

Prat, C. S., Madhyastha, T. M., Mottarella, M. J. et al. Relating Natural Language Aptitude to Individual Differences in Learning Programming Languages. *Scientific Reports, 10*, Article 3817. DOI 10.1038/s41598-020-60661-8

Remillard, J. T., & Bryans, M. B. (2004). Teachers' orientations toward mathematics curriculum materials: Implications for teacher learning. J*ournal for Research in Mathematics Education, 35*(5), 352–388. DOI 10.2307/30034820

Roy, G. J., Tobias, J. M., Safi, F. & Dixon, J. K. (2014). Sustaining social and sociomathematical norms with prospective elementary teachers in a mathematics content course. *Investigations in Mathematics Learning, 7*(2), 33–64. DOI 10.1080/24727466.2014.11790341

Saarelainen, M., & Heikkinen, L. (2013) Oppijakeskeisistä opiskelutaidoista eväät fyysikon uralle. *Yliopistopedagogiikka, 20*(1), 11–15.

Sawilowsky, S. S. (2009). New effect size rules of thumb. *Journal of Modern Applied Statistical Methods, 8*(2), 597–599. DOI 10.22237/jmasm/1257035100

Stevens, T., Olivárez, A., Lan, W. Y., & Tallent-Runnels, M. K. (2004). Role of mathematics self-efficacy and motivation in mathematics performance across ethnicity. *Journal of Educational Research, 97*, 208–221. DOI 10.3200/JOER.97.4.208-222

Tossavainen, T., & Juvonen, A. (2015). Finnish primary and secondary students' interest in music and mathematics relating to enjoyment of the subject and perception of the importance and usefulness of the subject. *Research Studies in Music Education, 37*(1), 107–121. DOI 10.1177/1321103X15589259

Tossavainen, T., Rensaa, R. J., & Johansson, M. (2019). Swedish first-year engineering students' view of mathematics, self-efficacy and motivation and their effect on task performance.

International Journal of Mathematical Education in Science and Technology. DOI 10.1080/0020739X.2019.1656827

Viholainen, A., Partanen, M., Piiroinen, J., Asikainen, M. & Hirvonen, P. E. (2015). The role of text-books in Finnish upper secondary school mathematics: theory, examples and exercises. *Nordic Studies in Mathematics Education, 20*(3-4), 157–178.

Yackel, E., & Cobb, P. (1996). Sociomathematical norms, argumentation, and autonomy in mathematics. *Journal for Research in Mathematics Education, 27*, 458–477. DOI 10.2307/749877

Yackel, E., Cobb, P., & Wood, T. (1991). Small-group interactions as a source of learning opportunities in second-grade mathematics. *Journal for Research in Mathematics Education, 22*, 390–408. DOI 10.2307/749187

Ylioppilastutkinto (2020). *Matriculation examination*. Retrieved from https://www.ylioppilastutkinto.fi/en

You, J. W. (2016). Identifying significant indicators using LMS data to predict course achievement in online learning. *The Internet and Higher Education, 29*(April), 23–30. DOI 10.1016/j.iheduc.2015.11.003

Appendix – The study habits and learning material items in the questionnaire

1. How often do you do the following things during a mathematics course?

	1=Never	2=Only when I prepare myself for an exam	3=A couple of times under the course	4=2–4 times a month	5=Once a week or more often
1.1 I participate in the lectures of the course					
1.2. I participate in the small-group practicals					
1.3. I solve exercises before the practicals.					
1.4. I read the lecture material before the lecture.					
1.5. I study the lecture material after the lecture.					
1.6. I ask for help from the lecturer if something about the lecture or the lecture material is unclear to me.					
1.7. I ask for help from my student fellows if something about the lecture or the lecture material is unclear to me.					
1.8. I ask for help from a social media discussion group if something about the lecture or the lecture material is unclear to me.					
1.9. After the practical, I study the correct solution which we were given at the session.					
1.10. I correct and improve my own solution during the practical.					
1.11. I correct and improve my own solution after the practical.					
1.12. I ask for help from the teacher of practical if something about the exercises is unclear to me.					
1.13. I ask for help from my fellow students if something about the exercises is unclear to me.					
1.14. I ask for help from a social media discussion group if something about the exercises is unclear to me.					
1.15. I spend my time on mathematical hobbies also in my spare time (e.g., programming).					

2. How often do you use the following materials or sources while you study mathematics?

	1=Never	2=Only when I prepare myself for an exam	3=A couple of times under the course	4=2–4 times a month	5=Once a week or more often
2.1. My own lecture notes					
2.2. The materials given by the lecturer (e.g., handouts)					
2.3. The course exercises defined by the lecturer					
2.4. The solutions for the exercises					
2.5. The textbooks mentioned in the course curriculum					
2.6. Other printed textbooks					
2.7. Electronical books and journals (excluding course books)					
2.8. Videos made for the course you are studying					
2.9. Other relevant videos in Internet					
2.10. Other relevant digital material in Internet					
2.11. Social media discussion groups					

Flipped classroom: Pedagogical model necessary to improve the participation of the students during the learning process

Ricardo-Adán Salas-Rueda

Instituto de Ciencias Aplicadas y Tecnología, Universidad Nacional Autónoma de México, Mexico

Nowadays, teachers can transform the organization and realization of school activities before, during and after the face-to-face sessions through the flipped classroom. The objective of this mixed research is to analyze the impact of the flipped classroom in the teaching-learning process on statistics considering data science and machine learning (linear regression). The sample consists of 61 students who took the Statistical Instrumentation for Business course during the 2018 school year. This research proposes the consultation of the YouTube videos before the class, performance of the collaborative exercises and use of the spreadsheet to check the results during the class and performance of the laboratory practices through the spreadsheet after the class. The results of machine learning (70%, 80% and 90% of training) indicate that the participation of the students before, during and after the class positively influences the assimilation of knowledge and development of mathematical skills about the frequencies and measures of central tendency. On the other hand, the decision tree technique identifies 6 predictive models on the use of the flipped classroom. Also, the students of the Statistical Instrumentation for Business course are motivated and satisfied to use the technological tools in the Introduction to statistics Unit. Finally, the flipped classroom allows the construction of new educational spaces and creation of creative activities before, during and after the class that favor the participation of the students during the learning process.

Keywords: flipped classroom, technology, higher education, data science, machine learning

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 271–296

Submitted 20 August 2020
Accepted 21 October 2020
Published 28 October 2020

Pages: 26
References: 27

Correspondence:
ricardo.salas@icat.unam.mx

https://doi.org/10.31129/LUMAT.8.1.1394

1 Introduction

The society of the 21st century demands the use of the technological tools in the educational field to improve the learning process (Ignatova, Dagiene, & Kubilinskiene, 2015; Ortiz-Colon, Muñoz-Galiano, & Colmenero-Ruiz, 2017). Therefore, teachers search, select and use new pedagogical models to facilitate the assimilation of knowledge and develop the skills of the students (Deng & Purvis, 2015; Karolcik, Cipkova, Hrusecky, & Veselsky, 2015).

Information and Communication Technologies (ICTs) allow the creation of educational spaces that favor the active participation of the students inside and outside of the classroom (Salas-Rueda, 2020; Shih & Tsai, 2017; Sun, 2017). In fact,

 | CC BY 4.0

the behavior and functions of the students are changing because teachers use the technological tools to organize and perform new school activities at any time and place (Salas-Rueda, Salas-Rueda, & Salas-Rueda, 2020; Sadeck & Cronje, 2017; Uyanga, 2014).

The flipped classroom is a pedagogical model that proposes the realization of the activities inside and outside the classroom (Shih & Tsai, 2017; Sun, 2017). Therefore, the use of ICTs such as audiovisual contents (Lo, Lie, & Hew, 2018), digital presentations (Burke & Fedorek, 2017), web applications (Wang, 2017), technological tools (Shih & Tsai, 2017), social networks (Burke & Fedorek, 2017) and educational platforms (Lo, Lie, & Hew, 2018) has a fundamental role in improving the teaching-learning conditions.

In a flipped classroom, students consult the videos and digital readings at home in order to review the contents of the courses (Burke & Fedorek, 2017; Burgoyne & Eaton, 2018; Chen, Yang, & Hsiao, 2016). Likewise, teachers organize new collaborative activities in order to discuss, reflect and exchange ideas inside and outside the classroom (Chen, 2016; Shih, & Tsai, 2017; Zahrani, 2015).

In particular, this research proposes the consultation of the YouTube videos before the class, performance of the collaborative exercises and use of the spreadsheet to check the results during the class and performance of the laboratory practices through the spreadsheet after the class. Therefore, this mixed research analyzes the use of flipped classroom in the teaching-learning process on statistics considering data science and machine learning (linear regression). The research questions are:

- What is the impact of the flipped classroom in the teaching-learning process on statistics?
- How does the participation of the students before, during and after the class (flipped classroom) influence the assimilation of knowledge and development of mathematical skills about the frequencies and measures of central tendency?
- What are the predictive models about the use of flipped classroom in the teaching-learning process on statistics?
- What are the students' perceptions about the use of the flipped classroom in the teaching-learning process?

2 Flipped classroom

During the 21st century, flipped classroom modifies the role, functions and activities of the teachers and students during the educational process (Shih & Tsai, 2017; Sun, 2017). In fact, this pedagogical model proposes that teachers use class time to organize and realize creative and dynamic activities (Burke & Fedorek, 2017; Ortiz-Colon, Muñoz-Galiano, & Colmenero-Ruiz, 2017).

Flipped classroom promotes the use of ICTs in the educational field to modify the traditional process of teaching and learning (Burgoyne & Eaton, 2018; Ortiz-Colon, Muñoz-Galiano, & Colmenero-Ruiz, 2017). For example, Lo, Lie and Hew (2018) propose the incorporation of the audiovisual contents and online questionnaires in the school activities. The benefits of this pedagogical model are related to the creation of a pleasant atmosphere for learning and flexibility of time and space to carry out the activities (Ortiz-Colon, Muñoz-Galiano, & Colmenero-Ruiz, 2017).

Before the face-to-face sessions, students use the educational platforms, digital resources and multimedia products in order to achieve the autonomous learning (Burke & Fedorek, 2017; Chen, 2016). In the classroom, students and teachers perform active strategies such as discussing, debating and solving problems (Hall & DuFrene, 2015; Sun, 2017). After the class, students review the digital resources and materials of the course at home (Shih & Tsai, 2017).

2.1 Use of flipped classroom in the educational field

Various authors (e.g., Blau & Shamir, 2017; Chen, Wang, Kinshuk, & Chen, 2014; Lo, Lie, & Hew, 2018; Wang, 2017) have used flipped classroom to improve the teaching-learning process. For example, this pedagogical model facilitates the development of mathematical skills (Lo, Lie, & Hew, 2018).

In the field of mathematics, Lo, Lie and Hew (2018) implemented flipped classroom through the consultation of the videos and realization of the online questionnaires before the face-to-face session. Also, the discussion among the participants of the educational process and resolution of the exercises is carried out in the classroom with the purpose of promoting the participation of the students (Lo, Lie, & Hew, 2018).

A flipped classroom allows creating new spaces for learning and teaching (Blau & Shamir, 2017; Wang, 2017). For example, Chen, Wang, Kinshuk and Chen (2014) propose the consultation of the videos and digital readings at home and realization of the online questionnaires and discussion forums in the classroom.

Universities are using a flipped classroom to facilitate the assimilation of knowledge and develop the skills of the students (Blau & Shamir, 2017; Wang, 2017). At the Israel University, the students consult the lectures, digital presentations and videos at home. In the classroom, these students acquire an active role through discussion and collaborative work (Blau & Shamir, 2017).

Teachers use flipped classroom to improve the quality of the educational process and perform creative activities inside and outside the classroom (Liu, 2019). For example, the students of architecture reviewed the videos at home and used various technological applications such as Socrative, Sticky note and PadLet in the classroom (Liu, 2019).

Wang (2017) explains that flipped classroom was used at the Taiwan University to improve the teaching-learning conditions, that is, the students consult the videos and digital files on the Moodle platform before the class, participate in the discussion forums during the class and solve the exams in Moodle after the class.

Finally, the flipped classroom is a pedagogical model that allows updating the school activities (Blau & Shamir, 2017; Wang, 2017), promoting the participation of the students (Burke & Fedorek, 2017; Lo, Lie, & Hew, 2018) and improving the teaching-learning conditions (Shih & Tsai, 2017; Wang, 2017) through the use of the technological tools.

3 Methodology

The objective of this mixed research is to analyze the impact of the flipped classroom in the teaching-learning process on statistics considering data science and machine learning (linear regression).

A flipped classroom allows the creation of new school activities inside and outside the classroom (Craft & Linask, 2020; Morin, Tamberelli, & Buhagiar, 2020). Therefore, the particular objectives of this research are (1) analyze the impact about the participation of the students before the class in the assimilation of knowledge through the consultation of the YouTube videos (2) analyze the impact about the participation of the students before the class in the development of mathematical skills through the consultation of the YouTube videos (3) analyze the impact about the participation of the students during the class in the assimilation of knowledge through the performance of the collaborative exercises and use of the spreadsheet (4) analyze the impact about the participation of the students during the class in the development of mathematical skills through the performance of the collaborative exercises and use of the spreadsheet (5) analyze the impact about the participation of the students after the class in the assimilation of knowledge through the performance of the laboratory practices (6) analyze the impact about the participation of the students after the class in the development of mathematical skills through the performance of the laboratory practices (7) identify the predictive models on the use of flipped classroom during the educational process of statistics and (8) analyze the students' perceptions about the use of flipped classroom.

3.1 Participants

The sample is composed of 61 students of the Statistical Instrumentation for Business course (33 men and 28 women) who completed the second semester of the careers in Administration (n = 9, 14.75%), Accounting (n = 15, 24.59 %), Commerce (n = 19, 31.15%), Computing (n = 2, 3.28%) and Marketing (n = 16, 26.23%) during the 2018 school year. The average age of the participants is 18.81 years.

3.2 Procedure

First, the teacher of the Statistical Instrumentation for Business course identified the technological tools that allow transforming the functions of the students during the Introduction to statistics Unit. In particular, this research proposes the consultation of the YouTube videos before the class, performance of the collaborative exercises and use of the spreadsheet to check the results during the class and performance of the laboratory practices through the spreadsheet after the class. In fact, flipped classroom allowed the organization of 3 sessions about the topics of Frequency, Mean, Standard deviation and Variance (See Table 1).

Table 1. Activities in the Introduction to statistics Unit

No.	Topic	Objective	Before the class	After the class	During the class
1	Frequency	Understand, analyze and apply the concepts of the frequency, relative frequency and percentage frequency	Consult the YouTube videos on the frequency and use of the formulas in the spreadsheet	Solve the exercises on the frequency collaboratively and check the results through the spreadsheet	Perform the laboratory practice on the frequency through the spreadsheet
2	Mean and Standard deviation	Understand, analyze and apply the concepts of the mean and standard deviation for the sample and population	Consult the YouTube videos on the mean, standard deviation and use of the formulas in the spreadsheet	Solve the exercises on the mean and standard deviation collaboratively and check the results through the spreadsheet	Perform the laboratory practice on the mean and standard deviation through the spreadsheet
3	Variance	Understand, analyze and apply the concepts of the variance for the sample and population	Consult the YouTube videos on the variance and use of the formulas in the spreadsheet	Solve the exercises on the variance collaboratively and check the results through the spreadsheet	Perform the laboratory practice on the variance through the spreadsheet

Figure 1 shows the technological acceptance model used to analyze the impact of a flipped classroom during the teaching-learning process.

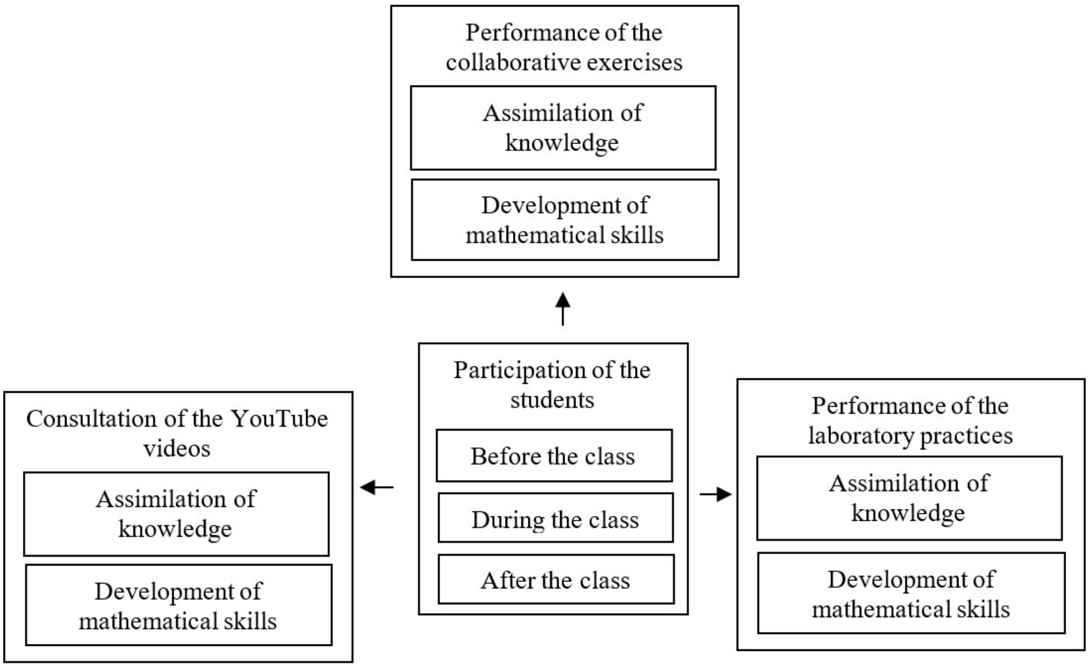


Figure 1. Technological acceptance model.

The review of videos at home facilitates the learning process during the flipped classroom (Krouss & Lesseig, 2020; Turra et al., 2019; Zainuddin & Perera, 2019). Therefore, the research hypotheses related to the activities before the face-to-face session are:

- Hypothesis 1 (H1): The participation of the students before the class positively influences the assimilation of knowledge through the consultation of the YouTube videos
- Hypothesis 2 (H2): The participation of the students before the class positively influences the development of mathematical skills through the consultation of the YouTube videos

The use of ICTs and collaborative work in the classroom improve the teaching-learning conditions during flipped classroom (Chan, Lam, & Ng, 2020; Craft & Linask, 2020; Morin, Tamberelli, & Buhagiar, 2020). Therefore, the research hypotheses related to the activities during the face-to-face session are:

- Hypothesis 3 (H3): The participation of the students during the class positively influences the assimilation of knowledge through the performance of the collaborative exercises and use of the spreadsheet
- Hypothesis 4 (H4): The participation of the students during the class positively influences the development of mathematical skills through the performance of the collaborative exercises and use of the spreadsheet

In a flipped classroom, students actively participate after the class through the realization of creative activities (Craft & Linask, 2020; Krouss & Lesseig, 2020; Morin, Tamberelli, & Buhagiar, 2020). Therefore, the research hypotheses related to the activities after the face-to-face session are:

- Hypothesis 5 (H5): The participation of the students after the class positively influences the assimilation of knowledge through the performance of the laboratory practices
- Hypothesis 6 (H6): The participation of the students after the class positively influences the development of mathematical skills through the performance of the laboratory practices

The decision tree technique (data science) identifies the following predictive models about the use of flipped classroom in the teaching-learning process on statistics:

- Predictive Model 1 (PM1) on the assimilation of knowledge and participation of the students before the class through the consultation of the YouTube videos
- Predictive Model 2 (PM2) on the development of mathematical skills and participation of the students before the class through the consultation of the YouTube videos
- Predictive Model 3 (PM3) on the assimilation of knowledge and participation of the students during the class through the performance of the collaborative exercises and use of the spreadsheet
- Predictive Model 4 (PM4) on the development of mathematical skills and participation of the students during the class through the performance of the collaborative exercises and use of the spreadsheet
- Predictive Model 5 (PM5) on the assimilation of knowledge and participation of the students after the class through the performance of the laboratory practices
- Predictive Model 6 (PM6) on the development of mathematical skills and participation of the students after the class through the performance of the laboratory practices

3.3 Data analysis

The Rapidminer tool allows the calculation of machine learning (linear regression) to evaluate the research hypotheses on the use of flipped classroom in the educational field and construction of the predictive models through the decision tree technique.

Machine learning allows evaluating the research hypotheses on the use of flipped classroom through the training and evaluation sections. The training section with 70% (n = 43), 80% (n = 49) and 90% (n = 55) of the sample allows calculating the linear regressions on the use of flipped classroom and evaluation section with 30% (n = 18), 20% (n = 12) and 10% (n = 6) of the sample allows identifying the accuracy of these linear regressions.

For example, Salas-Rueda, Salas-Rueda and Salas-Rueda (2020) used machine learning to analyze the impact on the use of a digital game in the field of statistics considering different sample sizes.

Likewise, the Rapidminer tool allows the construction of predictive models on the consultation of the YouTube videos before the class, the performance of the collaborative exercises and use of the spreadsheet during the class and performance of the laboratory practices through the spreadsheet after the class. Information about the student's profile and flipped classroom is used to build 6 predictive models through the decision tree technique.

3.4 Data collection

At the end of Introduction to statistics unit (February 2018), the measuring instrument (questionnaire) was applied to collect the information about the use of flipped classroom (see Table 2).

Table 2. Questionnaire on the use of flipped classroom

No.	Variable	Dimension	Question	Answer	n	%
1	Profile of the students	Career	1. Indicate your career	Administration	9	14.75%
				Commerce	19	31.15%
				Accountancy	15	24.59%
				Marketing	16	26.23%
				Computing	2	3.28%
		Age	2. Indicate your age	18 years	25	40.98%
				19 years	25	40.98%
				20 years	9	14.75%
				21 years	1	1.64%
				22 years	1	1.64%
		Sex	3. Indicate your sex	Man	33	54.10%
				Woman	28	45.90%
2	Flipped classroom	Activities before the face-to-face session	4. The activities before the class improve the participation of the students during the learning process	Too much (1)	32	52.46%
				Much (2)	26	42.62%
				Some (3)	3	4.92%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
			5. The consultation of the YouTube videos improves the assimilation of knowledge	Too much (1)	35	57.38%
				Much (2)	24	39.34%
				Some (3)	2	3.28%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
			6. The consultation of YouTube videos improves the development of mathematical skills	Too much (1)	29	47.54%
				Much (2)	29	47.54%
				Some (3)	3	4.92%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
			7. The activities during the class improve the participation of the	Too much (1)	45	73.77%
				Much (2)	16	26.23%

		Activities during the face-to-face session	students during the learning process	Some (3)	0	0.00%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
			8. The performance of the collaborative exercises and use of the spreadsheet improve the assimilation of knowledge	Too much (1)	42	68.85%
				Much (2)	19	31.15%
				Some (3)	0	0.00%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
			9. The performance of the collaborative exercises and use of the spreadsheet improve the development of mathematical skills	Too much (1)	43	70.49%
				Much (2)	16	26.23%
				Some (3)	2	3.28%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
		Activities after the face-to-face session	10. The activities after the class improve the participation of the students during the learning process	Too much (1)	35	57.38%
				Much (2)	25	40.98%
				Some (3)	1	1.64%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
			11. The performance of the laboratory practices through the spreadsheet improves the assimilation of knowledge	Too much (1)	32	52.46%
				Much (2)	29	47.54%
				Some (3)	0	0.00%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
			12. The performance of the laboratory practices through the spreadsheet improves the development of mathematical skills	Too much (1)	32	52.46%
				Much (2)	29	47.54%
				Some (3)	0	0.00%
				Little (4)	0	0.00%
				Too little (5)	0	0.00%
3	Perception of the students	Educational process	13. Does the flipped classroom improve the educational process?	Open	-	-
		Motivation	14. Does the flipped classroom increase the motivation during the teaching-learning process?	Open	-	-
		Benefits	15. What are the benefits of the flipped classroom?	Open	-	-
		Satisfaction	16. Are you satisfied to do the activities before, during and after the class?	Open	-	-
		Utility	17. Is the flipped classroom useful in the educational context?	Open	-	-
		Skills development	18. Does the flipped classroom facilitate the development of mathematical skills?	Open	-	-
		Innovation	19. Does the flipped classroom allow innovating the school activities?	Open	-	-
		Participation of the students	20. Does the flipped classroom favor the participation of the students during the learning process?	Open	-	-

To validate the measuring instrument, the questionnaire must present the values of Cronbach's Alpha (> 0.700), Load Factor (> 0.500) and Composite Reliability (> 0.700). Table 3 shows that the questionnaire on the use of flipped classroom in the educational field meets these criteria.

Table 3. Validation of the questionnaire

No.	Variable	Dimension	Load factor	Cronbach's alpha	Average Variance Extracted	Composite Reliability
1	Activities before the face-to-face session	Participation of the students	0.827	0.829	0.747	0.898
		Assimilation of knowledge	0.853			
		Development of mathematical skills	0.911			
2	Activities during the face-to-face session	Participation of the students	0.876	0.861	0.789	0.918
		Assimilation of knowledge	0.918			
		Development of mathematical skills	0.870			
3	Activities after the face-to-face session	Participation of the students	0.849	0.856	0.777	0.912
		Assimilation of knowledge	0.898			
		Development of mathematical skills	0.897			

4 Results

The results of machine learning with 70%, 80% and 90% training indicate that the participation of the students before, during and after the class positively influences the assimilation of knowledge and development of mathematical skills (See Table 4).

Table 4. Results of machine learning (linear regression)

Hypothesis	Training	Linear regression	Conclusion	Square error
H1: Participation of the students before the class → assimilation of knowledge	70%	y = 0.482x + 0.863	Accepted: 0.482	0.165
	80%	y = 0.510x + 0.811	Accepted: 0.510	0.163
	90%	y = 0.530x + 0.773	Accepted: 0.530	0.171
H2: Participation of the students before the class → development of mathematical skills	70%	y = 0.618x + 0.658	Accepted: 0.618	0.148
	80%	y = 0.634x + 0.594	Accepted: 0.634	0.131
	90%	y = 0.666x + 0.533	Accepted: 0.666	0.232
H3: Participation of the students during the class → assimilation of knowledge	70%	y = 0.894x + 0.140	Accepted: 0.894	0.256
	80%	y = 0.845x + 0.243	Accepted: 0.845	0.217
	90%	y = 0.772x + 0.330	Accepted: 0.772	0.142
H4: Participation of the students during the class → development of mathematical skills	70%	y = 0.756x + 0.416	Accepted: 0.756	0.110
	80%	y = 0.758x + 0.419	Accepted: 0.758	0.101
	90%	y = 0.721x + 0.432	Accepted: 0.721	0.023
H5: Participation of the students after the class → assimilation of knowledge	70%	y = 0.496x + 0.807	Accepted: 0.496	0.105
	80%	y = 0.550x + 0.712	Accepted: 0.550	0.106
	90%	y = 0.557x + 0.687	Accepted: 0.557	0.056
H6: Participation of the students after the class → development of mathematical skills	70%	y = 0.532x + 0.730	Accepted: 0.532	0.117
	80%	y = 0.582x + 0.645	Accepted: 0.582	0.142
	90%	y = 0.587x + 0.625	Accepted: 0.587	0.139

4.1 Before the class

The activities before the class improve too much (n = 32, 52.46%), much (n = 26, 42.62%) and some (n = 3, 4.92%) the participation of the students during the learning process. In addition, the consultation of YouTube videos improves too much (n = 35, 57.38%), much (n = 24, 39.34%) and some (n = 2, 3.28%) the assimilation of knowledge (See Table 2).

The results of machine learning with 70% (0.482), 80% (0.510) and 90% (0.530) of training indicate that H1 is accepted (See Table 4). Therefore, the participation of the students before the class positively influences the assimilation of knowledge through the consultation of the YouTube videos.

Table 5 shows the conditions of PM1. For example, if the student considers that the activities before the class improve much the participation of the students during the learning process, takes the career of Commerce, has an age > 18.5 years and is a man then the consultation of YouTube videos improves much the assimilation of knowledge.

Table 5. Conditions of the PM1

No.	Activities before the class → participation of the students	Sex	Career	Age	Consultation of the YouTube videos → assimilation of knowledge
1	Too much	-	-	-	Too much
2	Much	-	Administration	-	Much
3	Much	Man	Commerce	> 18.5 years	Much
4	Much	Woman	Commerce	> 18.5 years	Too much
5	Much	-	Commerce	≤ 18.5 years	Much
6	Much	Man	Accounting	-	Too much
7	Much	Woman	Accounting	-	Much
8	Much	-	Marketing	-	Too much
9	Some	Man	-	-	Much
10	Some	Woman	-	-	Too much

PM1 has an accuracy of 88.52% and presents 10 conditions on the consultation of the YouTube videos and assimilation of knowledge (See Table 5). For example, if the student considers that the activities before the class improve much the participation of the students during the learning process and takes the career of Marketing then the consultation of the YouTube videos improves too much the assimilation of knowledge.

The consultation of the YouTube videos improves too much (n = 29, 47.54%), much (n = 29, 47.54%) and some (n = 3, 4.92%) the development of mathematical skills (see Table 2). Likewise, the results of machine learning with 70% (0.618), 80% (0.634) and 90% (0.666) of training indicate that H2 is accepted (See Table 4). Therefore, the participation of the students before the class positively influences the development of mathematical skills through the consultation of YouTube videos.

Table 6 shows the conditions of the PM2. For example, if the student considers that the activities before the class improve much the participation of the students during the learning process and takes the career of Marketing, then the consultation of the YouTube videos improves too much the development of mathematical skills.

Table 6. Conditions of the PM2

No.	Activities before the class → participation of the students	Sex	Career	Age	Consultation of the YouTube videos → development of mathematical skills
1	Too much	-	-	-	Too much
2	Much	-	Administration	-	Much
3	Much	Man	Commerce	-	Much
4	Much	Woman	Commerce	> 18.5 years	Too much
5	Much	Woman	Commerce	≤ 18.5 years	Much
6	Much	Man	Accounting	> 18.5 years	Some
7	Much	Woman	Accounting	> 18.5 years	Much
8	Much	-	Accounting	≤ 18.5 years	Too much
9	Much	-	Marketing	-	Too much
10	Some	-	Commerce	-	Much
11	Some	-	Accountancy	-	Some
12	Some	-	Marketing	-	Much

PM2 has an accuracy of 81.97% and presents 12 conditions on the consultation of the YouTube videos and the development of mathematical skills (See Table 6). For example, if the student considers that the activities before the class improve much the participation of the students during the learning process and takes the career of Administration then the consultation of the YouTube videos improves much the development of mathematical skills.

4.2 During the class

The activities during the class improve too much (n = 45, 73.77%) and much (n = 16, 26.23%) the participation of the students during the learning process (See Table 2). Also, the performance of the collaborative exercises and use of the spreadsheet improve too much (n = 42, 68.85%) and much (n = 19, 31.15%) the assimilation of knowledge.

The results of machine learning with 70% (0.894), 80% (0.845) and 90% (0.772) of training indicate that H3 is accepted (See Table 4). Therefore, the participation of the students during the class positively influences the assimilation of knowledge through the performance of the collaborative exercises and use of the spreadsheet.

Table 7 shows the conditions of PM3. For example, if the student considers that the activities during the class improve much the participation of the students during the learning process and takes the career of Administration then the performance of the collaborative exercises and use of the spreadsheet improve much the assimilation of knowledge.

Table 7. Conditions of the PM3

No.	Activities during the class → participation of the students	Sex	Career	Age	Performance of the collaborative exercises and use of the spreadsheet → assimilation of knowledge
1	Too much	-	-	-	Too much
2	Much	-	Administration	-	Much
3	Much	-	Commerce	-	Much
4	Much	Man	Accounting	-	Too much
5	Much	Woman	Accounting	-	Much
6	Much	Man	Marketing	-	Much
7	Much	Woman	Marketing	-	Too much

PM3 has an accuracy of 90.16% and presents 7 conditions on the performance of the collaborative exercises, use of the spreadsheet and assimilation of knowledge (See Table 7). For example, if the student considers that the activities during the class improve much the participation of the students during the learning process and takes the career of Commerce then the performance of the collaborative exercises and use of the spreadsheet improve much the assimilation of knowledge.

The performance of the collaborative exercises and use of the spreadsheet improve too much (n = 43, 70.49%), much (n = 16, 26.23%) and some (n = 2, 3.28%) the development of mathematical skills (See Table 2). Likewise, the results of machine learning with 70% (0.756), 80% (0.758) and 90% (0.721) of training indicate that H4 is accepted (See Table 4). Therefore, the participation of the students during the class positively influences the development of mathematical skills through the performance of the collaborative exercises and the use of the spreadsheet.

Table 8 shows the conditions of the PM4. For example, if the student considers that the activities during the class improve much the participation of the students during the learning process and takes the career of Marketing then the performance of the collaborative exercises and use of the spreadsheet improve too much the development of mathematical skills.

Table 8. Conditions of the PM4

No.	Activities during the class → participation of the students	Sex	Career	Age	Performance of the collaborative exercises and use of the spreadsheet → development of mathematical skills
1	Too much	-	Marketing	-	Too much
2	Too much	-	Computing	-	Too much
3	Too much	-	Commerce	-	Too much
4	Too much	-	Accounting	-	Too much
5	Too much	-	Administration	≤ 18.5 years	Too much
6	Too much	Man	Administration	> 18.5 years	Some
7	Too much	Woman	Administration	> 18.5 years	Too much
8	Much	-	Administration	-	Much
9	Much	-	Commerce	-	Much
10	Much	-	Marketing	-	Too much
11	Much	Man	Accounting	≤ 18.5 years	Too much
12	Much	Man	Accounting	> 18.5 years	Some
13	Much	Woman	Accounting	-	Much

PM4 has an accuracy of 93.44% accurate and presents 13 conditions on the performance of the collaborative exercises, use of the spreadsheet and development of mathematical skills (See Table 8). For example, if the student considers that the activities during the class improve much the participation of the students during the learning process and takes the career of Commerce then the performance of the collaborative exercises and use of the spreadsheet improve much the development of mathematical skills.

4.3 After the class

The activities after the class improve too much (n = 35, 57.38%), much (n = 25, 40.98%) and some (n = 1, 1.64%) the participation of the students during the learning process (See Table 2). Also, the performance of the laboratory practices through the spreadsheet improves too much (n = 32, 52.46%) and much (n = 29, 47.54%) the assimilation of knowledge.

The results of machine learning with 70% (0.496), 80% (0.550) and 90% (0.557) of training indicate that H5 is accepted (See Table 4). Therefore, the participation of the students after the class positively influences the assimilation of knowledge through the performance of the laboratory practices.

Table 9 shows the conditions of the PM5. For example, if the student considers that the activities after the class improve too much the participation of the students during the learning process and takes the career of Marketing then the performance of the laboratory practices through the spreadsheet improves too much the assimilation of knowledge.

Table 9. Conditions of the PM5

No.	Activities after the class → participation of the students	Sex	Career	Age	Performance of the laboratory practices → assimilation of knowledge
1	Too much	-	Marketing	-	Too much
2	Too much	-	Computing	-	Too much
3	Too much	-	Accounting	-	Too much
4	Too much	Woman	Commerce	-	Too much
5	Too much	Man	Commerce	> 18.5 years	Too much
6	Too much	Man	Commerce	≤ 18.5 years	Much
7	Too much	Woman	Administration	-	Too much
8	Too much	Man	Administration	> 18.5 years	Much
9	Too much	Man	Administration	≤ 18.5 years	Too much
10	Much	Man	Administration	> 18.5 years	Much
11	Much	Man	Administration	≤ 18.5 years	Too much
12	Much	Woman	Administration	-	Much
13	Much	-	Commerce	-	Much
14	Much	-	Accounting	> 20 years	Too much
15	Much	-	Accounting	≤ 20 years	Much
16	Much	-	Marketing	-	Much
17	Some	-	-	-	Much

PM5 has an accuracy of 88.52% and presents 17 conditions on the performance of the laboratory practices and assimilation of knowledge (See Table 9). For example, if the student considers that the activities after the class improve much the participation of the students during the learning process and takes the career of Marketing then the performance of laboratory practices through the spreadsheet improves much the assimilation of knowledge.

The activities after the class improve too much (n = 32, 52.46%) and much (n = 29, 47.54%) the participation of the students during the learning process (See Table 2). The results of machine learning with 70% (0.532), 80% (0.582) and 90% (0.587) of training indicate that H6 is accepted (See Table 4). Therefore, the participation of the students after the class positively influences the development of mathematical skills through the performance of the laboratory practices.

Table 10 shows the conditions of PM6. For example, if the student considers that the activities after the class improve too much the participation of the students during the learning process and takes the career of Commerce then the performance of the laboratory practices through the spreadsheet improves too much the development of mathematical skills.

Table 10. Conditions of PM6

No.	Activities after the class → participation of the students	Sex	Career	Age	Performance of the laboratory practices → development of mathematical skills
1	Too much	-	Marketing	-	Too much
2	Too much	-	Computing	-	Too much
3	Too much	-	Commerce	-	Too much
4	Too much	-	Accounting	-	Too much
5	Too much	Woman	Administration	-	Too much
6	Too much	Man	Administration	> 18.5 years	Much
7	Too much	Man	Administration	≤ 18.5 years	Too much
8	Much	-	-	≤ 19.5 years	Much
9	Much	-	Administration	> 19.5 years	Too much
10	Much	-	Commerce	> 19.5 years	Much
11	Much	-	Accounting	> 19.5 years	Too much
12	Much	-	Marketing	> 19.5 years	Much
13	Some	-	-	-	Much

PM6 has an accuracy of 86.89% and presents 13 conditions on the realization of the laboratory practices and development of mathematical skills (See Table 10). For example, if the student considers that the activities after the class improve too much the participation of the student during the learning process and takes the career of Accounting then the performance of the laboratory practices through the spreadsheet improves too much the development of mathematical skills.

4.4 Perceptions of the students

The flipped classroom allows the construction of new educational spaces that improve the teaching-learning conditions and facilitate the active participation of the students. According to the students of the Statistical Instrumentation for Business course, flipped classroom facilitates the educational process on frequencies and measures of central tendency:

> "Yes, it helps to understand and review the topics of the class [...]. The videos and spreadsheet facilitate the learning [...]." (Student 10, Woman, 18 years, Accounting).
> "Yes, I learn faster with the help of technology [...]. I solve my doubts with the spreadsheet." (Student 28, Man, 19 years, Commerce).
> "Yes, because we have more tools to learn [...]. Also, I learn more with the help of my classmate." (Student 35, Woman, 18 years, Commerce).

Teachers can create new activities before, during and after the class through the flipped classroom. In fact, the students are motivated to use technology in the teaching-learning process:

> "Yes, it's more fun [...] we learn through the technology." (Student 1, Woman, 18 years, Marketing).
> "Yes, because it is more interactive [...]. I get the results of the exercises quickly with the spreadsheet." (Student 26, Man, 20 years, Commerce).
> "Yes, because they are different ways to learn [...] I really liked using the spreadsheet [...] I learn more and it's not boring." (Student 33, Woman, 18 years, Accounting).

The active participation of the students before, during and after the class improves the assimilation of knowledge and develops the skills. One of the benefits of the flipped classroom in the educational field is the improvement of the learning process:

> "I learn easier [...] I can see the information at home." (Student 19, Man, 18 years, Administration).
> "I use technology, learn and resolve my doubts." (Student 20, Man, 18 years, Marketing).
> "Facilitates the learning, helps me for the realization of the homework and prepare for the exam." (Student 25, Man, 21 years, Accounting).

The use of the videos and spreadsheet in the school activities improved the teaching-learning process on statistics. In fact, the students of Administration, Accounting, Commerce, Computing and Marketing are satisfied to use flipped classroom:

"Yes, we learn more and in different ways [...]. For example, I can watch the videos many times [...]." (Student 15, Woman, 20 years, Marketing).
"Yes, because everything is very clear due to the use of these technological tools. [...] with the activities carried out in the class I learn more [...]." (Student 44, Woman, 19 years, Marketing).
"Yes, it is a different way to learn. I verify the results with the spreadsheet [...]. In the classroom, I solve the doubts with my partner." (Student 47, Woman, 18 years, Commerce).

Technological advances and pedagogical models such as flipped classroom are changing the behavior and functions of the students and teachers during the educational process. In particular, the students of the Statistical Instrumentation for Business course consider that flipped classroom is useful for the educational context:

"Yes, it helps the learning process [...] I verify that my answers are correct with the spreadsheet." (Student 10, Woman, 18 years, Accounting).
"Yes, I learn in various ways [...]. I loved using the formulas in the spreadsheet. It is more practical." (Student 37, Man, 19 years, Accounting).
"Yes, I learn [...] it's interesting to watch the videos before the class, I had never done it." (Student 43, Woman, 20 years, Marketing).

Technological tools play a fundamental role during the realization of the learning process inside and outside the classroom. For example, the flipped classroom facilitates the development of mathematical skills in the Statistical Instrumentation for Business course through the spreadsheet:

"Yes, because I use the contents in the practical context and check the exercises with the formulas in the spreadsheet." (Student 10, Woman, 18 years, Accounting).
"Yes, because I analyze the exercises with the help of the spreadsheet [...] I apply the knowledge." (Student 11, Woman, 19 years, Commerce).
"Yes, I practice at home what I see in the class [...]. I use the technology to check the results." (Student 32, Woman, 19 years, Administration).

In the 21st century, flipped classroom facilitates the organization and creation of creative activities where students are the main actor during the learning process. The students of Administration, Accounting, Commerce, Computing and Marketing think that flipped classroom is an innovative pedagogical model for the educational field:

"Innovative and creative." (Student 4, Man, 20 years, Marketing).
"Yes, the videos and use of the spreadsheet are innovative and very useful." (Student 5, Man, 19 years, Marketing).
"Yes, few teachers use it." (Student 32, Woman, 19 years, Administration).

Finally, the flipped classroom fosters the participation of the students during the learning process through the consultation of the YouTube videos, performance of the collaborative exercises and realization of the laboratory practices:

> "Yes, the role of the student is more dynamic [...]. I liked doing the activities with my partner." (Student 3, Man, 19 years, Accounting).
> "Yes, it is interactive. It is easier to learn and study for the exam [...]." (Student 31, Woman, 18 years, Marketing).
> "Yes, it keeps us entertained by using different technological tools." (Student 33, Woman, 18 years, Accounting).

5 Discussion

Flipped classroom promotes the modification and updating of traditional educational practices through the use of pedagogical strategies and technology (Burgoyne & Eaton, 2018; Shih & Tsai, 2017). In fact, this mixed research use of the flipped classroom to improve the educational process on the frequencies and measures of central tendency (mean, standard deviation and variance).

5.1 Before the class

Most of the students (n = 32, 52.46%) consider that the activities before the class improve too much the participation of the students during the learning process. Also, the consultation of YouTube videos improves too much (n = 35, 57.38%) the assimilation of knowledge. The results of machine learning on H1 are greater than the value of 0.480, therefore, the participation of the students before the class positively influences the assimilation of knowledge through the consultation of the YouTube videos. In addition, the decision tree technique identifies 10 conditions for PM1 with an accuracy of 88.52%.

Most of the students (n=29, 47.54%) consider that the consultation of YouTube videos improves too much the development of mathematical skills. The results of machine learning on H2 are greater than the value of 0.610, therefore, the participation of the students before the class positively influences the development of mathematical skills through the consultation of the YouTube videos. In addition, data science identifies 12 conditions for PM2 with an accuracy of 81.97%.

5.2 During the class

Most of the students (n = 45, 73.77%) consider that the activities during the class improve too much the participation of the students during the learning process. Also, the performance of the collaborative exercises and use of the spreadsheet improve too much (n = 42, 68.85%) the assimilation of knowledge.

The results of machine learning on H3 are greater than the value of 0.770, therefore, the participation of the students during the class positively influences the assimilation of knowledge through the performance of the collaborative exercises and use of the spreadsheet. In addition, data science identifies 7 conditions for PM3 with an accuracy of 90.16%.

Most of the students (n = 43, 70.49%) consider that the performance of the collaborative exercises and use of the spreadsheet improve too much the development of mathematical skills. The results of machine learning on H4 are greater than the value of 0.720, therefore, the participation of the students during the class positively influences the development of mathematical skills through the performance of the collaborative exercises and use of the spreadsheet. In addition, the decision tree technique identifies 13 conditions for predictive model 4 with an accuracy of 93.44%.

5.3 After the class

Most of the students (n = 35, 57.38%) think that the activities after the class improve too much the participation of the students during the learning process. Also, the performance of the laboratory practices through the spreadsheet improves too much (n = 32, 52.46%) the assimilation of knowledge.

The results of machine learning on H5 are greater than the value of 0.490, therefore, the participation of the students after the class positively influences the assimilation of knowledge through the performance of the laboratory practices. Also, the decision tree technique identifies 17 conditions for the predictive model 5 with an accuracy of 88.52%.

Most of the students (n = 32, 52.46%) think that the performance of the laboratory practices through the spreadsheet improves too much the development of mathematical skills. The results of machine learning on H6 are greater than the value of 0.530, therefore, the participation of the students after the class positively influences the development of mathematical skills through the performance of the laboratory practices. Also, data science identifies 13 conditions for predictive model 6 with an accuracy of 86.89%.

5.4 Perceptions of the students

Technological advances and pedagogical models are changing the behavior of the students and teachers. For example, the students of the Statistical Instrumentation for Business course think that the flipped classroom facilitates the teaching-learning process on frequencies and measures of central tendency. The active participation of the students before, during and after the class improves the assimilation of knowledge on statistics and develops the mathematical skills through the consultation of the YouTube videos, performance of the collaborative exercises and realization of the laboratory practices.

In the 21st century, flipped classroom facilitates the organization of creative activities where students are the main actor during the learning process. In particular, the consultation of the YouTube videos, performance of the collaborative exercises and realization of the laboratory practices allow the creation of new educational spaces.

This mixed research shares the ideas of various authors (e.g., Blau & Shamir, 2017; Lo, Lie, & Hew, 2018) on the fundamental role of the flipped classroom to improve the teaching-learning conditions. In fact, teachers can create new activities before, during and after the class through the flipped classroom.

Technological tools play a fundamental role during the realization of the learning process inside and outside the classroom. For example, the use of the videos and spreadsheet in the school activities improved the teaching-learning process on statistics. Finally, the flipped classroom is a pedagogical model that allows the development of competencies and facilitates the creation of student-centered activities through the use of ICTs (Blau & Shamir, 2017; Lo, Lie, & Hew, 2018; Wang, 2017).

6 Conclusions

Educational institutions have the possibility to update the activities through the use of a flipped classroom. In particular, this research improved the teaching-learning process on statistics through the consultation of the YouTube videos before the class, performance of the collaborative exercises and use of the spreadsheet during the class and performance of the laboratory practices through the spreadsheet after the class.

The results of machine learning indicate that the participation of the students before, during and after the class positively influences the assimilation of knowledge and development of mathematical skills. Likewise, data science identifies 6 predictive models on the use of flipped classroom in the educational context through the decision tree technique.

The flipped classroom is a pedagogical model that allows the creation of new educational experiences. For example, the activities carried out inside and outside the classroom promote the participation of the students and improve the teaching-learning process on frequencies and measures of central tendency (mean, standard deviation and variance).

This research recommends the use of flipped classroom in the field of statistics because this pedagogical model allows innovating and updating the teaching-learning activities through ICTs. In fact, the consultation of YouTube videos, the performance of the collaborative exercises and realization of the laboratory practices allow the construction of new educational spaces that increase the motivation of the students during the learning process.

The limitations of this mixed research are the implementation of the flipped classroom in the educational field through the consultation of the YouTube videos and the use of the spreadsheet. Therefore, future research can analyze the impact of flipped classroom considering web 2.0 tools, web simulators, digital games, social networks, digital presentations, social networks and online questionnaires. Likewise, teachers can use flipped classroom considering distance education due to the conditions caused by Covid-19.

Finally, the flipped classroom has a fundamental role to meet the educational demands and expectations of the society in the 21st century. In particular, this pedagogical model improved the teaching-learning conditions in the field of statistics through the use of ICTs before, during and after the class.

References

Blau, I. & Shamir Inbal, T. (2017). Re-designed flipped learning model in an academic course: The role of co-creation and co-regulation. *Computers & Education*, *115*, 69–81. http://dx.doi.org/10.1016/j.compedu.2017.07.014

Burke, A. S. & Fedorek, B. (2017). Does flipping promote engagement?: A comparison of a traditional, online, and flipped class. *Active Learning in Higher Education*, *18*(1), 11–24. https://doi.org/10.1177/1469787417693487

Burgoyne, S. & Eaton, J. (2018). The Partially Flipped Classroom: The Effects of Flipping a Module on Junk Science in a Large Methods Course. *Teaching of Psychology*, *45*(2), 154–157. https://doi.org/10.1177/0098628318762894

Chan, S. Y., Lam, Y. K., & Ng, T. F. (2020). Student's perception on initial experience of flipped classroom in pharmacy education: Are we ready? *Innovations in Education and Teaching International*, 57(1), 62–73. https://doi.org/10.1080/14703297.2018.1541189

Chen, L. L. (2016). Impacts of Flipped Classroom in High School Health Education. *Journal of Educational Technology Systems*, *44*(4), 411–420. https://doi.org/10.1177/0047239515626371

Chen, S. C., Yang, S. J., & Hsiao, C. C. (2016). Exploring student perceptions, learning outcome and gender differences in a flipped mathematics course. *British Journal of Educational Technology*, 47(6), 1096–1112. https://doi.org/10.1111/bjet.12278

Chen,Y., Wang, Y., Kinshuk, C., & Chen, N. S. (2014). Is FLIP enough? Or should we use the FLIPPED model instead? *Computers & Education*, *79*, 16–27. http://dx.doi.org/10.1016/j.compedu.2014.07.004

Craft, E. & Linask, M. (2020). Learning effects of the flipped classroom in a principles of microeconomics course. *The Journal of Economic Education*, *51*(1), 1–18. https://doi.org/10.1080/00220485.2019.1687372

Deng, J. D., & Purvis, M. K. (2015). Teaching Service Modelling to a Mixed Class: An Integrated Approach. *Informatics in Education*, *14*(1), 35–50. http://dx.doi.org/10.15388/infedu.2015.03

Hall, A. A. & DuFrene, D. D. (2015). Best Practices for Launching a Flipped Classroom. *Business and Professional Communication*, *79*(2), 234–242. https://doi.org/10.1177/2329490615606733

Ignatova, N., Dagiene, V., & Kubilinskiene, S. (2015). ICT-based Learning Personalization Affordance in the Context of Implementation of Constructionist Learning Activities. *Informatics in Education*, *14*(1), 51–65. http://dx.doi.org/10.15388/infedu.2015.04

Karolcik, S., Cipkova, E., Hrusecky, R., & Veselsky, M. (2015). The Comprehensive Evaluation of Electronic Learning Tools and Educational Software (CEELTES). *Informatics in Education*, *14*(2), 243–264.

Krouss, P. & Lesseig, K. (2020). Effects of a Flipped Classroom Model in an Introductory College Mathematics Course. *Primus*, *30*(5), 617–635. https://doi.org/10.1080/10511970.2019.1625471

Liu, L. (2019). Face-to-face Teaching in the Flipped Classroom Supported by Visualization Tools - Taking the course of "Architectural Design of Housing" as an Example. *International Journal of Emerging Technologies in Learning*, *14*(3), 220–233. https://doi.org/10.3991/ijet.v14i03.10106

Lo, C. K., Lie, C. W., & Hew, K. F. (2018). Applying First Principles of Instruction as a design theory of the flipped classroom: Findings from a collective study of four secondary school subjects. *Computers & Education*, *118*, 150–165. https://doi.org/10.1016/j.compedu.2017.12.003

Morin, J., Tamberelli, F., & Buhagiar, T. (2020). Educating business integrators with a computer-based simulation game in the flipped classroom. *Journal of Education for Business*, *95*(2), 121–128. https://doi.org/10.1080/08832323.2019.1613951

Ortiz-Colon, A. M, Muñoz-Galiano, I. M., & Colmenero-Ruiz, M. J. (2017). Impact of the Flipped Classroom Model and Collaborative Learning in Childhood Teaching University Degree. *Journal of e-Learning and Knowledge Society, 13*(3), 131–143. https://doi.org/10.20368/1971-8829/1358

Sadeck, O. & Cronje, J. (2017). A Continuum of Teachers' e-Learning Practices. *Electronic Journal of e-Learning, 15*(5), 396–409.

Salas-Rueda, R. A. (2020). Design, Construction and Evaluation of a Web Application for the Teaching-Learning Process on Financial Mathematics. *International Journal of Emerging Technologies in Learning*, *15*(8), 100–115. https://doi.org/10.3991/ijet.v15i08.12275

Salas-Rueda, R. A., Salas-Rueda, E. P., & Salas-Rueda, R. D. (2020). Analysis and design of the web game on descriptive statistics through the ADDIE model, data science and machine learning. *International Journal of Education in Mathematics, Science and Technology*, *8*(3), 245–260. https://doi.org/10.46328/ijemst.v8i3.759

Shih, W. L. & Tsai, C. Y. (2017). Students' perception of a flipped classroom approach to facilitating online project-based learning in marketing research courses. *Australasian Journal of Educational Technology*, *33*(5), 32-49. https://doi.org/10.14742/ajet.2884

Sun, Y. C. (2017). Flipping every student? A case study of content-based flipped language classrooms. *E-Learning and Digital Media*, *14*(1), 20–37. https://doi.org/10.1177/2042753017692428

Turra, H., Carrasco, V., González, C., Sandoval, V., & Yáñez, S. (2019). Flipped classroom experiences and their impact on engineering students' attitudes towards university-level mathematics. *Higher Education Pedagogies*, *4*(1), 136–155. https://doi.org/10.1080/23752696.2019.1644963

Uyanga, S. (2014). Baseline Analysis on ICT in General Education of Mongolia. *Informatics in Education*, *13*(1), 121–140.

Wang, F. H. (2017). An exploration of online behaviour engagement and achievement in flipped classroom supported by learning management system. *Computers & Education*, *114*, 79–91. http://dx.doi.org/10.1016/j.compedu.2017.06.012

Zahrani, A. M. (2015). From passive to active: The impact of the flipped classroom through social learning platforms on higher education students' creative thinking. *British Journal of Educational Technology*, *46*(6), 1133–1148. https://doi.org/10.1111/bjet.12353

Zainuddin, Z. & Perera, C. J. (2019). Exploring students' competence, autonomy and relatedness in the flipped classroom pedagogical model. *Journal of Further and Higher Education*, *43*(1), 115–126. https://doi.org/10.1080/0309877X.2017.1356916

Pre-service teachers' conceptions about the quality of explanations for the science classroom in the context of peer assessment

Valeria M. Cabello[1] and Keith J. Topping[2]
[1] Pontificia Universidad Católica de Chile, Facultad de Educación,
Centro de Estudios de Políticas y Prácticas en Educación (CEPPE UC), Chile
[2] University of Dundee, School of Education and Social Work, United Kingdom

This study explored student-teacher conceptions of explanations for the science classroom during teacher education programs through peer-assessments of 20 pre-service teachers from three universities. The peer-assessments were reciprocal and focused on the explanation of scientific concepts during microteaching episodes. Student-teacher conceptions about the quality of scientific explanations were obtained by analysing their assessment-feedback comments to peers and by focus groups. The results showed that student-teacher conceptions about the quality of explanations for the science classroom were related to constructivist theory applied to science teaching, for instance, the participants noticed that better explanations were those that connected the concepts with the students' ideas and experiences. A follow-up with a sub-sample of six participants during a practicum in schools explored through interviews the perceived enablers and obstacles that affected their explanation construction in real settings leading to reframing their conceptions. This study revealed that peer assessment and feedback could play a significant role in teacher education by eliciting student-teacher conceptions about essential teaching practices and the challenges of explaining in real teaching, which might enhance and empower their skill development. We discuss implications for research and practice, with emphasis on peer assessment as a tool for internalising assessment criteria for fruitful science teaching.

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 297–318

Submitted 6 October 2020
Accepted 3 November 2020
Published 3 December 2020

Pages: 22
References: 75

Correspondence:
vmcabello@uc.cl

https://doi.org/10.31129/LUMAT.8.1.1416

Keywords: pre-service teachers, scientific explanation, peer assessment, learning

1 Introduction

There is an international discussion about the capacity of teacher education programs in the development of student-teacher skills and knowledge for implementing teaching strategies (e.g., Lawson, Askell-Williams, & Murray-Harvey, 2009). There is also a call for sustainable assessment practices in teacher education programs, aimed at encouraging pre-service teachers to reflect on their practices and improve their teaching strategies by autonomously seeking professional development opportunities (e.g., Borman, Mueninghoff, Cotner, & Frederick, 2009).

Additionally, it is recognised that for pre-service teachers, changing roles from student to teacher is a complex process (Fernandez, 2010; Jian, Odell, & Schwille, 2008) that might be facilitated by early teaching experiences in real contexts or

 | CC BY 4.0

simulated ones, through microteaching, co-teaching or peer coaching of critical teaching practices (Hume, 2012; Inoue, 2009; Lu, 2010; Ostrosky, Mouzourou, Danner, & Zaghlawan, 2013). On these role-change processes, eliciting pre-service teachers' ideas of teaching through reflection is crucial for detecting change (Benedict-Chambers & Aram, 2017).

Some of the essential teaching practices are based on a type of knowledge that is unique to pedagogy, called Pedagogical Content Knowledge (PCK). Shulman proposed the idea of PCK and stated it included "the most useful forms of representation of ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p.9). More specifically in science education, PCK has been described as teacher knowledge at the interface between knowledge and practice (Rollnick & Mavhunga, 2015), combining knowledge of the subject matter, knowledge of students, general pedagogical knowledge and knowledge of context that affects certain teaching practices; representations, curricular saliency, and topic-specific strategies such as explanations (Davidowitz & Rollnick, 2011).

In our study, we focus on this last point; teacher explanation, because it is a common concern in the field and, more importantly, explaining has been proven to be one of the central practices highly conducive to student learning (Windschilt, Thompson, & Braaten, 2018; Windschitl, Thompson, Braaten, & Stroupe, 2012). Additionally, teacher explanations might expand or limit student-teacher knowledge about the nature of science and their understanding of how scientific knowledge is constructed in classrooms (Leinhardt, 2001).

The explanations that teachers construct during the lessons are manifestations of teachers' PCK (Davidowitz & Rollnick, 2011). The model actualised by Rollnick & Mavhunga (2015) recognises the importance of teachers' beliefs and conceptions about PCK as mediators of the enactments in practice. Indeed, not only knowledge, but also teachers' beliefs are likely to determine the teaching quality of explanations (Kulgemeyer & Riese, 2018). Recently, the connections between pre-service teachers' explanations and PCK have been empirically supported. We know now that science pre-service teachers' PCK is a mediator of their explaining performance; then, PCK affects their enacted knowledge to explain (Kulgemeyer & Riese, 2018; Kulgemeyer et al., 2020).

Teacher explanations have been generally defined as communicative actions used to connect some part of the subject matter knowledge to the learners and support their understanding (Leinhardt, 2001), a necessary form of discourse in classroom teaching (Wittwer & Renkl, 2008). In science education student understanding through explanations is promoted by models, analogies, metaphors, representations, making the nature of science explicit, linking the contents with the history of science, and the students' intuitive ideas (Duit & Treagust, 2003; Lehrer & Schauble, 2010; Thagard, 1992; Treagust & Harrison, 2003). The construct of such an explanatory framework enriched the idea of explanation as an answer to a why-question, highlighting how teachers use analogy, metaphor, examples, axioms and concepts, linking them together into a coherent whole for the classroom (Geelan, 2003). However, constructing explanations is a complicated process, and many teachers struggle to transform academic knowledge into explanations for the school (Cabello, Real, & Impedovo, 2019; Charalambous, Hill, & Ball, 2011; Gobierno de Chile, 2013; Hadzidaki, 2008; Kulgemeyer, et al., 2020; Inoue, 2009; Wittwer & Renkl, 2008). Indeed, this is even more critical for beginner teachers (Leinhardt, 2001; Ospina-Quintero & Bonan, 2011; Marzabal et al., 2019), and practical experience without reflection is unlikely to automatically lead to better results in explaining. Practical experience of working as a science teacher helps pre-service teachers to become aware of how difficult it is to be a good explainer (Kulgemeyer & Riese, 2018).

Those difficulties might be due to the lack of opportunities for practising and reflecting on explanations during initial teacher education (Charalambous et al., 2011; Inoue, 2009; Marzabal et al., 2019). Moreover, the research regarding student-teacher explanations is still not as developed as the studies focused on student explanations (e.g., Besson, 2010; Herman et al., 2019; Kampourakis & Zogza, 2008). Hence, the intersection of explanation construction and the factors affecting its development in teacher education is still an under-researched field of inquiry (Charalambous et al., 2011; Geelan, 2012; Kulgemeyer & Riese, 2018; Kulgemeyer et al., 2020; Marzabal et al., 2019). Therefore, there is little knowledge about the development of pre-service explanations and relevance for future classroom practice.

In connection to this, some have argued that peer assessment (PA) is an effective strategy to enhance general teaching performance (Andreu et al., 2006; Sluijsmans & Prins, 2006), which also promotes reflection and self-reflection about practice (Nilsson, 2013). PA is a process that allows learners to consider and specify the level, value, or quality of a product or performance of other equal-status learners (Topping, 2010), in this case, between pre-service teachers. Indeed, PA is a form of collaborative learning between peers (Kollar & Fisher, 2010). Specifically, PA of performance aims to help learners make judgments about structured tasks and provide their impressions of peer performances, the quality of those actions and their suitability for a purpose (Norcini, 2003). Peer feedback seems to be an essential element of PA (Liu & Carless, 2006). However, useful peer feedback depends on the assessor's skills in giving feedback on a particular task (Van der Pol, Van den Berg, Admiraal, & Simons, 2008). Microteaching is a context for applying PA - a short episode of simulated teaching to their peers, usually in reciprocal turns (Mohan, 2007). This teaching rehearsal strategy might help pre-service teachers become reflective practitioners by discussing their performance with peers (l'Anson, Rodrigues, & Wilson, 2003).

Previous research about PA has shown its applicability at different stages of teacher preparation, in initial (undergraduate) education, as well as in professional development programs (in-service training) (Kilic & Cakan, 2007; Tsai, Lin, & Yuan, 2002; Wen & Tsai, 2008). Important aspects of PA are the definition of assessment criteria and roles (Kim, 2009; Sluijsmans, Brand-Gruwel, & van Merriënboer, 2002), self-reflection and critical analysis of peers and their practice (Harford & MacRuairc, 2008; Kim, 2009; Sluijsmans, Brand-Gruwel, van Merriënboer, & Martens, 2004) and the enhancement of attitudes towards assessment (Kim, 2009). Nonetheless, studies that follow-up with the pre-service teachers when they are actually in service are required for understanding what occurs in real teaching contexts after being part of PA (Sluijsmans, Brand-Gruwel, van Merriënboer, & Bastiaens, 2002).

PA as a social process involves negotiation and inter-subjective construction of meaning (Moje, Collazo, Carrillo, & Marx, 2001), which in this case was developed among students of a similar level of teaching experience and knowledge (as per Nicol & Boyle, 2003). Stiggins (1991) asserted that internalisation of assessment criteria during PA is crucial to promoting understanding and high-quality performance. PA allows self-regulation of learning which is, according to Vermunt and Endedijk (2011), necessary but not sufficient to develop pre-service teachers' skills to teach in real settings.

Regarding the teachers' practices and the factors that might affect them, the role of teachers' thinking - theories, beliefs and conceptions - has been identified as crucial (Isikoglu, Basturk, & Karaca, 2009). The terms "belief" and "conception" have had different definitions in educational research (Pajares, 1992), and some shared usages, making the boundaries between the concepts somewhat arbitrary. Moreover, there are some common aspects between beliefs and conceptions: they are part of personal practical knowledge for teaching (Crawford & Capps, 2018), they are deeply rooted in personal histories about the nature of knowledge, and they are usually acquired through the student-teacher's own learning experiences - as tacit knowledge (Da-Silva et al., 2006). Expressing tacit knowledge verbally is typically challenging; it results mainly from experience (Grangeat & Kapelari, 2015). It is likely to guide the teacher's actions and situational responses despite him or her being unaware of the principles that govern the thinking behind those actions (Kahneman, 2011).

To differentiate these concepts, in this study, we take educational belief as a general set of representations about teaching, linked to students' learning. At the same time, conceptions are representations or ideas focused on specific teaching topics or strategies used for certain purposes (Hermans, van Braak, & Van Keer, 2008). Conceptions of teaching are instructional ideas about the nature of the content to be taught, about how to teach the content to students and about how students learn the content (Da-Silva et al., 2006). We use these notions due to their potential influence on teaching and the chances of capturing them through collective reflection, knowing that conceptions of teaching are usually accessed as complex sets of propositions classified in dimensions (Chan & Elliott, 2004; Koballa et al., 2005).

Some studies on teacher conceptions have found a correlation between teacher actions and their thinking, while others saw only a partial relationship or no link (Alt, 2018; Mellado, 1998). Zhang and Liu (2013) found that teachers who held constructivist conceptions of learning favoured student participation and interaction, while teachers with traditional conceptions placed more importance on students' memorisation processes and teachers' authority in the classroom. Although there is no agreement on the extent to which teachers thinking predicts teaching practices, it is clear that changes in the quality of teaching are unlikely to happen without changes in teacher conceptions of what high-quality teaching means (Kember & Kwan, 2000).

The current study explored the extent to which PA prompted more developed student-teacher conceptions regarding the quality of explanations for the science classroom, and the reframing of the conceptions in this context. The two research questions we posed were: RQ1. What are the conceptions of pre-service teachers about the quality of explanations for the science classroom, and how are these developed by peer assessment? RQ2. What factors affect pre-service teachers possible reframing of their conceptions about the quality of explanations for the classroom when in a real teaching context?

2 Methods

This study was action research, which not only seeks to investigate a phenomenon but to transform practitioners' actions (Goodnough, 2010). The study was embedded in a ten-session workshop based on PA and intended to analyse student-teacher skills in microteaching. The workshop was conducted in three Chilean universities in undergraduate teacher education, in each case with a cohort who were about to finish the program. After six months, a case study followed a sub-sample of the participants, who were involved in a practicum at schools as beginner teachers.

2.1 Participants

The sampling sought information-rich cases for in-depth study (Patton, 2001). The initial participants were 60 pre-service teachers from three universities who voluntarily enrolled in the workshop. However, just 20 of them completed six of the ten sessions (this was a time of considerable student unrest in this country), which represented the minimum number of sessions required for inclusion in this study. The final group had similar teaching experience of around three weeks, mostly in observation of practice but not teaching implementation. They were 25 years old on average (SD=1.7) and came from an urban zone with low-middle socioeconomic status. For the follow-up study, six of these participants were selected because they were in practicum teaching in real settings. The follow-up participants represented each of the three universities. The schools hosting the practicum were located in urban zones near the universities and were from different socioeconomic groups.

2.2 Procedure

The PA workshop had a simple design. First, the methodology and ethical issues were described, and if the pre-service teachers decided to participate, they signed the consent form. Then, the researchers showed a video of an explanation and modelled the assessment. It was a ten-minute video in which a young teacher explained the concept of matter. The video was used to avoid possible anxiety in participants regarding PA and to rehearse the practice of evaluating an explanation performed by a student-teacher. This element was necessary because it familiarised the participants with the process of noticing aspects of teaching performance and learning to take useful notes for the next assessment.

Second, the pre-service teachers prepared a microteaching lesson with an explanation of a concept they chose, with the requirement that it should be part of the national curriculum and the first time the students would study it. The participants simulated the explanation to a small group of peers (between two and five) and mutually assessed their explanations, giving feedback and changing roles. After the experience, throughout several discussions based on their conceptions -not on theoretical inputs - they designed and refined the assessment criteria for the next round of peer assessments, using these criteria to improve their explanation about the same concept for the second round. Third, they simulated the second round of microteaching episodes. Finally, a focus group was conducted with each group to reflect on the experience.

The follow-up study consisted of observing each student-teacher of the sub-sample during one or two science lessons, in which they constructed an explanation in front of real students. We interviewed them after the class to explore what they thought about the quality of the scientific explanation delivered. We also inquired about the factors that they consider might have affected the quality of their explanations in a real teaching context compared to the simulated context in the university, and the elements affecting the way they currently evaluated their explanations.

The ethics committee of the university leading the study approved the complete procedure.

2.3 Data gathering

Student-teacher conceptions about the quality of explanations were obtained through questions oriented to collective reflection in the context of PA and reflection on practice in real classrooms. An expert panel viewed and revised a preliminary version of the items. Then, a pilot study used the questions focused on the conceptions of pre-service teachers of a different cohort, using video analysis instead of PA.

The participants' conceptions were first gathered for 14 sessions of reciprocal PA in a simulated context, in which they progressively constructed criteria for mutually assessing the quality of the explanations by their peers. During these sessions, open-ended questions were posed to gather pre-service teachers' conceptions and facilitate group reflection. The questions were: How would you assess the quality of the scientific explanation your peer constructed for the classroom? Why? Why do you think he/she took these pedagogical decisions? What would you do in the same situation? Why? The questions were repeated during the peer assessment, and the participants constructed assessment criteria based on the group emergent ideas.

Additionally, three focus groups were conducted at the end of the workshop with the aim of exploring to what extent the pre-service teachers considered the seminar was a valuable learning experience. The main focus group questions were: Do you think it was useful doing the microteaching and receiving feedback from a peer? Why? /Why not? (If they say yes) In what aspects was it worthwhile? Why? Do you believe this method of teaching should be used with other students? Why? What were the most important things that you learned in these sessions? Do you think what you learned will be sustained over time? Why?

In the follow-up study, six semi-structured interviews were conducted at the participants' schools after observing their lessons, and asked: How would you assess the quality of the scientific explanation you constructed? Why? What factors affect the quality of your explanations in a simulated and real teaching context? What elements affect the way you evaluate your explanations? Do these elements affect the way you think about the quality of explanations for teaching?

In these three instances of gathering information, student-teacher answers were transcribed, and their conceptions were interpreted following a systematic coding process according to the nature and extension of the data. The coding categories were organised in vignettes, and two independent researchers conducted inter-rater reliability on the interpretations.

2.4 Data analysis

Student-teacher answers during assessment sessions and the assessment criteria design were examined through thematic analysis to understand their underlying conceptions. NVivo software was used to organise the transcripts and code the assessment sessions (QSR, 2011), and methods triangulation was utilised to work towards reliability (Patton, 2001). Thematic analysis is a method for identifying and reporting patterns or themes within data, through the organisation and description of the data set in detail (Braun & Clarke, 2006). The assessment sessions, the focus groups and interviews were transcribed verbatim and coded following Grounded Theory types of coding: open and axial using comparisons until saturation (Glaser, 2004). The interviews in the follow-up study were coded using the constant comparative method of analysis adapted to teacher narratives, recommended by Valanides (2010).

3 Results

The following section summarises the results obtained, pursuant to the research questions. First, the results of the exploration of pre-service teachers' conceptions about the quality of explanations are organised from most to least frequent, according to data gathered through the PA sessions and focus groups (RQ1). Details about the participants' actual explanation quality can be found in prior work (Cabello & Topping, 2018). Second, the crucial factors that promoted a reframing of conceptions about the quality of explanations for the classroom once real teaching instances are faced are presented and organised as perceived enablers and obstacles.

3.1 RQ1. What are the conceptions of pre-service teachers about the quality of explanations for the science classroom and how are these developed by peer assessment?

Most of the pre-service teachers' conceptions about the quality of the explanations for the science classroom in the context of PA were related to constructivist theory. Contextualisation of the content appeared as a fundamental idea that they recognised as helping to increase students' understanding of the concepts. A useful context involved the participants in structuring the scientific explanation in more concrete terms while using simpler or broader elements to connect students' ideas with the concept, theory or phenomena taught. The participants conceived good explanations for the science classroom if they were linked with students' prior knowledge, and the teacher explicitly used this prior knowledge in the explanation. The explanation would be then be constructed with students by integrating their questions, intuitive ideas, experiences, etc.

The participants highlighted the importance of constructing scientifically clear explanations. Clarity was achieved, for instance, when the scientific terms used in an explanation were agreed between teacher and students, or communicated in a simple language, with evident connections between the concepts and students' ideas, or making explicit the similarities and differences of conceptual meaning when used in daily life versus in a scientific context. The participants saw posing questions to deepen and verify student understanding of the concepts as a form of checking the clarity of the explanations. Finally, the use of examples in the explanation emerged as relevant - all of the pre-service teachers considered examples as a crucial part of generating scientific explanations for the classroom. In their view, examples were useful if they were as concrete as possible to illustrate the content, if they were related and pertinent to the scientific concept being explained and familiar or closer to learners' experiences.

As attributes of the explaining action in the classroom, the pre-service teachers valued the explicit inclusion of a diversity approach in the selection of examples, for instance, including gender, cultural differences, ethnical inter or intraindividual differences in the selection of learning resources and images to support the explanation construction.

3.2 RQ2. What factors affect pre-service teachers possible reframing of their conceptions about the quality of explanations for the classroom when in a real teaching context?

The factors that influenced participant conceptions during their first teaching experience were organised into enablers and obstacles. In order to illustrate the interpretations of participants' ideas, excerpts are presented as quotations, on which "I" indicates the number of the interviewee, followed by the paragraph number of the interview transcription.

1. Perceived enablers

The participants indicated that they felt confident explaining scientific concepts in the classroom if they were able to transfer what they had learnt at university. However, this did not necessarily mean that their explanations would be good quality; thus the role of a tutor or guide teacher was fundamental to reframe their conceptions and practice. The tutor was seen as the primary support in the participants' daily work, helping to make decisions and preparing lesson plans. Thus, this figure was mentioned by four of six beginning teachers as a facilitator of transference of a successful explaining performance when he or she was perceived as a good teacher, with high levels of content knowledge and available for being a role model.

> “Once a week, I sit with the coordinator to discuss lesson plans for half an hour… Before, I thought that a good quality explanation was, for example, when you know everything by memory, you can stand up in front of the class, and recall the topic transmitting it. But I never thought about emphasising the use of examples, the correct use of the concepts and prioritising them well ... to make them easier to understand and to be more consistent about that, because the examples must be consistent with the concept, about what you are teaching. Then you are creating the model.” (I5:19)

> “My guide teacher motivates me; I think she is one of the only good teachers in this school because the others do not have a good academic level, she is one of the few that does ... She is an outstanding teacher because knows how to teach, and she handles the content well.” (I2:32)

> “The teacher, for example, my teacher is for me a guide and a strong pillar.” (I4:14)

The second issue mentioned by three of the six participants was the school support or flexibility. It included support for beginning teachers' lessons and flexibility to incorporate their ideas, styles and interests in their way of teaching through explanations. This idea is shown, for instance, in these quotes:

> “And the other is also the access I have to the laboratory, the facilities the laboratory has in structure and implements... Or just if you want to do something different, you have it; in a different environment, here you have the water and everything you want to work differently. Then the laboratory is an enabler, a good facilitator.” (I4:14)

> “There is a lot of flexibility in this school to do the type of lesson I want.” (I5:13)

Finally, an element that facilitated teachers' reframing of conceptions about good explanations for the classroom was the process of criteria construction as a tool for their current practice and the critique they received in PA intervention, and as a way of learning which might be internalised as self-critique.

> “I think the creation of criteria was fundamental. Because now I check it in my mind, and I am going to the criterion I formulated. Because the things we saw in the university - after we do not remember it, but when you create criteria, it is different, because you think 'let's see how I did the lesson.” (I1:11)

> “I think our ability to create an instrument was essential because it helps us to improve our practices. Then, from what we have created, we correct ourselves now.” (I5:3)

> “...and because several times in the placement places they go once a day or twice, but doing the explanation within the [PA] seminar context, and then another explanation in the practice place would allow us to evaluate and compare reality with what we can do during the peer assessment seminar.” (I4:21)

> “I agree on the fact that now we are more concise and precise in what we are assessing, we are not focused only in macro aspects, but we are more focused now in the connecting ties of the lesson, or things that we were not focused on before. Now we can attack direct points, not general.” (I3:16)

2. Perceived obstacles

The participants identified four main impediments. The first two were associated with the students: their lack of scientific knowledge and participation or interest during the lessons. Some participants described this low interest as an obstacle to getting students motivated to learn science, to pay attention or think about alternative explanations. These were mentioned by four of the six teachers.

> "Well, in this case, I could easily explain and explain generating a monologue. But when you ask questions to the students, and you make students participate, you notice here students do not participate when I ask them." (I1, 29)

> "The pupils have the concepts in a still very basic way... I have to start levelling out to be able to teach." (I3, 14)

> "The pupils had problems with previous teachers, and then they have some content deficiencies." (I5, 7)

> "When you try to focus them [students] and get them interested in learning what you are showing... There are only 5 or 6 students who are interested in learning science because others are more interested in learning music or other things. They are also important areas to teach but getting them motivated to study science is difficult. This allowed me to think 'but if I had been explaining it, how I would do it? How would I take it?" (I4, 8)

Another obstacle was the limited time they had to plan the lessons, prepare the materials for the explanations and reflect on their explaining performance. This was a persistent factor mentioned, nine times by two of the teachers:

> "I would like to have more time to prepare lessons because time is a crucial determining factor. I dedicate the weekend to do it, in between that I have to have time for family life, and now, for example, I am taking paperwork to be done while I teach the other lesson." (I3, 16)

> "As I have little time for preparing the lessons, I would like to distribute less time to it and being able to apply what I already have structured only. I would like to do that." (I3, 20)

> "I would consider that here [in real classrooms], the teacher reflection process is much more valuable than how the lesson was made." (I3:39)

> "Each of us says we follow constructivism but in practice, but when you stand in front of the class it is different." (I1:30)

> "I believe that more than the lack of time for planning, the problem is the time for teaching reflection. When I am supposed to do my teaching reflection? On my pillow?" (I1, 57)

Additionally, some participants mentioned that trying to deal with low school resources hindered explanations for the classroom.

> "Here there is very little material to create worksheets, all that is printing I need to do it; and I pay for it. So, in that sense I would like to have more support, in order to do more exercise sheets, more explanatory sheets, having that resource ... I just want them to print it and distribute it to my two grades, fourth and fifth grade... that would facilitate my work a lot." (I3, 22)

Furthermore, some participants were critical about the initial teacher education they received, considering it disconnected from real teaching contexts. This might make them feel less confident at the moment of explaining to real students.

> "But I think that lessons we received in the university were planned considering that we will have an ideal class, where students' skills are high, where the classroom climate is good, where we are not considering the problems that students are exposed to." (I5, 11)

> "Regarding the explanations, they are always more related with the students' knowledge they already have, than with what I want to teach them." (I1, 27)

Finally, there was an element perceived with a potential role of enablers or obstacles, which reframed conceptions towards the relevance of classroom climate for constructing explanations. Five beginning teachers identified it as a potent mediator that could facilitate or hinder explaining in the way they wanted.

> "But only when I generate this good classroom climate, I can explain, and I am achieving a real lesson." (I1, 13)

> "I believe that children sometimes... they are not staying quiet, and then they do not listen. So, if they do not listen, you lose the connective thread of the explanation, because there are people making noise, disturbing, and there are other pupils concentrating. You think, 'Why are they not listening to me, maybe they do not care'... and I think that makes teaching more difficult sometimes." (I2, 26)

4 Discussion

From the participants' perspective, they gained awareness about their conceptions about explaining for the classroom after PA. They mentioned that most of their conceptions were related to the constructivist theory of learning. After comparing the ideas they had about teaching with their actual practice during the PA experience and reflecting on it, their elicited conceptions about explanations for the classroom were that scientific explanations that are fruitful for the classroom are contextualised. This means that the contents are not isolated but presented through concrete terms, using simpler or broader elements to connect students' ideas with the concept, theory or phenomena taught, and linked with students' prior knowledge. From this view, explanations should be constructed *with* students by integrating their questions, ideas, experiences, etc.; not delivered from teachers' knowledge only. Furthermore, scientifically clear explanations made explicit the similarities and differences of the concept meaning when used in daily life versus in a scientific context, including illustrative or worked examples. Some of these elements have also been proposed as a framework for explaining in the classroom (Kulgemeyer and Riese, 2018), such as explaining concepts in everyday language. Our participants pointed out crucial elements for dialogical explanations; considering the students' ideas and questions, and contextualising the explanation in broader terms. Those elements help shift the notion of explanation as a transmissive dispositive of knowledge towards a more horizontal view of knowledge creation opportunity.

After six months of the PA experience, the former attributes of the explaining action in the classroom were triggered by constructing the assessment criteria collectively. Participants mentioned that being systematically assessed and receiving constructive feedback was a key factor for noticing their conceptions and reframing their focus of analysis. This might contribute to having more tools for self-regulating their practices of constructing explanations (Nilsson, 2013). Changing the focus of analysis is crucial for participants' attention and observation for teaching, which has three main components; (a) identifying what is essential in teaching and learning interactions, (b) using principles of teaching and learning to reason about what one sees, and (c) making choices about how to respond on the basis of an analysis of the observations (Benedict-Chambers & Aram, 2017). In our study, the pre-service teachers identified what was fundamental for interaction through explanations, linked these ideas with theories of teaching and learning and used these ideas to reflect on their application and decision-making process in real teaching contexts.

The participants worked together to develop the criteria to assess their peers' explanations, which were, moreover, a form of negotiation of meaning about quality teaching through explanations. This might imply that PA works by increasing the critical capacity of pre-service teachers before they start teaching in real contexts. This necessary capacity for developing an analytical view of the explanations for science education might challenge pre-service teachers' tacit knowledge about teaching through explanations. Considering that explanations are manifestations of teachers'

PCK (Davidowitz & Rollnick, 2011; Rollnick & Mavhunga, 2015), the conceptions of explanations by the participants, as dually constructed from fragments of students' ideas and teachers' knowledge, opens new lenses for the notion of explaining. Some of the participants' considered the questions as part of the explanation, not only as a method for checking their understanding. Thus, explanations can be understood as a complex process that implies the use of representations of knowledge in construction, instead of teaching artefacts as final points of finished knowledge. Consequently, the notion of an explanatory framework as the way in which teachers use an analogy, metaphor, examples, axioms and concepts, linking them together into a coherent whole for the classroom (Geelan, 2003), would be enriched from the perspective of the participants in this study, resonating with the notion of explanations as communicative actions used to connect some part of the subject matter knowledge to the learners (Leinhardt, 2001), *with* the learners.

The development of pre-service teachers' professional knowledge comprises not only declarative knowledge but also procedural knowledge (Kulgemeyer & Riese, 2018). In our study, tacit knowledge about teaching through explanations was elicited and then confronted with real teaching challenges, perhaps helping pre-service teachers to arrive at a more realistic view of the processes of teaching, contributing to the awareness of how difficult it is to be a good explainer in the science classroom (Kulgemeyer & Riese, 2018). Moreover, the follow-up showed that the participants confronted the conceptions they elicited through PA during their real experience, while many of their ideas about high-quality explanations were constrained by the challenges of actual teaching. The beginner teachers seemed to self-evaluate their explanations focused more on the classroom environment they created and less on their explanation construction process. This perhaps brings into question the induction mechanisms of schools, in light of the fact that accompanying beginner teachers in their reflection on practice can be beneficial and that role models and mentors were mentioned as relevant for pre-service teachers. The participants showed concern about the quality of their explanations when they were observed in schools, due to the high level of noise in their classrooms and various students not concentrating on the lesson. This relates to Treagust and Harrison's (2003) ideas:

> "Teachers who are conscious of the constraining influence of the science content, the educational context, the students and their teaching and content knowledge limitations are more likely to recognise the challenge posed by classroom explanations. Indeed, teachers who purposefully reframe some of their explanations in light of these factors will likely enhance the quality of their classroom interactions." (pp. 40-41).

The present research showed that from the pre-service teachers' perspective, the design of assessment criteria and their application was the crucial element in further internalisation of criteria about constructing explanations and generalisation of these strategies into the teaching context, more so than receiving feedback on their other activities. Given that teachers in classrooms usually work alone, the internalisation of PA criteria seems a crucial element for promoting autonomous improvement in real teaching contexts. Furthermore, previous works in initial teacher education using PA were able to demonstrate that PA can help pre-service teachers' self-reflection and critical analysis of their peers' and their own practices (Harford & MacRuairc, 2008; Kim, 2009; Sluijsmans et al., 2004). Our study adds the relevance of the social construction of student-teacher conceptions, supporting Stiggins' (1991) idea of internalising quality criteria through PA with a perspective coming from the practitioners, not only from researchers. So, pre-service teachers could have a personal repositioning through discussing their performance in microteaching episodes with tutors and peers (l'Anson, et al., 2003).

Finally, an important point pertains to peer feedback and assessment. Van der Pol, Van den Berg, Admiraal, and Simons (2008) argued that useful peer feedback depends mainly on the assessor's skills in giving feedback. However, in our study, the peer assessors did not have prior training in delivering or receiving feedback. The present research resonates with the relevance of feedback but further extends the argument. Significant learning in teacher education is not only achieved as a consequence of the assessor's ability to give feedback, but in the internalisation and enactment of assessment criteria by the assesses. Perhaps the pre-service experience of constructing assessment criteria together and reciprocally peer evaluating their explanations contributed to facilitating observation of relevance for teaching. Moreover, the use of shared criteria for good quality explanations in the context of PA might have prompted participants' tacit knowledge into a more explicit - and modifiable - form of knowledge, crucial for self-regulated learning and teaching science in daily life (Nilsson, 2013). In other words, the design of assessment criteria in teacher education for PA and feedback could contribute to teachers developing an internalised self-assessment tool, useful for making autonomous decisions for their practice or future performance evaluation.

Teaching science through explanations is still an area in which much research remains to be done (Kulgemeyer & Riese, 2018), especially from the practitioners' perspective. We have identified student-teacher conceptions aided by peer assessment as a novel contribution. However, critically analysing the methodology of the present research, a consequence of implementing action research based on an elective workshop was the reduced number of participants and the progressive modification of participants' ideas, with no possibility to establish an initial and final state on those. We did however combine multiple sources of data regarding the participants' conceptions. Thus, the results of this research might be considered useful for other teacher education programs, although with careful contextual interpretation.

5 Conclusion

Student-teacher conceptions about the quality of scientific explanations were elicited in this study by analysing their assessment-feedback comments to peers, focus groups and interviews. The results showed that student-teacher conceptions about the quality of explanations for the science classroom were declared in connection with constructivist theory applied to science teaching, for instance, noticing that better explanations were those which connected the concepts with the students' ideas. The follow-up study showed the perceived enablers and obstacles about explaining in the classroom, reframing the participants' conceptions in the light on the constraints of real science instruction. This study revealed that peer assessment and feedback could play a significant role in teacher education by eliciting student-teacher conceptions about essential teaching practices, which might enhance end empower their skill development. Constructing explanations is a comprehensive strategy in teaching, but the opportunities for reflecting on it by pre-service teachers are still insufficient in teacher preparation programs. The few studies that reported using PA in science teacher education positioned it as a new research area. These studies were not focused on understanding the formative power of PA, as in the present research, which increases the range of available research in the usage of PA and highlights the significant role that PA can play in teacher education.

Moreover, the reframing of teacher conceptions in simulated and real teaching contexts as presented in this study is perhaps an input to sustainable project assessment. This point is made under the assumption that maintaining good practice is problematic if it is not underpinned by inward dispositions. The results obtained here revealed student-teacher conceptions about the quality of a common practice for teaching and the different focus between simulated and real contexts. We recommend to other programs that intend to modify specific student-teacher strategies, patterns or routines, that starting first by deconstructing the ideas that support practice in order to reconstruct them is a good idea. The participants in this study appreciated this method as a source of sustainable professional learning, embedded in free workshops. This can help both pre-service teachers and in-service teachers to assume a more professional role and give them a sense of ownership of their learning. For instance, constructing criteria to assess their work among peers within the schools could mean depending less on external examiners to define the quality of their practices - and more on local communities of learning.

Finally, this study opens new research questions about the role of peer assessment in teacher education. Is it possible to design opportunities for enhancing practices that rely upon student-teacher judgements? Is the incorporation of PA at the early stages of teacher education worthwhile for promoting autonomy and self-regulation of teaching practices? These and other questions are for further study.

6 Acknowledgements

This work was financially supported by CONICYT Programa de Cooperación Internacional REDES180109, Concurso de apoyo a la formación de redes internacionales entre centros de investigación, currently ANID/PCI/REDES180109.

References

Alt, D. (2018). Science teachers' conceptions of teaching and learning, ICT efficacy, ICT professional development and ICT practices enacted in their classrooms. *Teaching and Teacher Education, 73*, 141–150. https://doi.org/10.1016/j.tate.2018.03.020

Andreu, R., Canos, L., de Juana, S., Manresa, E., Rienda, L., & Tari, J. J. (2006). Quality performance assessment as a source of motivation for lecturers: A teaching network experience. *International Journal of Educational Management, 20*, 73–82. https://doi.org/10.1108/09513540610639602

Benedict-Chambers, A., & Aram, R. (2017). Tools for teacher noticing: Helping preservice teachers notice and analyse student thinking and scientific practice use. *Journal of Science Teacher Education, 28*(3), 294–318. https://doi.org/10.1080/1046560X.2017.1302730

Besson, U. (2010). Calculating and understanding: Formal models and causal explanations in science, common reasoning and physics teaching. *Science & Education, 19*(3), 225–257. https://doi.org/10.1007/s11191-009-9203-9

Borman, K. M., Mueninghoff, E., Cotner, B. A., & Frederick, P. B. (2009). Teacher preparation programs. In L. J. Saha & A. G. Dworkin (Eds.), *International handbook of research on teachers and teaching* (Vol. 21, pp. 123-140). New York: Springer.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Cabello, V. M., Real, C. & Impedovo, M. (2019). Explanations in STEM areas: An analysis of representations through language in teacher education. *Research in Science Education, 49*(4), 1087–1106. https://doi.org/10.1007/s11165-019-9856-6

Cabello, V. M. & Topping, K. (2018) Making scientific concepts explicit through explanations: Simulations of a high-leverage practice in teacher education. *International Journal of Cognitive Research in Science, Engineering and Education, 6*(3), 35–47 https://doi.org/10.5937/ijcrsee1803035C

Chan, K. W., & Elliott, R. G. (2004). Relational analysis of personal epistemology and conceptions about teaching and learning. *Teaching and Teacher Education, 20*(8), 817–831. https://doi.org/10.1016/j.tate.2004.09.002

Charalambous, C., Hill, H., & Ball, D. (2011). Prospective teachers' learning to provide instructional explanations: How does it look and what might it take? *Journal of Mathematics Teacher Education, 14*(6), 441–463. https://doi.org/10.1007/s10857-011-9182-z

Crawford B.A., Capps D.K. (2018) Teacher Cognition of Engaging Children in Scientific Practices. In: Dori Y., Mevarech Z., Baker D. (eds) *Cognition, Metacognition, and Culture in STEM Education. Innovations in Science Education and Technology*, vol 24. Springer, Cham. https://doi.org/10.1007/978-3-319-66659-4_2

Da-Silva, C., Mellado, V., Ruiz, C., & Porlan, R. (2007). Evolution of the conceptions of a secondary education biology teacher: Longitudinal analysis using cognitive maps. *Science Education, 91(3)*, 461–491. https://doi.org/10.1002/sce

Davidowitz, B., & Rollnick, M. (2011). What lies at the heart of good undergraduate teaching? A case study in organic chemistry. *Chemistry Education Research and Practice, 12*(3), 355–366. https://doi.org/10.1039/C1RP90042K

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*(6), 671–688. https://doi.org/10.1080/09500690305016

Fernandez, M. L. (2010). Investigating how and what prospective teachers learn through microteaching lesson study. *Teaching and Teacher Education, 26*(2), 351–362. https://doi.org/10.1016/j.tate.2009.09.012

Geelan, D. (2003). Teacher expertise and explanatory frameworks in a successful physics classroom. *Australian Science Teachers Journal, 49*(3), 22–32.

Geelan, D. (2012). Teacher explanations. In B. J. Fraser (Ed.), *Second international handbook of science education* (pp. 987-999). Dordrecht, The Netherlands: Springer.

Glaser, B. (2004). Remodeling Grounded Theory. *Forum Qualitative Social Research, 5*(2). http://dx.doi.org/10.17169/fqs-5.2.607

Gobierno de Chile. (2013). *Resultados nacionales de la evaluación docente 2012*. Santiago de Chile: Ministerio de Educación.

Goodnough, K. (2010). Teacher learning and collaborative action research: Generating a "knowledge-of-practice" in the context of science education. *Journal of Science Teacher Education*, 1–19. https://doi.org/10.1007/s10972-010-9215-y

Grangeat, M., & Kapelari, S. (2015). Exploring the growth of science teacher professional knowledge. In M. Grangeat (Ed.), *Understanding science teacher professional knowledge growth* (pp. 1-9). Boston: Sense Publisher.

Hadzidaki, P. (2008). 'Quantum mechanics' and 'scientific explanation': An explanatory strategy aiming at providing 'understanding'. *Science & Education, 17*(1), 49–73. https://doi.org/10.1007/s11191-006-9052-8

Harford, J., & MacRuairc, G. (2008). Engaging student-teachers in meaningful reflective practice. *Teaching and Teacher Education, 24*(7), 1884–1892. https://doi.org/10.1016/j.tate.2008.02.010

Herman, B. C., Owens, D. C., Oertli, R. T., Zangori, L. A., & Newton, M. H. (2019). Exploring the complexity of students' scientific explanations and associated nature of science views within a place-based socioscientific issue context. *Science & Education*, 28(3-5), 329–366. https://doi.org/10.1007/s11191-019-00034-4

Hermans, R., van Braak, J., & Van Keer, H. (2008). Development of the Beliefs about Primary Education Scale: Distinguishing a developmental and transmissive dimension. *Teaching and Teacher Education, 24*(1), 127–139. http://dx.doi.org/10.1016/j.tate.2006.11.007

Hume, A. C. (2012). Primary Connections: Simulating the classroom in initial teacher education. *Research in Science Education, 42*(3), 551–565. https://doi.org/10.1007/s11165-011-9210-0

Inoue, N. (2009). Rehearsing to teach: Content-specific deconstruction of instructional explanations in preservice teacher training. *Journal of Education for Teaching, 35*(1), 47–60. https://doi.org/10.1080/02607470802587137

Isikoglu, N., Basturk, R., & Karaca, F. (2009). Assessing in-service teachers' instructional beliefs about student-centered education: A Turkish perspective. *Teaching and Teacher Education, 25*(2), 350–356. https://doi.org/10.1016/j.tate.2008.08.004

Jian, W., Odell, S. J., & Schwille, S. A. (2008). Effects of teacher induction on beginning teachers' teaching. *Journal of Teacher Education, 59*(2), 132–152. https://doi.org/10.1177/0022487107314002

Kampourakis, K., & Zogza, V. (2008). Students' intuitive explanations of the causes of homologies and adaptations. *Science & Education, 17*(1), 27–47. https://doi.org/10.1007/s11191-007-9075-9

Kahneman, D. (2011). *Thinking, fast and slow*. New York: Farrar, Starus and Corby.

Kember, D., & Kwan, K.-P. (2000). Lecturers' approaches to teaching and their relationship to conceptions of good teaching. *Instructional Science, 28*(5), 469–490. https://doi.org/10.1023/A:1026569608656

Kilic, G. B., & Cakan, M. (2007). Peer assessment of elementary science teaching skills. *Journal of Science Teacher Education, 18*(1), 91–107. https://doi.org/10.1007/s10972-006-9021-8

Kim, M. (2009). The impact of an elaborated assessee's role in peer assessment. *Assessment & Evaluation in Higher Education, 34*(1), 105–114. https://doi.org/10.1080/02602930801955960

Kollar, I., & Fischer, F. (2010). Peer assessment as collaborative learning: A cognitive perspective. *Learning and Instruction, 20*(4), 344–348. doi: http://dx.doi.org/10.1016/j.learninstruc.2009.08.005

Koballa, T. R., Glynn, S. M., & Upson, L. (2005). Conceptions of teaching science held by novice teachers in an alternative certification program. *Journal of Science Teacher Education, 16*(4), 287–308. https://doi.org/10.1007/s10972-005-0192-5

Kulgemeyer, C., & Riese, J. (2018). From professional knowledge to professional performance: The impact of CK and PCK on teaching quality in explaining situations. *Journal of Research in Science Teaching, 55*(10), 1393–1418. https://doi.org/10.1002/tea.21457

Kulgemeyer, C., Borowski, A., Buschhüter, D., Enkrott, P., Kempin, M., Reinhold, P., & Vogelsang, C. (2020). Professional knowledge affects action-related skills: The development of preservice physics teachers' explaining skills during a field experience. *Journal of Research in Science Teaching,* 1–29 https://doi.org/10.1002/tea.21632

l'Anson, J., Rodrigues, S., & Wilson, G. (2003). Mirrors, reflections and refractions: The contributions of microteaching to reflective practice. *European Journal of Teacher Education, 26*(2), 189–200. https://doi.org/10.1080/0261976032000088729

Lawson, M. J., Askell-Williams, H., & Murray-Harvey, R. (2009). Dimensions of quality in teacher knowledge. In L. J. Saha & A. G. Dworkin (Eds.), *International handbook of research on teachers and teaching* (Vol. 21, pp. 243-257): Springer US.

Lehrer, R., & Schauble, L. (2010). What kind of explanation is a model? In M. K. Stein & K. L. (Eds.), *Instructional explanations in the disciplines*. Pittsburg: Springer.

Leinhardt, G. (2001). Instructional explanations: A commonplace for teaching and location for contrast. In V. Richardson (Ed.), *Handbook of research on teaching* (4th ed., pp. 333-357). Washington, DC: American Educational Research Association.

Liu, N., & Carless, D. (2006). Peer feedback: The learning element of peer assessment. *Teaching in Higher Education, 11*(3), 279–290. https://doi.org/10.1080/13562510600680582

Lu, H. (2010). Research on peer coaching in preservice teacher education – A review of literature. *Teaching and Teacher Education, 26*(4), 748–753. http://dx.doi.org/10.1016/j.tate.2009.10.015

Marzabal, A., Merino, C., Moreira, P., & Delgado, V. (2019). Assessing science teaching explanations in initial teacher education: How is this teaching practice transferred across different chemistry topics? *Research in Science Education. 49*(4),1107–1123. https://doi.org/10.1007/s11165-019-9855-7

Mellado, V. (1998). The classroom practice of preservice teachers and their conceptions of teaching and learning science. *Science Education, 82*(2), 197–214. https://doi.org/10.1002/(SICI)1098-237X(199804)82:2<197::AID-SCE5>3.0.CO;2-9

Mohan, R. (2007). *Innovative science teaching for physical science teachers* (3rd ed.). India: Prentice Hall.

Moje, E., Collazo, T., Carrillo, R., & Marx, R. W. (2001). "Maestro, what is 'quality'?": Language, literacy and discourse in project-based science. *Journal of Research in Science Teaching, 38*(4), 469–498. https://doi.org/10.1002/tea.1014

Nicol, D. J., & Boyle, J. T. (2003). Peer instruction versus class-wide discussion in large classes: A comparison of two interaction methods in the wired classroom. *Studies in Higher Education, 28*(4), 457–473. https://doi.org/10.1080/0307507032000122297

Nilsson, P. (2013). What do we know and where do we go? Formative assessment in developing student-teachers' professional learning of teaching science. *Teachers and Teaching: Theory and Practice, 19*(2), 188–201. https://doi.org/10.1080/13540602.2013.741838

Norcini, J. J. (2003). Peer assessment of competence. *Medical Education, 37*(6), 539–543. https://doi.org/10.1046/j.1365-2923.2003.01536.x

Ospina-Quintero, N., & Bonan, L. B. (2011). Explicaciones y argumentos de profesores de química en formación inicial: La construcción de criterios para su evaluación. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 8*(1), 2–19. http://dx.doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2011.v8.i1.02

Ostrosky, M. M., Mouzourou, C., Danner, N., & Zaghlawan, H. Y. (2013). Improving teacher practices using microteaching: Planful video recording and constructive feedback. *Young Exceptional Children, 16*(1), 16–29. https://doi.org/10.1177/1096250612459186

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307-332. https://www.jstor.org/stable/1170741

Patton, M. (2001). *Qualitative evaluation and research methods* (3rd ed.). Newbury Park, CA: Sage Publications.

QSR. (2011). NVivo qualitative data analysis software (Version 9). Daresbury, UK: QSR International Pty Ltd.

Rollnick, M. & Mavhunga, E. (2015). The PCK Summit and its effect on work in South Africa. In A. Berry, P. Friedrichsen & J. Loughran (Eds.). *Re-examining pedagogical content knowledge in science education*. New York: Routledge https://doi.org/10.4324/9781315735665

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14. https://doi.org/10.3102/0013189X015002004

Sluijsmans, D., Brand-Gruwel, S., & van Merriënboer, J. J. G. (2002). Peer assessment training in teacher education: Effects on performance and perceptions. *Assessment & Evaluation in Higher Education, 27*(5), 443–454. https://doi.org/10.1080/0260293022000009311

Sluijsmans, D., Brand-Gruwel, S., van Merriënboer, J. J. G., & Bastiaens, T. J. (2002). The training of peer assessment skills to promote the development of reflection skills in teacher education. *Studies in Educational Evaluation, 29*(1), 23–42.

Sluijsmans, D., Brand-Gruwel, S., van Merriënboer, J. J. G., & Martens, R. L. (2004). Training teachers in peer-assessment skills: Effects on performance and perceptions. *Innovations in Education and Teaching International, 41*(1), 59–78. https://doi.org/10.1080/1470329032000172720

Sluijsmans, D., & Prins, F. (2006). A conceptual framework for integrating peer assessment in teacher education. *Studies in Educational Evaluation, 32*(1), 6–22. https://doi.org/10.1016/j.stueduc.2006.01.005

Stiggins, R. (1991). Relevant classroom assessment training for teachers. *Educational Measurement: Issues and Practice, 10*, 7–12. www. https://eric.ed.gov/?id=EJ423893

Thagard, P. (1992). Analogy, explanation, and education. *Journal of Research in Science Teaching, 29*(6), 537–544. https://doi.org/10.1002/tea.3660290603

Topping, K. J. (2010). Peers as a source of formative assessment. In G. J. Cizek (Ed.), *Handbook of formative assessment* (pp. 61-74). London & New York: Routledge.

Treagust, D., & Harrison, A. (2003). The genesis of effective scientific explanations for the classroom. In J. Loughran (Ed.), *Researching teaching: Methodologies and practices for understanding pedagogy*. (2ª ed. pp. 28-43). New York: Routledge.

Tsai, C., Lin, S. S. J., & Yuan, S.-M. (2002). Developing science activities through a networked peer assessment system. *Computers & Education, 38*(1–3), 241–252. https://doi.org/10.1016/S0360-1315(01)00069-0

Valanides, N. (2010). Analysis of interview data using the constant comparative analysis method. In S. Rodrigues (Ed.), *Using analytical frameworks for classroom research* (Vol. 1). London: Routledge.

Van der Pol, J., Van den Berg, B. A. M., Admiraal, W. F., & Simons, P. R. J. (2008). The nature, reception, and use of online peer feedback in higher education. *Computers & Education, 51*(4), 1804–1817. doi: http://dx.doi.org/10.1016/j.compedu.2008.06.001

Vermunt, J., & Endedijk, M. (2011). Patterns in teacher learning in different phases of the professional career. *Learning and Individual Differences, 21*, 294–302. https://doi.org/10.1016/j.lindif.2010.11.019

Wen, M. L., & Tsai, C. (2008). Online peer assessment in an inservice science and mathematics teacher education course. *Teaching in Higher Education, 13*(1), 55–67. https://doi.org/10.1080/13562510701794050

Windschitl, M., Thompson, J., & Braaten, M. (2018). *Ambitious science*. Boston, MA: Harvard Education Press.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education, 96*(5), 878–903. https://doi.org/10.1002/sce.21027

Wittwer, J., & Renkl, A. (2008). Why instructional explanations often do not work: A framework for understanding the effectiveness of instructional explanations. *Educational Psychologist, 43*(1), 49–64. https://doi.org/10.1080/00461520701756420

Zhang, F., & Liu, Y. (2014). A study of secondary school English teachers' beliefs in the context of curriculum reform in China. *Language Teaching Research, 18*(2), 187–204.

Draw-A-Science-Comic: Alternative prompts and the presence of danger

Jaakko Lamminpää[1] and Veli-Matti Vesterinen[2]

[1] Department of Physics and Astronomy, University of Turku, Finland
[2] Department of Chemistry, University of Turku, Finland

The early years of primary school are important in shaping how children see scientists and science, but researching younger children is known to be difficult. The Draw-A-Scientist Test (DAST), in which students are asked to draw a scientist, has been one of the most popular ways to chart children's conceptions of scientists and science. However, DAST tends to focus mainly on children's conceptions about the appearance of scientists. To focus more on children's conceptions of scientific activities as well as the emotions and attitudes associated with science, the Draw-A-Science-Comic test (DASC) was recently introduced. This study compares three alternative DASC prompts for two age groups of respondents (8- to 10-year-olds and 10- to 13-year-olds). The prompts asking students to draw a comic or a set of pictures produced significantly more sequential storytelling and depictions of science related emotions and attitudes than the prompt asking students to depict a story. The depictions of elements of danger, such as accidents and hazards in the laboratory, were also frequent in drawings with sequential storytelling. A more detailed analysis of the depictions showed that the frequency of elements of danger was closely associated with depictions of activity especially in the field of chemistry. For example, several comics included failed chemical experiments leading to explosions. Although depictions of danger are sometimes interpreted as a negative conception, in the children's drawings the explosions and overflowing flasks were often seen also as a source of excitement and joy. Based on the result of this study, the use of DASC seems a suitable way for charting children's conceptions of scientific activities as well as the emotions and attitudes associated with science from the early years of primary education until the beginning of secondary education.

Keywords: Draw-A-Scientist Test, DAST, science education, primary school, stereotypes, drawing, misconceptions

Article Details

LUMAT General Issue
Vol 8 No 1 (2020), 319–339

Received 22 July 2020
Accepted 4 December 2020
Published 21 December 2020

Pages: 21
References: 60

Correspondence:
jaakko.lamminpaa@utu.fi
veli-matti.vesterinen@utu.fi

https://doi.org/10.31129/LUMAT.8.1.1385

1 Introduction

If you were asked to picture a scientist, you would most likely think of an older man in lab coat, fizzy hair, safety glasses and chemistry equipment. This is not surprising as it is the predominant way children depict a scientist (Chambers, 1983; Finson, 2002; Miller, Nolla, Eagly, & Uttal, 2018), and it is so deeply rooted that even teachers and adults hold similar stereotypic views (Losh, 2010; McCarthy, 2015). When questioned further, people might additionally have alternative and more accurate views on scientists (e.g. Finson, Beaver, & Cramond, 1995), but the stereotype is

Published by the University of Helsinki, Finland / LUMA Centre Finland | CC BY 4.0

usually the first one to pop into one's mind. At first glance, this might not seem particularly harmful, but it paints a distorted image of science as suitable only for eccentric, old and overly genius men (e.g. Finson, 2002; Reis & Galvao, 2004) and lonely researchers who have devoted their whole life to science (e.g. Christidou, Bonoti, & Kontopoulou, 2016). These kinds of conceptions might be the underlying cause why students won't find science interesting or consider taking up a career in sciences (e.g. Archer et al., 2013).

Drawing tasks have been a common method for data collection to study these stereotypes and other conceptions of scientists. One of the most frequently used method has been the Draw-A-Scientist Test (DAST) (see Chang et al., 2020; Finson, 2002; Miller et al., 2018). Drawing is especially useful for studying children as it doesn't require advanced writing or verbal skills (Finson et al., 1995; Prosser & Burke, 2008), but it has also turned out to be an effective tool for studying older students and adults alike (e.g. McCarthy, 2015; Reinisch, Krell, Hergert, Gogolin, & Krüger, 2017). The DAST was originally designed to determine when students' drawings begin to exhibit stereotypic indicators of scientists (Chambers, 1983). It has since then been modified by using alternative prompts (e.g. Symington & Spurling, 1990), revised checklists (e.g. Finson et al., 1995) and evaluation rubrics (e.g. Farland-Smith, 2012). The studies have also focused to address different research questions, such as the effects of ethnicity, culture and gender (Christidou, 2011; Christidou et al., 2016; Miller et al., 2018) as well as the impact of different teaching interventions (Cakmakci et al., 2011; Hillman, Bloodsworth, Tilburg, Zeeman, & List, 2014; Miele, 2014).

Originally DAST focused on the stereotypic appearance, but lately it has also been used to study students' conceptions of research environments and research activities (e.g. Farland-Smith, 2012; Reinisch et al., 2017). Emvalotis and Koutsianou (2018) have pointed out that students' attitudes towards science are probably more linked to their views about science as an activity than to their conceptions about the appearance of scientists. This in mind, Lamminpää, Vesterinen and Puutio (2020) introduced a new method: the Draw-A-Science-Comic (DASC). It was built on DAST, but the idea was to focus especially to the scientific activities and the related emotions by drawing comics. The results showed that children would be able to express their thoughts about scientists' work better than in DAST by using sequential pictures. However, in their comics children often included dangerous elements and situations, such as explosions when mixing liquids, which might be due to the comic format. This study develops the method introduced in the aforementioned pilot study further by evaluating the use of three different prompts. It also explores the way children depict danger in their sequential drawings.

2 Literature

2.1 The influence of the stereotypic image

A standard or a stereotypic image of scientist plays a crucial role in shaping people's conceptions and attitudes from childhood to adulthood. The stereotypic image develops already during the first years of primary school (Arthur, Bigler, Liben, Gelman, & Ruble, 2008; Chambers, 1983; DeWitt & Archer, 2015), and from that point on stereotypes, conceptions and views related to science have a notable impact on children's attitudes towards science (Archer et al., 2013; Christidou, 2011; Dimopoulos & Smyrnaiou, 2005). This also affects their motivation, interest in the subject, and even school and career choices (Britner, 2008; DeWitt & Archer, 2015; Fung, 2002). Even greater impact comes from the fact that these views persist firmly to adulthood (Losh, 2010; Rahm & Charbonneau, 1997), after which the aspirations are unlikely to change dramatically (Aschbacher, Li, & Roth, 2010; Maltese & Tai, 2011).

These attitudes can be seen in many developed countries. For example, in Finland a report including over 65 000 9th graders noted that while students acknowledge the importance of natural sciences, they find it uninteresting or even off-putting (Kärnä, Hakonen, & Kuusela, 2012). Jenkins and Nelson (2005) noticed similar results among secondary school students in England. The phenomenon is peculiar because students still considered science as important and something that 'everybody should learn in school' (Jenkins & Nelson, 2005; Kärnä et al., 2012). While some students still find science fascinating, in the end, they do not see themselves working as scientists (DeWitt & Archer, 2015). This leads to a conclusion that the usual way of highlighting the importance of science is not enough to encourage students to pick up a career in sciences.

In addition to the standard image, this can be applied to the stereotypes regarding the scientific activities (cf. Emvalotis & Koutsianou, 2018) and other aspects, and it is paramount to address these issues at an early age. In order to do so, we must have a wider and deeper understanding of young children's stereotypes and conceptions affecting their attitudes (Campbell, Schwarz, & Windschitl, 2016; Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012; Farland-Smith, Finson, Boone, & Yale, 2012).

2.2 The stereotypic image and the modified DAST

David Chambers (1983) was the first to use drawing as a method to observe when children began to form the stereotypical conception of the appearance of a scientist. In his Draw-A-Scientist Test (DAST), primary school students were asked to ‘draw a picture of a scientist’ and the instances of indicators for a standard image of a scientist were counted. The standard image could better be described as a stereotype of a scientist as on older Caucasian male with a lab coat, glasses, fizzy hair, and surrounded by chemistry equipment, and it developed during the first four years of elementary school. Later on, researchers have modified the DAST to include additional aspects and to answer alternative research questions. The following summary focuses on the most relevant modifications and studies. For a more detailed history of the (modified) DAST, using drawings as a research instrument, and the related methodical challenges, see studies by Finson (2002), Losh et. al (2008), Reinisch et. al (2017), and Chang et. al (2020).

Symington and Spurling (1990) compared the original prompt (‘Draw a picture of a scientist’) to a new one: ‘do a drawing which tells me what you know about scientists and their work’. Although some children produced similar depictions with both instructions, the majority did not. The inclusion of participants’ own beliefs and the differences in the drawings indicated that children might hold alternative views but are inclined to draw the stereotype when the traditional prompt is used. The prompt is guiding the focus to scientists’ work and not just the appearance. In a similar fashion, the impact of the prompt has been noted and utilized for alternative research foci, like conceptions related to scientists in different fields of science (e.g. Hansen et al., 2017; Oktay & Eryurt, 2012).

In 2003, Donna Farland introduced the modified DAST, which included a revised prompt and a new rubric to evaluate the drawings (Farland-Smith, 2012). She had a more detailed prompt asking the participants to imagine scientists working, draw them busy with work, and add captions what they are saying or doing. The pictures were evaluated for the level of accuracy in three different categories: appearance (what scientists look similar to), location (where scientists work), and activity (what scientists do). Including activity into the evaluation was a step towards better understanding children’s views and attitudes towards science. As recent studies show, the attitudes are more related to conceptions of what scientists do instead of what they look like (Christidou et al., 2016; Emvalotis & Koutsianou, 2018).

Scientific activities are difficult to portray in a single picture (see Reinisch et al., 2017), which led to the development of the Draw-A-Science-Comic test (DASC) (Lamminpää et al., 2020). The test was based on the modified DAST, but instead of using a single picture, the participants were asked to draw a comic. With a comic the participants could depict activities, human interaction, emotions, and tell a story through sequential pictures (cf. Eisner, 2008; Kress, 2010; Kuttner, Sousanis, & Weaver-Hightower, 2017). The prompt was designed as open as possible (see Reinisch et al., 2017), and the participants received only the prompt: 'Draw a comic about how you think science is done'. [1] The results showed that almost every comic depicted scientific activities, such as different phases of research, solving problems, and discussing or evaluating results. Furthermore, many comics showed an affective side of science, such as frustration and anger due to failed experiments, astonishment of chemical reaction and joy of a successful task (cf. Hsieh & Tsai, 2017). However, DAST seemed to be more suited to observe the appearance and the location. Lamminpää and his colleagues (2020) also noted a significant amount of dangerous elements and situations, such as explosions after mixing chemicals, when compared to DAST. In light of these findings, they suggested testing alternative prompts to study the impact of the comic format.

2.3 The critique of DAST and drawing instruments

Despite being popular, drawing as a research instrument has also received a fair amount of critique. For example, when prompted to draw another scientist, some children tend to draw a character that is vastly different from their earlier depiction. This has lead researchers to conclude that children can hold multiple conceptions of scientists (e.g. Losh et al., 2008; Maoldomhnaigh & Hunt, 1988). Finson and Pederson (2011) even stated that children's presentations often differ from the views they express in interviews. They argued that drawing assignments might encourage the children to draw pictures they think are easily recognizable to the viewer. While this might be true, charting the stereotypes still holds value. Even if the students do not fully believe their depicted stereotypes to be factual, the portrayal of stereotypes shows the children are at least aware of them, and such awareness might affect their

[1] Translated from Finnish.

attitudes towards science. However, all drawings are subjected to interpretations, and as such, it is difficult to explicitly connect different aspects in drawings to conceptions or attitudes of individual students (Losh et al., 2008). This is especially important when interpreting symbols that might hold multiple or even hidden meanings (Ball & Smith, 1992; Reinisch et al., 2017). Furthermore, the children's ability or willingness to depict their conceptions has been criticised (e.g. Yuen, 2004). While drawing does not require verbal or written answers, children have limited drawing abilities and they might struggle to convey their ideas through drawings.

To address the aforementioned challenges it has been suggested, that additional data gathering methods should be utilized to verify researchers' interpretations and to assign meaning to drawn items (e.g. Reinisch et al., 2017). Thus several studies have used additional questionnaires and interviews to triangulate children's thoughts more accurately (e.g. Ehrlen, 2009; Hillman et al., 2014; Reinisch et al., 2017). Questionnaires and interviews can be considered appropriate for older students and adults (McCarthy, 2015; Reinisch et al., 2017), but younger children may harbour stereotypes before being able to express them explicitly (Galdi, Cadinu, & Tomasetto, 2014). Therefore, the use of indirect measurements, such as drawing, might be more effective for younger children than verbal or written methods (Cvencek & Meltzoff, 2015; Losh et al., 2008). Similarly, Chang and colleagues (2020) summarized in their systematic review four main justifications for using drawings as a research tool: a) an alternative to overcome the young participants verbal and writing abilities, b) a method to reveal aspects not easily recognized with other methods, c) a major method that reflects characteristics of science subjects and (d) a formative assessment to diagnose students' ideas to benefit their learning.

3 Rationale and research questions

This study continues the development of the Draw-A-Science-Comic test (DASC). In DASC the children are able to depict especially their conceptions of scientific activities and emotions related to science through sequential pictures (Lamminpää et al., 2020). However, the prompt might affect the way children depict science and research (e.g. Symington & Spurling, 1990). For example, in DASC the word 'comic' in the prompt might invite children to draw unwanted accidents and dangerous situations. The goal of this study was to test alternative prompts and their effect on the children's depictions of science and scientists while maintaining the sequential story-telling format. A more detailed description of the different categories and the analysis is presented in the method section. Three different DASC prompts were used and their impact on the depictions of science was compared. As the data was collected from two different age groups, the differences between the age groups were also analysed. The research questions were:

1. How do the alternative prompts for the Draw-A-Science-Comic test (DASC) affect the frequency of sequential storytelling as well as the frequency of depictions of appearance, location, activity, emotions and attitudes, and elements of danger?
2. How children's age affects the frequency of sequential storytelling as well as the frequency of depictions of appearance, location, activity, emotions and attitudes, and elements of danger.

To further understand the results of the first round of analysis, the results in each category were compared with other categories. The closer analysis revealed that the elements of danger were associated with activities and especially with laboratory work in chemistry. Thus, the second round of analysis focused on the depictions of elements of danger and sought to answer two interconnected research questions which were:

3. How elements of danger were depicted in a sequential format?
4. How prevalent were the depictions of elements of danger in the most frequently depicted fields of science?

4 Method

4.1 Design of the prompts

The Draw-A-Science-Comic test uses the prompt 'Draw a comic about how you think science is done' (Lamminpää et al., 2020). The prompts used in the study were in Finnish and prompts presented here are translations of the prompts. The idea of DASC is to invite the children to draw sequential pictures and enable them to tell a story about how scientists work through a wide array of different modes of communication (see Lamminpää et al., 2020). Two alternative prompts with the same aim were designed for this study. The first revised prompt replaced the word 'comic' with the word 'story' and the second revised prompt used the phrasing 'set of pictures'. Both prompts have a similar purpose as the comic and they invite to tell a story through multiple frames and sequential storytelling. The complete prompts are presented in Table 1.

Table 1. Participants and their age group for each prompt.

Prompt	Age	Participants
Draw a comic about how you think science is made	8–10	37
	10–13	36
Draw a story about how you think science is made	8–10	40
	10–13	28
Draw a set of pictures about how you think science is made	10–13	39

4.2 Participants and data collection

The data was collected from 180 children attending the science camps of a Finnish university during summer 2018. The summer camp participants were chosen randomly from those who applied. The main topics for the camps were physics and astronomy, nature science (biology and chemistry), and robotics. The camps were organized for two separate age groups (8-10 year-olds and 10-13 year olds) which allowed us to compare the effects on different age groups. However, we had 5 test groups which consisted of 2 younger and 3 older groups. As we considered the set of pictures task to be less tangible, it was chosen to be drawn only by the older participants. The DASC was administered before the camps started during the info session and the prompts included roughly equal distribution of participants from all camp themes. By request of the organizers, no personal data was gathered to ensure the anonymity of the children. According to the guidelines set by the Finnish National Board of Research Integrity TENK (Kohonen, Kuula-Luumi, & Spoof, 2019) consent to participate was obtained from the children as well as their parents. The number of participants for both age groups are presented in the Table 1.

The data was collected before the science camp started, but the children were most likely influenced by their expectations about the upcoming camp. This increases the probability to include these ideas in their drawings. In addition, it should be taken into account that children taking part in science camp are also most likely more interested and better informed about science than their peers on average. Thus, we refrain from making generalisations about the prevalence of the views depicted.

4.3 Method of analysis

During the first phase each drawing was analysed using four main categories. These mutually non-exclusive categories included the depictions about the (i) appearance of scientists, (ii) locations of research, (iii) research activities, and (iv) emotions and attitudes related to science and research. The definitions for each category are intuitive and include depictions and information of the category (see Lamminpää et al., 2020). The exact nature of these depictions, however, is not included in the analysis due to the lack of supporting data gathering methods, and the aim of this study is to focus on the effect of the different prompts. As the use of sequential storytelling is the central characteristics of DASC, the instances of sequential stories were also calculated. Non-sequential drawings included both single DAST-like pictures as well as collections of separate pictures that did not tell a linear story (cf. Reinisch et al., 2017). One of observation of the initial DASC study (Lamminpää et al., 2020) was that elements of danger seemed to be rather prevalent in DASC drawings. Therefore, the instances of elements of danger were also included in the analysis. The Chi-squared test was used to calculate the significance of differences between the original DASC task and the two alternative tasks. To ensure the reliability of the analysis, all drawings were independently analysed by two coders. To measure the inter-rater reliability during the first phase of analysis, Cohen's Kappa was calculated for each category. After this, the differences in the analysis were discussed until a consensus was reached.

As an example of the first phase of the analysis, we present a comic drawn by a 10- to 13-year-old (Figure 1). The comic consists of three separate sequential depictions of scientists doing research in the fields of astronomy, chemistry and biology. In the first one, a person is observing stars with a telescope. The second part shows how mixing wrong liquids leads to an explosion or the mixture pouring over. The experiment still seems to yield a new scientific finding. The last depiction shows a researcher finding a flower. When she cannot find the description of the species in a book, she comes to a conclusion that she has found a new species. Even though the comic portrays scientists as stick figures, it still includes variation in the depictions of the appearance of scientists. For example, only one of the scientists—the astronomer—had glasses. The comic included also depictions of several locations of research as well as research activities.

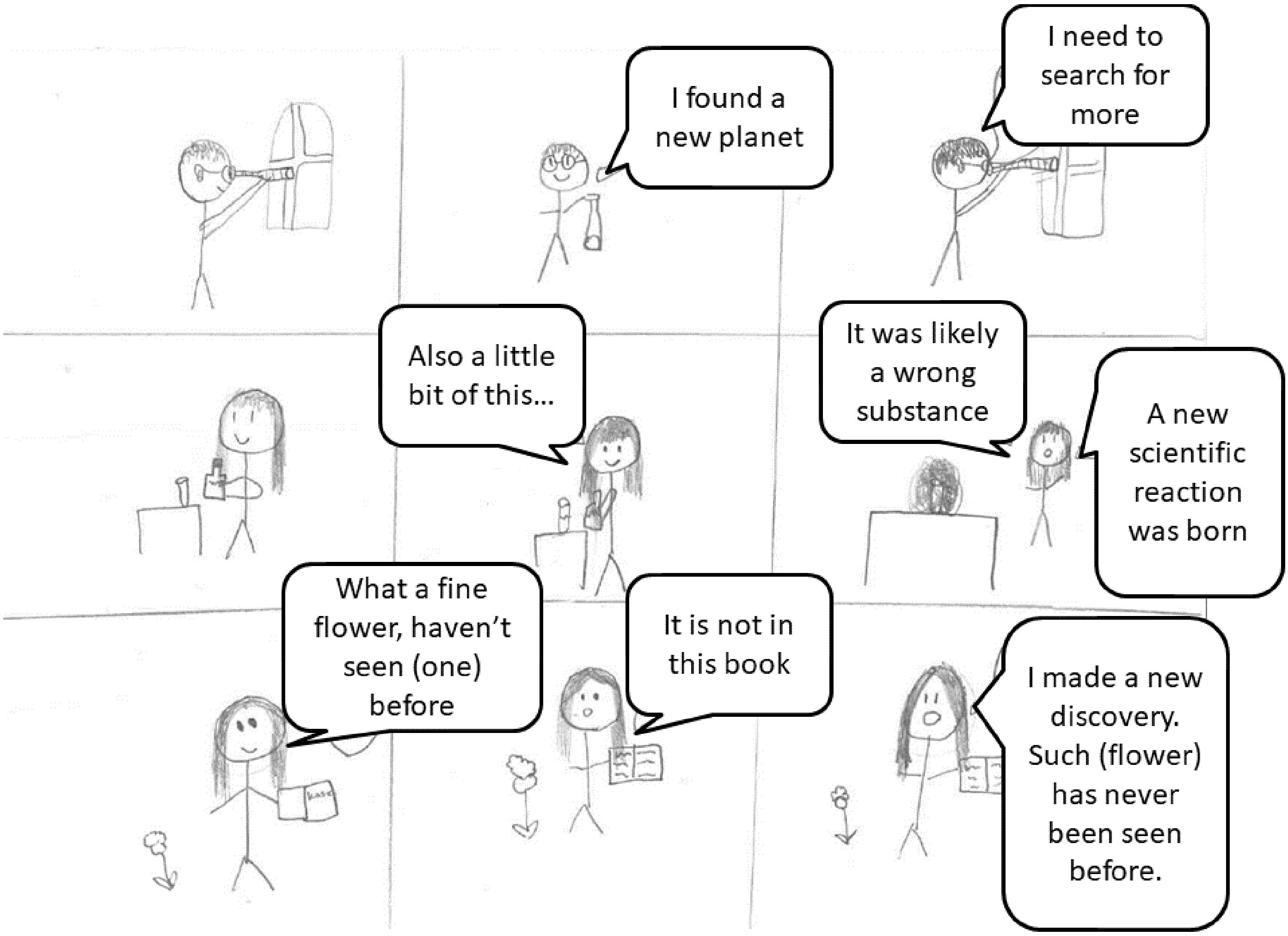


Figure 1. A comic with three strips depicting different scientific research activities. The text is translated from Finnish.

By comparing the results in each category of analysis with others, it was noticed, that the depictions of elements of danger were related to the depictions of activity. To provide a better overview of how the activities and dangers were related, the elements of danger were further categorized into two inductively formed categories. In this second phase of analysis, each element of danger was categorized either as a part of the activity, such as an explosion resulting from mixing liquids, or as a static symbol of danger, such as a warning sign.

During the closer analysis of the depictions of elements of danger, it was also noticed, that most of the elements of danger seemed to be connected with depictions of chemical laboratory experiments. To evaluate the significance of this observation, different activities were categorized based on the fields of science depicted in the drawing. The categories were again formed inductively. The most often depicted fields of science included chemistry, biology, space research and robotics. Some of the drawings included multiple activities with different fields of science (see Figure 1). The Chi-squared test was used to calculate the statistical significance of the differences in the frequency of the elements of danger associated with each recognized field of science. As an example of a drawing depicting danger associated with chemistry, the story from an 8- to 10-year-old depicts a female scientist with a lab coat and safety glasses mixing liquids in a laboratory (Figure 2). In this drawing, the danger was clearly part of the activity. The story also included depictions of emotions related to scientific research. The story begins with frustration caused by constant explosions. After a while the researcher tries again, changes clothes and is seemingly happier. However, another explosion follows, causing some disorientation or confusion, which leads to boiling anger and a packed suitcase. The story ends with a phrase ’I quit’.

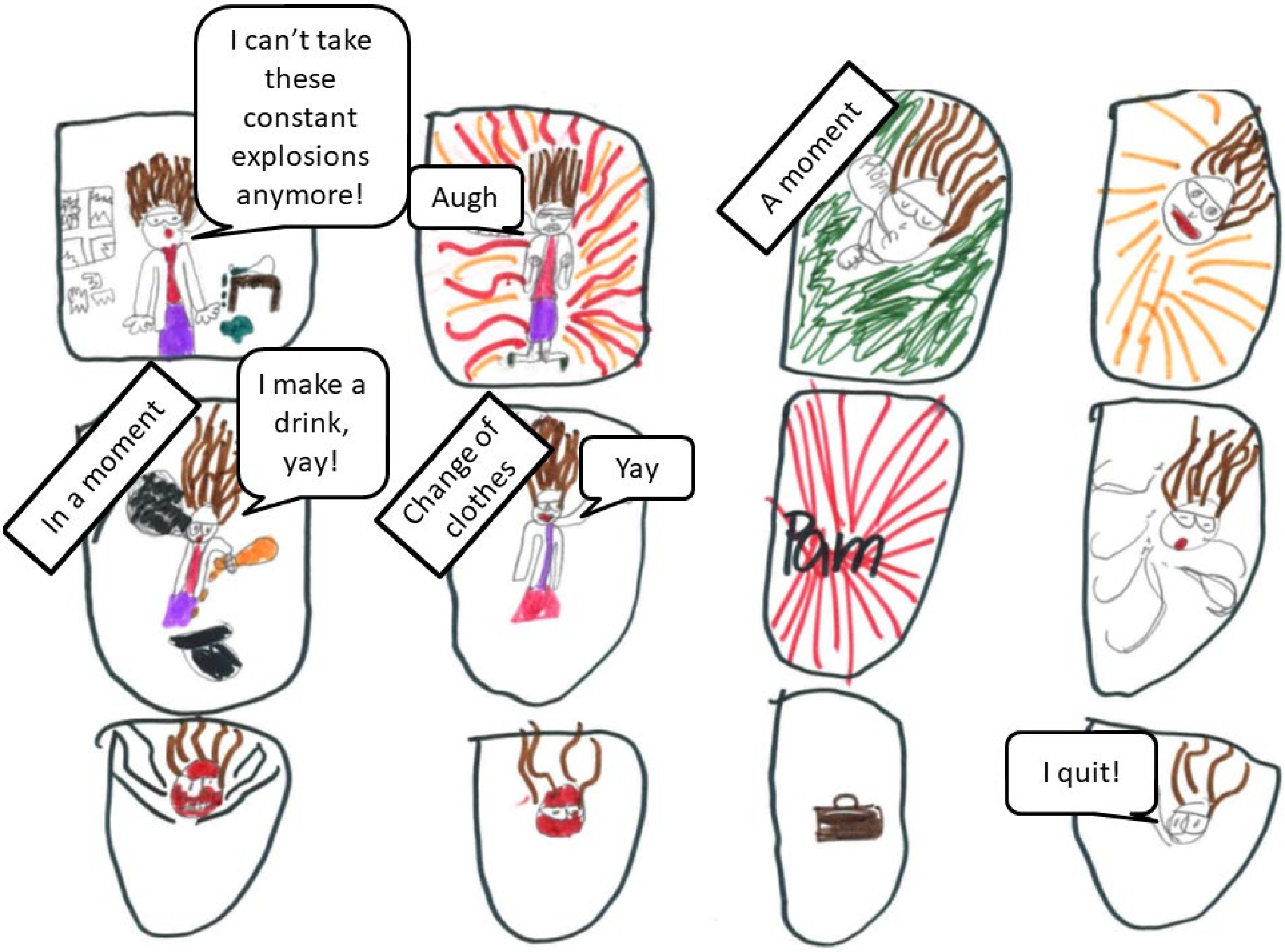


Figure 2. A story depicting a female scientist becoming fed up with explosions and quitting her job. The text is translated from Finnish.

5 Results

Regardless of the prompt used, most drawings (88 %) included depictions of activity. With all three prompts the depictions of locations and appearances were less frequent than depictions of activities. The frequencies of depictions of activity, emotions and attitudes, and elements of danger were consistently higher in the older age group than in the younger age group. The results of the first round of analysis for each prompt and age group are presented in Table 2.

Table 2. Percentages of different categories for each prompt and age group. For statistical significance *p<.05 and **p<.005 when compared to the comic prompt. The inter-rater reliability measured with Cohen's Kappa is presented in last column.

Categories	**Comic**		**Story**		**Set of pictures**		**Cohen's Kappa**
	Younger	Older	Younger	Older	Older	Total	
Appearance	.35	.50	.40	.36	.26*	.37	.90
Location	.46	.75	.68	.61	.77	.66	.84
Activity	.73	.94	.80	.96	.97	.88	.85
Emotions and attitudes	.41	.58	.20*	.29*	.44	.38	.89
Sequential storytelling	.86	.94	.58**	.50**	.95	.78	.95
Elements of danger	.22	.53	.20	.36	.23*	.30	.86

The comic and story prompts were used in data collection for both age groups. When the results of the analysis these two prompts were compared, there were no statistically significant differences in most categories of analysis (see Table 2). Statistically significant differences were seen in two categories of analysis. In both age groups, the story prompt provided significantly less depictions of emotions and attitudes, χ^2 (1, N = 77) = 3.87, p = .05 for younger and χ^2 (1, N = 64) = 5.63, p = .02 for older, as well as drawings that used sequential storytelling, χ^2 (1, N = 77) = 7.91, p = .05 and χ^2 (1, N = 64) = 16.59, p = .001 respectively.

The set of pictures prompt was used only for the older age group. Again, for most categories of analysis, there were no statistically significant differences between the set of pictures and comic prompts (see Table 2). Both prompts produced a relatively high proportion of drawings using sequential storytelling. The set of pictures prompt produced less drawings with depictions of emotions and attitudes, but the difference was not statistically significant, χ^2 (1, N = 75) = 1.63, p = .20. Statistically significant differences were found in the frequency of the depictions of appearance χ^2 (1, N = 75)

= 4.75, $p = .03$ and elements of danger χ^2 (1, N = 75) = 7.06, $p = .008$. When the categories of analysis were compared with each other, it could be seen that the drawings depicting activities had significantly more depictions of elements of danger than other drawings χ^2 (1, N = 180) = 7.73, $p = .005$. There were also slightly more depictions of emotions in drawings with depictions of elements of danger. However, the difference was not statistically significant χ^2 (1, N = 180) = 1.22, $p = .27$.

The depictions of elements of danger were usually the repercussions of the research and portrayed through sequential pictures. For example, in chemistry the mixing of two substances preceded the reaction which was then observed as an explosion or a rapid overflowing of the mixture. Altogether, in 89 % of all depictions of danger, the danger was depicted as a part of an activity and only six out of the 54 dangerous elements depicted (11 %) were traditional static warning signs such as warning labels. The emotions depicted in connection with elements of danger included varying emotions, such as joy, surprise, fear and bewilderment.

Each prompt provided depictions of research on various fields of science. For these categories of analysis there were no statistically significant differences between the different prompts. The most common field of science depicted in the drawings were chemistry (101), biology (33), astronomy (30) and robotics (13). The dangerous elements were predominantly related to chemistry, χ^2 (1, N = 177) = 28.50, $p < .001$, and 87 % of all elements of danger were portrayed in drawings including chemistry activities. These depictions consisted mostly of explosions or rapid reactions resulting in overflowing flasks. These explosions could not directly be associated with fear and they often included emotions such as joy and bewilderment. In contrast, drawings with biology were depicted as significantly less dangerous than other fields of science ($p=.004$) and included only two depictions of danger. Even in these two cases the depictions of danger were part of chemistry laboratory activities.

6 Discussion

As expected, the frequency of depictions in all categories of analysis increased with age (see Table 2) and this supports the findings of DAST and drawing related studies. Firstly, the stereotypes and conceptions develop during the first years of primary school (e.g. Chambers, 1983). The older children have a more exact or refined conceptions of science and other categories and thus they can provide more information about these categories. At the same time, older children tend to have better drawing abilities and are able to express themselves better through drawings (cf. Jolley, Fenn, & Jones, 2004). Despite the use of labels and written text, younger children might leave out information they are unable to draw. However, the use of indirect and implicit measurements might be more effective than written or verbal responses (Cvencek & Meltzoff, 2015). The challenging nature of studying children's conceptions and the complex nature of these conceptions makes it impossible to attribute the results solely to either of these factors.

For all prompts the depictions of appearance of scientists and location of research were considerably less frequent than depictions of activities. Based on the results of this study, the DASC format seems to offer no clear advantage in examining the conceptions regarding the appearance of the scientist or the research locations when compared to the traditional or modified DAST (cf. Chambers, 1983; Emvalotis & Koutsianou, 2018; Fung, 2002).

Almost all prompts provided drawings with frequent descriptions of scientific activities. However, the drawings collected using the story prompt were more often non-sequential and bore resemblance to the traditional DAST. Sequential storytelling, inherent to comic format, is especially suited to the description of action and activities (see Eisner, 2008; McCloud, 1994). Drawings using only a single picture to describe the activity can be more prone for misinterpretations as the activity has to be deciphered from the context of the picture without further information about the activity, such as how the depicted instruments are used (see Reinisch et al., 2017). Thus, the use of the comics and the set of pictures prompts seem more suited than the story prompt or the traditional DAST for charting students conceptions of scientific activities and the process of doing science.

Depictions of emotions and attitudes were more frequent when using the comics prompt than the other two prompts. However, the difference was statistically significant only compared with the story prompts (see Table 2). As emotions are often based on a stimulus and a response, sequential storytelling can be used to illustrate situations that provoke emotions. Thus, sequential drawings such as comics are well suited for depicting how scientific activities evoke emotions, such as frustration caused by a failed experiment. Measuring the exact nature of the emotions and attitudes expressed in the drawings was not in the scope of this study, and in the future, it would be beneficial to try to categorize and link the emotions in the drawings to children's attitudes towards science by using additional data gathering methods focusing on children's views about science and scientific inquiry (see Johnson & Onwuegbuzie, 2011; Lederman et al., 2014; Walls, 2012).

As suggested by Lamminpää and his colleagues (2020), the children might be more prone to present elements of danger when asked to draw a comic. In DAST the elements of danger are usually warning signs or labels but in DASC the elements of danger were mostly depicted sequentially as part of an activity. However, it is not self-evident that seemingly dangerous situations such as liquids shooting out of containers should be considered as dangerous. They can also be the desired result of the experiment and not a dangerous accident. This interpretation is supported by multiple comics showing bewilderment and joy after the experiment with captions like 'wow'. In contrast, the traditional warning signs and labels occurring in the DAST might be considered as more distinct indications of danger. However, Fu and her colleagues (2015) pointed out that even these can also be related to safety precautions learnt at school and, therefore, might not illustrate the actual perceived danger. The problem with the current method is that it might not reveal actual conceptions of danger and its relation to the drawing. The other common factor among the elements of danger is the portrayed activity. Most dangerous elements were related to chemistry whereas biology was always depicted as a safe activity.

Regardless of the prompt, the occurrences of dangerous elements, such as explosions, were still considerably more frequent than in the DAST studies (cf. Emvalotis & Koutsianou, 2018; Türkmen, 2008). The elements of danger depicted were usually portrayed through sequential pictures as the repercussion of the research activity. For example, in chemistry, the mixing of two substances preceded the reaction which was then observed as an explosion or a rapid overflowing of the mixture. This shouldn't be surprising as many polls and questionnaires indeed show that many people consider scientific work as dangerous or at least are worried by the potential risks (cf. Edwards, Ceci, & Ratcliffe, 2016; National Science Board, 2002). On the other hand, the static warning labels were observed only in few drawings and the number is more in line with the aforementioned DAST studies. To ensure the actual meaning and reason for drawing the explosion, we recommend interviewing children because the drawings do not necessarily depict actual conceptions of danger. Moreover, as the depictions of danger were much more frequent when depicting chemical research than other fields of science, the conception of science as something dangerous seems to be associated mainly with the chemical sciences. Thus, generalisations about children's conceptions about the elements of danger in science in general should not be made from a single drawing.

While drawings included variety of scientific activities from hypothesizing and analysing to experimenting and discussing science, the main emphasis in the depictions was on research through experimentation and observations within the context of chemistry, biology, and astronomy. Unsurprisingly, the most usual conception of scientific activities are related to research and its various aspects (see Emvalotis & Koutsianou, 2018; Reinisch et al., 2017). However, Hsieh and Tsai (2018) observed that children consider that learning science happens mainly through teacher oriented classes. This was also observed in drawings showing classroom environment and lecturing. Our analysis did not differentiate between doing science in school or actual scientists working, and the drawings depicted both real scientists and children doing science while some of the characters could not be label as either. In the future, it might be beneficial to differentiate between children doing or learning science and actual scientists working.

Before making conclusions we wish to point out some observations and limitations. Firstly, when making inferences based on the p-values, they should not be used as definitive proof but more as incremental evidence (see Baker, 2016; Vidgen & Yasseri, 2016). To increase the reliability of the inferences made, triangulation with additional data gathering methods should be used whenever possible. As no additional data gathering methods, like interviews, were in this study the interpretations of the elements in drawings are debatable to some extent despite the Cohen's Kappa values. Lastly, the participants had most likely a positive bias towards science and they were affected by the upcoming camp, which is why we refrain from making generalisations about the prevalence of the conceptions.

7 Conclusions

The aim of this study was to test alternative prompts and their effect on children's drawings of science while providing a sequential picture format. From the three prompts the comic and the set of pictures offer a suitable instrument to observe students' conceptions of the scientific activities and the related emotions and attitudes. The story prompt, on the other hand, resulted often in non-sequential drawings more similar to DAST. In line with the previous DASC study (Lamminpää et al., 2020), the effectiveness comes from the sequential pictures that describe the activities and the use of instrumentation more explicitly than a single picture (cf. Reinisch et al., 2017). Similarly sequence is often needed to express emotions which are usually a response to events or situations (see Lamminpää et al., 2020). In contrast, the DASC and different formats seem to offer no advantage to examine the appearance of the scientist or the location where the scientists work when compared to the traditional or modified DAST. The differences between the age groups could be attributed either or both to the development of conceptions during primary school ages or the improved drawing ability (cf. Jolley, Fenn, and Jones 2004; Chambers 1983).

The comics and the set of picture drawings both included more dangerous elements than the DAST (cf. Emvalotis & Koutsianou, 2018; Türkmen, 2008) and highlight how the dangerous elements are connected to the activity instead of static warning labels. However, the occurrence of dangerous elements was higher in the comics. While the prompt might be responsible, other factors such as the activity and field of science were observed to affect the occurrence of danger. For example, the majority of dangerous elements were depicted as part of chemistry related activities. However, it does not necessarily mean that children see chemistry as dangerous. Firstly, the dangerous situations are our interpretation, and for children the liquid shooting out from a flask might be the intended, controlled and safe result. Secondly, the dangerous elements were often seen as exhilarating and inspiring instead of causing worry or fear. The exact nature of these depictions and the connection to attitudes cannot be determined without additional questionnaires or interviews (see Reinisch et al., 2017) and further research is required. Whereas many people consider science dangerous (e.g. National Science Board, 2002), based on the results we propose that researchers would instead focus on specific fields of science. Describing natural sciences as a whole is not viable if the conceptions and stereotypes differ wildly across different fields of science. For teaching practices this implies that it is paramount to distinguish different fields of science when discussing and addressing stereotypes or misconceptions.

As almost every activity was related to research, we propose that in the future the prompt could be changed to explicitly focus how scientists do research. This might be beneficial for the younger children by being more concrete and ruling out portrayals of students learning themselves (see Hsieh & Tsai, 2018). As an alternative, it would be interesting to study how children see themselves doing science. However, the repeating portrayal of research indicates that children might not be aware of other aspects of scientific work. The prompt could also be modified to focus on different fields of science. This could help us to better understand how conceptions and stereotypes differ between fields of science.

This study did not include triangulation by using additional data gathering techniques. To have a more accurate understanding of children's drawings and conceptions behind them, additional questionnaires or interviews should be used as has been done in modified DAST (e.g. Hillman et al. 2014; Reinisch et al. 2017). An open interview in which children explain their drawings would help researchers in making interpretations and offer the possibility to link drawings to actual conceptions and attitudes (see Losh et al., 2008). For example, this would allow verifying if the explosions are truly considered dangerous.

References

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2013). "Not girly, not sexy, not glamorous": Primary school girls' and parents' constructions of science aspirations. *Pedagogy, Culture and Society*, *21*(1), 171–194. https://doi.org/10.1080/14681366.2012.748676

Arthur, A. E., Bigler, R. S., Liben, L. S., Gelman, S. A., & Ruble, D. N. (2008). Gender Stereotyping and Prejudice in Young Children: A developmental intergroup perspective. In S. R. Levy & M. Killen (Eds.), *Intergroup attitudes and relations in childhood through adulthood.* (pp. 66–86). New York, NY, US: Oxford University Press.

Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, *47*(5), 564–582. https://doi.org/10.1002/tea.20353

Baker, M. (2016). Statisticians issue warning over misuse of P values. *Nature*, *531*(7593), 151–151. https://doi.org/10.1038/nature.2016.19503

Ball, M., & Smith, G. (1992). Analyzing Visual Data. Thousand Oaks, California. https://doi.org/10.4135/9781412983402

Britner, S. L. (2008). Motivation in high school science students: A comparison of gender differences in life, physical, and earth science classes. *Journal of Research in Science Teaching*, *45*(8), 955–970. https://doi.org/10.1002/tea.20249

Cakmakci, G., Tosun, O., Turgut, S., Orenler, S., Sengul, K., & Top, G. (2011). Promoting an inclusive image of Scientists among Students: Towards research evidence-based practice. *International Journal of Science and Mathematics Education*, *9*(3), 627–655. https://doi.org/10.1007/s10763-010-9217-4

Campbell, T., Schwarz, C., & Windschitl, M. (2016). What we call misconceptions may be necessary stepping-stones toward making sense of the world. *Science and Children*, *53*(7), 28–33.

Chambers, D. W. (1983). Stereotypic images of the scientist: The draw-a-scientist test. *Science Education*, *67*(2), 255–265. https://doi.org/10.1002/sce.3730670213

Chang, H. Y., Lin, T. J., Lee, M. H., Lee, S. W. Y., Lin, T. C., Tan, A. L., & Tsai, C. C. (2020). A systematic review of trends and findings in research employing drawing assessment in science education. *Studies in Science Education*, *56*(1), 77–110. https://doi.org/10.1080/03057267.2020.1735822

Christidou, V. (2011). Interest, attitudes and images related to science : Combining students ' voices with the voices of school Science, teachers, and popular science. *International Journal of Environmental Science Education*, *6*(2), 141–159.

Christidou, V., Bonoti, F., & Kontopoulou, A. (2016). American and Greek Children's Visual Images of Scientists: Enduring or Fading Stereotypes? *Science and Education*, *25*(5–6), 497–522. https://doi.org/10.1007/s11191-016-9832-8

Cvencek, D., & Meltzoff, A. N. (2015). Developing implicit social cognition in early childhood: Methods, phenomena, prospects. In S. Flannery Quinn & S. Robson (Eds.), *The Routledge international handbook of young children's thinking and understanding* (pp. 43–53). Abingdon, England: Routledge.

DeWitt, J., & Archer, L. (2015). Who Aspires to a Science Career? A comparison of survey responses from primary and secondary school students. *International Journal of Science Education*, *37*(13), 2170–2192. https://doi.org/10.1080/09500693.2015.1071899

Dimopoulos, K., & Smyrnaiou, Z. (2005). Factors related to students' interest in science learning. In D. Koliopoulos & A. Vavouraki (Eds.), *Science Education at Cross Roads: Meeting the Challenges of the 21st Century* (pp. 135–142). Athens: Association for Science Education.

Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The Model of Educational Reconstruction – A Framework for Improving Teaching and Learning Science. In D. Jorde & J. Dillon (Eds.), *Science Education Research and Practice in Europe: Retrospective and Prospective* (pp. 13–37). Rotterdam: SensePublishers. https://doi.org/10.1007/978-94-6091-900-8_2

Edwards, J., Ceci, C., & Ratcliffe, E. (2016). What the Public Really Thinks About Chemistry. *Chemistry International*, *38*(3–4), 16–19. https://doi.org/10.1515/ci-2016-3-406

Ehrlen, K. (2009). Drawings as representations of children's conceptions. *International Journal of Science Education*, *31*(1), 41–57. https://doi.org/10.1080/09500690701630455

Eisner, W. (2008). *Graphic Storytelling and Visual Narrative*. New York: W. W. Norton & Company.

Emvalotis, A., & Koutsianou, A. (2018). Greek primary school students' images of scientists and their work: has anything changed? *Research in Science and Technological Education*, *36*(1), 69–85. https://doi.org/10.1080/02635143.2017.1366899

Farland-Smith, D. (2012). Development and field test of the modified Draw-a-Scientist Test and the Draw-a-Scientist Rubric. *School Science and Mathematics*, *112*(2), 109–116. https://doi.org/10.1111/j.1949-8594.2011.00124.x

Farland-Smith, D., Finson, K., Boone, W. J., & Yale, M. (2012). An Investigation of Media Influences on Elementary Students' Representations of Scientists. *Journal of Science Teacher Education*, *25*(3), 36–40. https://doi.org/10.1007/s10972-012-9322-z

Finson, K. D. (2002). Drawing a Scientist: What We Do and Do Not Know After Fifty Years of Drawings. *School Science and Mathematics*, *102*(7), 335–345. https://doi.org/10.1111/j.1949-8594.2002.tb18217.x

Finson, K. D., Beaver, J. B., & Cramond, B. L. (1995). Development and field test of a checklist for the draw-a-scientist test. *School Science and Mathematics*, *95*(4), 195–205. https://doi.org/10.1111/j.1949-8594.1995.tb15762.x

Finson, K., & Pederson, J. (2011). What are Visual Data and What Utility do they have in Science Education? *Journal of Visual Literacy*, *30*(1), 66–85. https://doi.org/10.1080/23796529.2011.11674685

Fu, E., Fitzpatrick, A., Connors, C., Clay, D., Toombs, B., Busby, A., & O'Driscoll, C. Public attitudes to chemistry, Royal Society of Chemistry § (2015).

Fung, Y. Y. H. (2002). A Comparative Study of Primary and Secondary School Students' Images of Scientists. *Research in Science & Technological Education*, *20*(2), 199–213. https://doi.org/10.1080/0263514022000030453

Galdi, S., Cadinu, M., & Tomasetto, C. (2014). The Roots of Stereotype Threat: When Automatic Associations Disrupt Girls' Math Performance. *Child Development*, *85*(1), 250–263. https://doi.org/10.1111/cdev.12128

Hansen, A. K., Dwyer, H. A., Iveland, A., Talesfore, M., Wright, L., Harlow, D. B., & Franklin, D. (2017). Assessing Children's Understanding of the Work of Computer Scientists. In *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education - SIGCSE '17* (pp. 279–284). New York, New York, USA: ACM Press. https://doi.org/10.1145/3017680.3017769

Hillman, S. J., Bloodsworth, K. H., Tilburg, C. E., Zeeman, S. I., & List, H. E. (2014). K-12 Students' Perceptions of Scientists: Finding a valid measurement and exploring whether exposure to scientists makes an impact. *International Journal of Science Education*, *36*(15), 2580–2595. https://doi.org/10.1080/09500693.2014.908264

Hsieh, W. M., & Tsai, C. C. (2017). Exploring students' conceptions of science learning via drawing: a cross-sectional analysis. *International Journal of Science Education*, *39*(3), 274–298. https://doi.org/10.1080/09500693.2017.1280640

Hsieh, W. M., & Tsai, C. C. (2018). Learning illustrated: An exploratory cross-sectional drawing analysis of students' conceptions of learning. *Journal of Educational Research*, *111*(2), 139–150. https://doi.org/10.1080/00220671.2016.1220357

Jenkins, E. W., & Nelson, N. W. (2005). Important but not for me: students' attitudes towards secondary school science in England. *Research in Science & Technological Education*, *23*(1), 41–57. https://doi.org/10.1080/02635140500068435

Johnson, R. B., & Onwuegbuzie, A. J. (2011). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher*, *33*(7), 14–26.

Jolley, R. P., Fenn, K., & Jones, L. (2004). The development of children's expressive drawing. *British Journal of Developmental Psychology*, *22*(4), 545–567. https://doi.org/10.1348/0261510042378236

Kärnä, P., Hakonen, R., & Kuusela, J. (2012). *Luonnontieteellinen osaaminen perusopetuksen 9. luokalla 2011*. Tampere: Opetushallitus.

Kohonen, I., Kuula-Luumi, A., & Spoof, S. K. (2019). *The ethical principles of research with human participants and ethical review in the human sciences in Finland. Finnish National Board on Research Integrity TENK guidelines 2019*. Helsinki, Finland: TENK. Retrieved from https://www.tenk.fi/sites/tenk.fi/files/Ihmistieteiden_eettisen_ennakkoarvioinnin_ohje_2019.pdf

Kress, G. R. (2010). *Multimodality: A Social Semiotic Approach to Contemporary Communication*. New York: Routledge.

Kuttner, P. J., Sousanis, N., & Weaver-Hightower, M. B. (2017). How to draw comics the scholarly way. In P. Leavy (Ed.), *Handbook of Arts-Based Research* (pp. 396–422). Guilford Publications.

Lamminpää, J., Vesterinen, V., & Puutio, K. (2020). Draw-A-Science-Comic: exploring children's conceptions by drawing a comic about science. *Research in Science & Technological Education*, *00*(00), 1–22. https://doi.org/10.1080/02635143.2020.1839405

Lederman, J. S., Lederman, N. G., Bartos, S. A., Bartels, S. L., Meyer, A. A., & Schwartz, R. S. (2014). Meaningful assessment of learners' understandings about scientific inquiry - The views about scientific inquiry (VASI) questionnaire. *Journal of Research in Science Teaching*, *51*(1), 65–83. https://doi.org/10.1002/tea.21125

Losh, Susan C., Wilke, R., & Pop, M. (2008). Some methodological issues with "Draw a Scientist Tests" among young children. *International Journal of Science Education*, *30*(6), 773–792. https://doi.org/10.1080/09500690701250452

Losh, Susan Carol. (2010). Stereotypes about scientists over time among US adults: 1983 and 2001. *Public Understanding of Science*, *19*(3), 372–382. https://doi.org/10.1177/0963662508098576

Maltese, A. V., & Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students. *Science Education*, *95*(5), 877–907. https://doi.org/10.1002/sce.20441

Maoldomhnaigh, M., & Hunt, Á. (1988). Some Factors Affecting the Image of the Scientist Drawn by Older Primary School Pupils. *Research in Science & Technological Education*, *6*(2), 159–166. https://doi.org/10.1080/0263514880060206

McCarthy, D. (2015). Teacher candidates' perceptions of scientists: images and attributes. *Educational Review*, *67*(4), 389–413. https://doi.org/10.1080/00131911.2014.974510

McCloud, S. (1994). *Understanding Comics: The Invisible Art*. HarperPerennial. Retrieved from https://books.google.fi/books?id=oJ1vPwAACAAJ

Miele, E. (2014). Using the Draw-a-Scientist Test for Inquiry and Evaluation. *Journal of College Science Teaching*, *43*(4), 36–40. https://doi.org/10.2505/4/jcst14_043_04_36

Miller, D. I., Nolla, K. M., Eagly, A. H., & Uttal, D. H. (2018). The Development of Children's Gender-Science Stereotypes: A Meta-analysis of 5 Decades of U.S. Draw-A-Scientist Studies. *Child Development*, *00*(0), 1–13. https://doi.org/10.1111/cdev.13039

National Science Board. (2002). *Science and engineering indicators 2002* (Vol. 1). Arlington, VA: National Science Foundation.

Oktay, O., & Eryurt, K. (2012). How High School Students Represent the Image of Scientists in their Minds. *Procedia - Social and Behavioral Sciences*, *46*, 2482–2486. https://doi.org/10.1016/j.sbspro.2012.05.507

Prosser, J., & Burke, C. (2008). Image-Based Educational Research: Childlike Perspectives. In J. G. Knowles & A. L. Cole (Eds.), *Handbook of the Arts in Qualitative Research: Perspectives, Methodologies, Examples, and Issues* (1st ed., Vol. 4, pp. 407–420). Thousand Oaks, California: SAGE Publications Ltd. https://doi.org/10.4135/9781452226545

Rahm, J., & Charbonneau, P. (1997). Probing stereotypes through students' drawings of scientists. *American Journal of Physics*, *65*(8), 774–778. https://doi.org/10.1119/1.18647

Reinisch, B., Krell, M., Hergert, S., Gogolin, S., & Krüger, D. (2017). Methodical challenges concerning the Draw-A-Scientist Test: a critical view about the assessment and evaluation of learners' conceptions of scientists. *International Journal of Science Education*, *39*(14), 1952–1975. https://doi.org/10.1080/09500693.2017.1362712

Reis, P., & Galvao, C. (2004). Socio-scientific controversies and students' conceptions about scientists. *International Journal of Science Education*, *26*(13), 1621–1633. https://doi.org/10.1080/0950069042000205413

Symington, D., & Spurling, H. (1990). The 'Draw a Scientist Test': interpreting the data. *Research in Science & Technological Education*, *8*(1), 75–77. https://doi.org/10.1080/0263514900080107

Türkmen, H. (2008). Turkish primary students' perceptions about scientist and what factors affecting the image of the scientists. *Eurasia Journal of Mathematics, Science and Technology Education*, *4*(1), 55–61.

Vidgen, B., & Yasseri, T. (2016). P-Values: Misunderstood and Misused. *Frontiers in Physics*, *4*(March), 10–14. https://doi.org/10.3389/fphy.2016.00006

Walls, L. (2012). Third grade African American students' views of the nature of science. *Journal of Research in Science Teaching*, *49*(1), 1–37. https://doi.org/10.1002/tea.20450

Yuen, F. C. (2004). "It was fun... I liked drawing my thoughts": Using drawings as a part of the focus group process with children. *Journal of Leisure Research*, *36*(4), 461–482. https://doi.org/10.1080/00222216.2004.11950032