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Research article

In-service teachers' expressions of TSPCK: Professional knowledge regarding teaching autotrophy and heterotrophy

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Abstract: This study addresses the question of how teachers reason about teaching autotrophy and heterotrophy, and contributes to TSPCK research in biology. Topic-specific pedagogical content knowledge (TSPCK) is a knowledge base in the framework of PCK and is found both on a personal level and a collective level in the teaching community. TSPCK is practice-based and comes to the fore in everyday teaching and lesson planning. Knowledge on how to teach specific topics directly impacts learning, and examples of TSPCK are therefore valuable both in the context of teacher education and professional development. The aim of this study was to examine in-service teachers' TSPCK concerning the teaching of autotrophic and heterotrophic organisms. Seven Finnish biology teachers participated in the study. Content representation (CoRe) was used as an instrument to document teacher knowledge in written responses and in semi-structured interviews. Five components of TSPCK (curricular saliency, learner prior knowledge, representations, what is difficult to teach and conceptual teaching strategies) were used analytically to find what kind of TSPCK teachers expressed. The components curricular saliency and what is difficult to teach were most represented in the empirical material, while representations and learner prior knowledge were less frequent. Conceptual teaching strategies is an integrative knowledge component building on and incorporating other TSPCK components, and examples of this component were expressed by nearly all teachers. All teachers discussed the challenge and need to take two inherent aspects into consideration when teaching about autotrophy and heterotrophy: the abstract concepts and the interactions of abstract concepts on both a subcellular level and an ecosystem level. The written answers and the interview complemented each other, the prompts of the CoRe tool giving a certain structure to the reflection, and the semi-structured interview allowing for reasoning on a deeper level. The teachers found the CoRe instrument useful for reflection and presented suggestions for its use and adaptations in didactical courses.

Keywords: topic-specific pedagogical knowledge, CoRe, in-service teachers, autotrophy, heterotrophy

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1 Introduction

The relationship between autotrophic and heterotrophic organisms is a key ecological principle in biology but challenging for both teachers and learners of all ages. The topic is rich in concepts and complexity, and everyday experience does not offer much assistance for developing deeper knowledge. This study strives to map experienced Finnish teachers' didactical knowledge of teaching an important topic in biology in the form of topic-specific pedagogical content knowledge.

In the 1980's Shulman (1986, 1987) proposed that pedagogical content knowledge (PCK) is a specific knowledge base held by teachers. Since then, PCK has both influenced and been developed by pedagogical research. Documenting subject-specific descriptions or examples of PCK offers not only insights into teaching practices, but also possibilities for researchers and teachers to apply knowledge into similar contexts.

For the subject teacher, topics rather than discipline come into the fore in the classroom. In a refined consensus model of PCK (Carlson et al., 2019) topic-specific PCK (TSPCK) and concept-specific PCK are more fine-tuned levels of teacher knowledge that the teacher operates with on a daily basis. Mavhunga and Rollnick (2013) argue that TSPCK is a knowledge base that functions as a steppingstone for developing both PCK on a discipline level as well as PCK of other topics. Examples of TSPCK are therefore valuable for both student teachers and experienced teachers as a means for professional development. Mavhunga (2016) separates between five components of TSPCK; *curricular saliency, learner prior knowledge, representations, what makes a topic difficult to teach* and *conceptual teaching strategies*.

PCK is often described as tacit knowledge, expressed in the actions of the teacher but not always verbalized. To support teachers in making their pedagogical reasoning visible, a tool called content representation (CoRe) was developed by Loughran et al. (2004, 2012). CoRe has been used in many different contexts as both a planning and reflection tool for teaching topics. The tool offers a structured approach for reflection about pedagogical questions such as content, learner prior knowledge and teaching methods.

As teacher educators, we are interested in how TSPCK can be used as a theoretical frame for portraying teacher knowledge and how CoRe can be used to stimulate pedagogical reasoning. The present study focuses on how in-service Finnish teachers express TSPCK components concerning a central topic in the biology curriculum. Although there are studies concerning PCK and TSPCK in biology there is little research of experienced teachers TSPCK regarding this particular topic. The use of both CoRe and interviews as empirical material provide valuable insights into teacher thinking. The result of the study gives some insight into teachers' personal topic-specific PCK (pTSPCK) about the topic as well as a general summary of teacher knowledge on a collective topic-specific PCK (cTSPCK). This informs teacher educators on what might be productive perspectives or questions to address in didactical courses or professional development. The study was designed to answer the following research question:

1. What TSPCK can be extracted from in-service Finnish ~~t~~eachers' reasoning about teaching autotrophy and heterotrophy with CoRe?

For this study, the following topic was chosen: Some organisms use energy from the sun to produce nutrients that all other organisms depend on. The topic represents core biology content that all biology teachers teach regardless of the age of the students. Teacher´s TSPCK knowledge of this topic was analyzed in relation to the five components curricular saliency, learner prior knowledge, what is difficult to teach, representations and conceptual teaching strategies. CoRe was used as a reflection tool for teacher´s reasoning and its role was also discussed.

2 Theoretical background

Formal education is strongly influenced by both policy-makers and technical advancements, but teacher qualities remain the most important factor for students' academic success (Cochran-Smith, 2004), and teaching practices and judgement are key factors for learning (Hattie & Zierer, 2018). It is fair to assume that experienced teachers have more extensive knowledge about teaching than novice teachers as they have encountered both content and students in a classroom and therefore acted on pedagogical decisions. A crucial part in becoming an experienced teacher is developing pedagogical and didactical knowledge in a learning context. Teachers with a rich personal TSPCK can therefore be assumed to be able to express complex pedagogical reasoning and to create rich pedagogical learning environments and learning opportunities.

We argue that TSPCK is a productive theoretical construct as it connects classroom practice with research; it is practical enough to be valid in the eyes of teachers, but still theoretical enough to challenge preconceptions of teaching and stimulate discussions about teaching and learning. Topics are the main arena where teachers and learners engage with both content and each other, as well as productive starting points for pedagogical reasoning.

Pedagogical reasoning is the process where teachers draw on their professional knowledge to address pedagogical dilemmas (Shulman, 1987). During the busy day of a teacher, informed decision making might not always be practically possible, and decisions are made intuitively, on tacit knowledge. In the classroom, teachers often resolve dilemmas by routine instead of pedagogical reasoning (Gotwalt, 2023). Taking the time to reflect on teaching and challenging aspects of a topic might therefore offer valuable insights to both the teacher and the teaching community.

2.1 TSPCK

Topic-specific PCK (TSPCK) refers to professional knowledge that can be shared with colleagues, pre-service teachers and the teaching community to improve practice and student learning. Articulated TSPCK could be especially fruitful in teacher education (Mavhunga & Rollnick, 2013) where student teachers develop teaching skills by planning and teaching specific topics. It is in the teaching preparation that the operationalization of PCK takes place (Carlson et al., 2019; Mavhunga, 2016).

Since the introduction of the concept in 1986 by Shulman, a considerable amount of research has either applied PCK as a theoretical framework or tried to develop understanding about it (Berry et al., 2015, Kind, 2009, Veal & MaKinster, 1999;). PCK can be described as teachers' pedagogical knowledge of a specific teaching content; for example biology on a discipline-specific level, of energy transfer in food chains on a topic-specific level and of photosynthesis on a concept-specific level. In the refined consensus model of PCK Carlson et al. (2019) establishes a framework for PCK that visualizes *where* we can expect to find PCK (from a personal to a collective level), *how* it develops (through knowledge exchange between different layers in the model) and *what knowledge bases* it is constituted of.

The current study focuses on how teachers' personal knowledge can be described in terms of TSPCK components. According to Carlson et al. (2019) teachers' personal PCK (pPCK) can be described as "the cumulative and dynamic pedagogical content knowledge and skills of an individual teacher" (p. 87). This knowledge develops under the influence of other actors and resources, as well as of the students that the teacher has encountered (Figure 1). Additionally, there is a knowledge exchange between the layers in the model, hence pPCK is informed by and informs both enacted PCK (ePCK) and the learning context. The learning context on the other hand is defined as the space and time where the learning takes place, which in turn is influenced by the educational climate, the learning environment and student attributes (Carlson et al., 2019). The outermost layer in this simplified picture represents collective PCK (cPCK), that is, the shared knowledge found in the teaching community and literature.

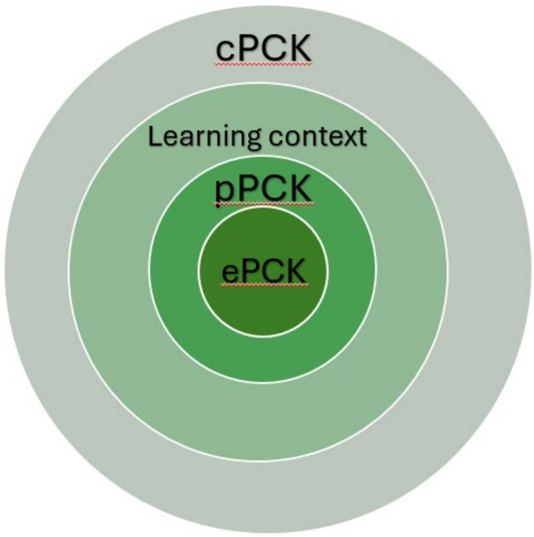

Figure 1. The knowledge bases discussed in the present study, adapted from the refined consensus model (Carlson et al. 2019), including collective PCK, the learning context, personal PCK and enacted PCK.

The refined consensus model of PCK presents a valuable model of how teacher knowledge develops and how types of teacher knowledge relate to one another. The model does include TSPCK as one level of PCK (see Carlson et al., 2019) but does not offer a definition for TSPCK. Mavhunga and Rollnick develop TSPCK as a construct and suggest five components that constitute TSPCK based on empirical research in teacher education. TSPCK was discussed already in the 1990's as a part of the pedagogical content knowledge taxonomy (Veal & MaKinster, 1999). As a theoretical construct TSPCK was validated in an empirical study by Mavhunga and Rollnick (2013, see also Taber & Akpan, 2017) where five different components were identified. The components are presented in Table 1.

Of the five TSPCK components, the component conceptual teaching strategies functions as an integrative component, drawing on knowledge of the other components for synthesis of an explicit teaching strategy. For example, a teacher could discuss a representation in relation to learner prior knowledge and curricular saliency. In an empirical study by Mavhunga and Rollnick (2013), evidence of conceptual teaching strategies is provided when a pre-service teacher expresses awareness of common misconceptions among students and considers specific concepts and their sequencing in the lesson plan. A characteristic feature of this component is its explicit focus on the content (Taber & Akpan, 2017).

Table 1. TSPCK components according to Mavhunga & Rollnick (2013)

Component	**Definition**
Curricuar saliency (CS)	Identification and sequencing of big ideas, as well as important concepts for a topic.
Learner prior knowledge (LPK)	The ideas and understandings (both correct and incorrect) that learners bring with them, as well as the teachers understanding of the learner context.
Representations (REP)	Ways to represent the content in a meaningful way.
What is dificult to teach (WDT)	Learner difficulties.
Conceptual teaching strategies (CTS)	The concrete effort to enhance learning based on the integration of other components.

Note. The table presents the five TSPCK components and their definitions as described by Mavhunga and Rollnick (2013).

Interactions of multiple components are recognized as rich TSPCK. Park and Chen (2012) argued that high-quality teaching involves demonstration of more than two components simultaneously, and consequently, a lack of component interaction indicates weak PCK with teaching methods more focused on memorization of concepts and facts. Rich TSPCK could be a prerequisite for developing higher levels of knowledge in accordance with Blooms' taxonomy.

There are several examples of empirical research on PCK on a topic-specific level in biology; e.g. photosynthesis (Park et al., 2018), respiration (Mapulanga et al., 2023), circulation (Loughran et al., 2012) and evolution (Veal & Kubasko Jr, 2003). Park et al. (2018) investigated secondary science teachers' PCK concerning photosynthesis albeit using other knowledge domains than the TSPCK components. In a teacher education context, the teacher educator's ePCK concerning meiosis was studied to investigate how the integration of teaching and learning of content and methodology could stimulate PCK development among student teachers (Kahn & Nyamupangedengu, 2022).

2.2 CoRe

Developing teacher knowledge and reasoning is not straightforward. Hence, a tool like CoRe especially developed for this purpose is needed. CoRe consists of eight prompts and can be used as an aid when teachers are expected to reflect for and on teaching (see appendix A). Loughran et al. (2012, p. 16) describe the intention behind collecting descriptions of PCK with CoRe as follows: "our representations of topic specific PCK have been developed to make explicit the nature of successful teachers' pedagogical reasoning and the associated decision making within the context of the teaching of the particular science content".

CoRe has been used for documenting and developing teacher knowledge among both practicing teachers and student teachers (Buldu & Buldu, 2021; Forsler et al., 2024; Hume & Berry, 2011; Loughran et al., 2012; Nilsson & Karlsson, 2019). Forsler et al. (2024) used CoRe to capture teachers' knowledge about sustainable development and found that CoRe in combination with video-based reflection made PCK explicit and supported pedagogical reasoning. Nilsson and Karlsson (2019) studied how CoRe could be used by teacher students in their reflection on critical incidents during practicum. They concluded that the CoRe-tool, combined with the use of video connotations, was a useful framework for scaffolding and structuring the reflection of the students.

CoRe consists of prompts that are to be answered in relation to a big idea, or a topic. The topic of the present study constitutes a key ecological principle in biology: some organisms use energy from the sun to produce nutrients that all other organisms depend on. This topic was chosen because it is relevant in many areas in biology as a discipline; it appears several times in the biology curriculum and is of great interdisciplinary importance. Further, it incorporates different levels of understanding, ranging from system thinking to details on the molecular level. System thinking requires the capacity to understand interactions and relationships between components within the system and the ability to think across scales (Jin et al., 2019). The ecological principle is also important for fostering a willingness to care for the environment and citizenship.

2.3 Teaching autotrophy and heterotrophy

The concepts of autotrophy and heterotrophy are fundamental for understanding different organisms and how organisms interact in the ecosystem. Organisms that use energy from the sun to produce energy rich molecules (autotrophs) and organisms that depend on these for consumption (heterotrophs) explain the basic structure and processes of ecosystems. It is the circle of life; green plants and algae photosynthesize and are grazed upon by herbivores; herbivores in turn are predated upon by carnivores, and in the end all organisms are consumed by decomposers.

Although this is core biology content it has implications for all science teaching and corresponds to a big idea of science (*Organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms*) suggested by Harlen (2010). Hartley et al. (2011) state that the ability to trace energy and matter across processes and scales builds scientific literacy and citizenship. To understand the processes in the carbon cycle, students should be able to trace matter and energy separately, but a learning obstacle is the coupling of energy and matter in photosynthesis and decoupling during cell respiration. Doherty et al. (2025) argue that the laws of conservation of energy and matter are scientific principles that can help students reason across different contexts.

Research has consistently shown that students of all ages have a very limited scientific and conceptual understanding of energy, and further, that the difference between matter and energy is unclear (Harms & Bertsch, 2018). In Brown (2013) plant nutrition and the relationship between photosynthesis and cell respiration are given as examples of difficult topics in biology. Understanding the concepts of food and nutrition is crucial as it paves the way for a deeper understanding of photosynthesis (Brown, 2013).

In addition to energy, Schramm et al. (2018) identified mass, subsystems and large-scale systems as core aspects of carbon-transforming processes that students frequently demonstrate misconceptions about. Ecosystems are complex, nested hierarchical systems as subsystems on a smaller scale (molecules, cells biochemical processes, populations) form a system on larger scale (Jin et al., 2019). Ecosystems are shaped by interactions between smaller systems, feedback loops, and emergent properties that arise from interactions between the living and non-living components (Jin et al., 2019).

There are a multitude of studies concerning teaching autotrophy and heterotrophy. In a literature review by Jancarikova and Jancarik (2022) it was found that the number of articles concerning teaching photosynthesis have doubled every decade since the 1980. Several studies emphasize strategies that engage students actively with the topic. According to O'Connell (2008) step-by-step activities fail to engage students in the learning process and often function as mere demonstrations, or proof of, photosynthesis and cell respiration as biochemical phenomena (O'Connell, 2008).

3 Methodology

The present study was conducted as a deductive educational case study with the aim to investigate teacher pedagogical reasoning in a Finnish context (Stenhouse 1985, in Bassey, 2000). The case is constituted by seven in-service teachers who all have experience of biology teaching in secondary education and explicit knowledge of teaching autotrophy and heterotrophy. Teachers' pedagogical knowledge was documented as written responses to the CoRe prompts as well as semi-structured interviews and analysed with the TSPCK components as an analytical tool.

3.1 Study context

A group of seven in-service teachers with varying amount of teaching experience (2-40 years) functioned as informants. All teachers had experience of teaching the topic in secondary education. These teachers were chosen as informants as it can be argued that they have developed knowledge about teaching specific topics (Sannert et al., 2025) and therefore can be expected to be able to share their knowledge even though the CoRe-instrument was unfamiliar to them. All teachers were contacted personally and were either a part of a local teacher network or attended a professional development course organized partly by the first author. The teachers were chosen by convenience while they all could be expected to have experience of teaching autotrophy and heterotrophy at lower and secondary education. As the study focuses on personal experience and reasoning another sampling procedure was not seen as necessary, as all personal experience can be regarded as equally valuable. Seven informants were seen as sufficient for this case study while there were similarities between teacher expressions and a larger group of informants would not have contributed with more diversity in the expressions. A convenience sampling procedure was not considered to lead to any bias in the results, although there might be some risk in interpretation of expressions due to familiarity between informants and the first researcher.

3.2 Empirical material

The empirical material for the study was gathered in 2022 by the first author and consisted of written answers to the eight prompts in the CoRe tool (see appendix A) and semi-structured interviews based on the same prompts. The teachers received a document with the eight CoRe prompts and the topic either by e-mail or personally. No further instructions or explanations were given, and the teachers could choose how much time they spent on the prompts. Time spent on answering the prompts varied from 15 to 90 minutes according to the teachers' own reports. Written responses were anticipated to be short, and the semi-structured interviews were expected to produce more in-depth material to detect pedagogical reasoning. Teachers often share knowledge by stories and descriptions, and a narrative format offers valuable additional information (Loughran et al., 2012). Face-to-face meetings were held with all teachers in accordance with their preferred time and place. The interview started off with general questions about the teacher's impression of the CoRe-tool and its usefulness and then the answers to the prompts were discussed to give the teacher the opportunity elaborate on the written response. No interview questions were piloted beforehand as the prompts are established in the field. The length of the interviews varied from 30 to 90 minutes.

3.3 Analysis

The written responses and semi-structured interviews were used as sources of data, and expressions concerning teaching the topic were considered as data. Data was extracted with the TSPCK framework as an analytical instrument and the TSPCK components as categories. As the written responses were provided mostly by handwriting the material was digitalized for an anonymized analysis. Sentences were completed when needed.

Interviews were transcribed by the first author in a denaturalized manner as described by Oliver et al. (2005). As the research question focuses on teacher knowledge, the focus is on what the teachers are articulating rather than how they are expressing themselves. In a denaturalized transcription the substance is emphasized rather than portraying the interview as realistically as possible (Oliver et al., 2005). The goal in the transcription process was to preserve *meaning* while at the same time making this meaning more accessible to a reader.

The transcription process consisted of two stages. In the first stage the interviews were transcribed close to the actual sayings of the teacher. This was done by the first author to get familiar with the material. In the second stage adjustments were made: spoken language was turned into a more standardized language, excessive use of filler words or expressions were ignored, and segments were rephrased into more coherent sentences. Parts of an interview that went beyond the scope of this study were not transcribed. Examples of not transcribed material are general insights into teaching but not related to the topic of this study, as well as insights from university studies that shape teaching practices.

As the TSPCK components functioned as analytical categories derived directly from theory, directed content analysis was applied (Hsieh & Shannon, 2005). The definitions of the TSPCK components, as presented by Mavhunga and Rollnick (2013), were used in the analysis (table 2). In the process of gathering the empirical material, the first author noticed that many teachers identified specific teaching strategies for the topic in writing but did not continue to justify or elaborate on these. Strategies that were not specific enough to be categorized as a representation, but still specific for the topic, i.e. bringing plants to the classroom, were therefore coded as specific teaching strategies (STS). These examples contributed to answering the research question and were included as data even though they did not meet the criteria of conceptual teaching strategies. Therefore, the material was coded according to components curricular saliency, learner prior knowledge, representations, what is difficult to teach, conceptual teachings strategies and specific teaching strategies.

The first and third author were involved in the analysis and coding process to assure result reliability. By including the third author in the analysis process the categories became clearer and more consistent (Cohen et al., 2018). Written responses to the CoRe prompts were coded independently by the first and the third author. Results were compared and discussed to reach a joint understanding of the components. The first author continued with coding the transcripts for additional expressions to the prompts. Differences in coding were resolved by discussion until agreement was made.

The analytical process consisted of two stages. First the number of expressions were summarized for each TSPCK component and teacher and summarized in a table. Within each component, themes emerged, and these were used by the first author to create a richer description and understanding of each component. These themes offer a qualitative description of the content of the expressions, and a more tangible understanding of the component in this context. No specific themes emerged for components specific and conceptual teaching strategies. The number of expressions of these components were few in relation to other components, and in addition the nature of these components is somewhat different. Conceptual teaching strategies incorporate several components and can be seen as a justification of a pedagogical decision. In the second stage, the first and third author identified segments where the teacher used two or more components in the expressions as conceptual teaching strategies. This part of the analysis generated results that gave examples of pedagogical reasoning and how teachers justify their pedagogical decisions.

Even though TSPCK components appeared to be clear and distinguishable, some difficulties were encountered in the analytical process. Especially when teachers discussed challenges in teaching, it was not always obvious whether this was a consequence of learner prior knowledge or the difficulty with the topic itself. For example, one teacher discussed the concept of energy as both something students struggle with (as a difficult topic) and as a source of misconceptions. The expression “photosynthesis and cell respiration are difficult” could be interpreted as either weak learner prior knowledge, or that the concepts are difficult to learn because of their abstract nature. In the analysis the authors agreed that an expression where the learner perspective is central is coded as learner prior knowledge, i.e: “they do not understand the difference between organic and inorganic”, while expressions with no explicit consideration of the learner were coded as what is difficult to teach.

Table 2. Examples of teacher expressions for TSPCK components

TSPCK component	Example
Curricular saliency (CS)	"That you understand how everything is connected, that we are dependent on the environment." (T2)
Learner prior knowledge (LPK)	"They understand that glucose and oxygen are produced [in photosynthesis]". (T6)
Representations (REP)	"I've used the yeast experiment since it is easy to get results during the lesson". (T6)
What is difficult to teach (WDT)	"The energy flows through [the ecosystem] and some is lost as heat. It is not a cycle; energy has to be refilled."(T3)
Conceptual teaching strategies (CTS)	"When you introduce the topic, you can test their preconceptions: how do plants get energy, do plants also do cell respiration? That can be quite abstract. I've been thinking about whether you should bring up cell respiration in plants with seventh graders." (T4)
Specific teaching strategies (STS)	"To think about what the words mean and where the words come from, so that they can communicate the knowledge". (T1)

Note. The table presents examples of how teachers express TSPCK components.

3.4 Ethical aspects

The study was conducted according to the ethical guidelines of scientific research stated by Åbo Akademi and the Finnish National Board on Research Integrity (TENK). All teachers signed a form of informed consent and were notified that they could withdraw from participation at any point.

The empirical material of the study contained a minimum of personal information. The personal information included voice in the semi-structured interviews and handwriting in written responses. Both voice and handwriting are markers of a person's identity. The only background information requested by the teachers was the extent of studies in biology and years of teaching experience. The empirical material was anonymized and stored by the first author behind a password.

4 Result

All teachers demonstrated personal topic-specific PCK (pTSPCK) about teaching autotrophy and heterotrophy throughout the empirical material, thereby addressing the research question *what TSPCK can be extracted from Finnish teachers' reasoning about teaching autotrophy and heterotrophy*. CoRe was a useful instrument for expressing pTSPCK, even though all the teachers most certainly had additional knowledge that was not expressed in this situation. Teachers provided descriptions and arguments about teaching the topic regardless of different amounts of teaching experience, and the general impression was that there were many similarities between the teachers' pedagogical reasoning. On both an individual and group level some components were more frequent than others.

4.1 Outline of TSPCK components

The number of coded expressions per component and teacher is presented in Table 3. The summary can therefore be interpreted as a portrayal of the pTSPCK that each teacher expressed when encountering CoRe for the first time. For each teacher the number of written expressions of pTSPCK for different components are presented in the column named CoRe, and oral expressions in the column named Interview. As seen in table 3 most of the articulations are expressed in written responses to the CoRe prompts. As only "new" articulations were coded from the transcripts, the interviews mostly contributed by deepening the information already provided in writing. The total number of expressions per teacher varied from 13 (T5) to 36 (T7).

On a group level the expressions from CoRe added up to 94, and the semi-structured interviews generated an additional 55 expressions. A total amount of 149 expressions of TSPCK were coded in the empirical material. The components that generated the most articulations were curricular saliency and what is difficult to teach. This is expected as these components are closely connected to content teaching. Components learner prior knowledge, representations and specific teaching strategies are represented in similar numbers and could indicate similarities in the teaching context. Conceptual teaching strategies, the integrative component, was expressed less frequently. Most segments of conceptual teaching strategies were found in the interviews.

Table 3. Summary of expressions per teacher from CoRe and interviews

	Teacher 1		Teacher 2		Teacher 3		Teacher 4		Teacher 5		Teacher 6		Teacher 7	
Component	CoRe	Interview	CoRe	Interview	CoRe	Interview	CoRe	Interview	CoRe	Interview	CoRe	Interview	CoRe	Interview
CS	8		6	2	9	3	10	1	5		5	10	12	4
LPK			2	1			1	1		1	1	3	3	4
REP			1			1	1	2				5	5	1
WDT	6		3	1	1		2	1	1	1	1	2		4
STS	4	1	1						2				2	
CTS			1	1				1	1	2		1		1
Sum	18	1	14	5	10	4	14	6	9	4	7	21	22	14
Total	19		19		14		20		13		28		36	

Note. The table presents the amount of expressions of TSPCK per teacher. Abbreviations as follows: curricular saliency (CS), learner prior knowledge (LPK), representations (REP), what is difficult to teach (WDT), specific teaching strategies (STS), conceptual teaching strategies (CTS).

The number of expressions of teacher 6 and 7 deviated from the rest of the group. Teacher 6 demonstrated the greatest difference between the CoRe and the interview. This can be explained by the fact that the teacher only spent 15 minutes answering the prompts but considerably more time on the interview. Teacher 7 on the other hand articulated considerably more expressions of TSPCK components compared to the other teachers. The total amount of time this teacher spent on both CoRe and interview was longer compared to the other teachers.

The content of the expressions is summarized and exemplified in table 4 according to emergent themes. Each component is further described to give a more detailed description of the TSPCK found.

Table 4. Themes and examples of TSPCK components

TSPCK component	Themes	Example	Number of teachers
Curricular saliency (CS)	Concepts	"There are other types of autotrophs that don't use the sun as an energy source." (T3)	7/7
	Sequencing	"Can be simplified as words, a simple chemical reaction or detailed at electron level" (T1)	2/7
	Value	"The topic is important to create understanding, respect and care for the environment" (T2)	7/7
Learner prior knowledge (LPK)	Food chains	"Students struggle with explaining how ecosystems are built and interpreting relationships between organisms" (T7)	2/7
	Photosynthesis, cell respiration	"They do understand that glucose and oxygen are produced [in photosynthesis] and that sunlight is needed" (T6)	2/7
	Chemistry as a learning barrier	"Most do not understand the concept of organic molecules and the basics of energy" (T2)	3/7
	Misconceptions	There are misconceptions about fungi being autotrophic organisms" (T4)	2/7
What is difficult to teach (WDT)	Energy, energy transfer	"Energy is difficult to understand, even for me. How it is transformed in different ways from sunlight to other forms" (T5)	6/7
	Biochemical nature	"It's difficult to grasp the transformation from one organic molecule to another, and particularly the role of energy in the process." (T2)	7/7
	The big picture	"When we talk about producers and consumers and that most things in nature are blurred" (T3)	5/7

Representations (REP)	Experiments, practical work	"Closed terrestrial ecosystems show how elemental photosynthesis and cell respiration are, and how they are related" (T7)	5/7
	Pictures	"You can draw a sun, a plant and a hare and then you continue with the chemical formulas" (T1)	6/7
	Symbolic representation	"The important part in the chemical reaction is energy, it is often included as almost a parenthesis (T4)	1/7
Conceptual teaching strategies (CTS)		The senior students do oxygen and carbon dioxide measurements with LabQuest on *Chlorophytum comosum* in darkness and under a plant light. That shows how photosynthesis and cell respiration interact. (T7)	5/7
Specific teaching strategies (STS)		Drawing a picture parallel with note taking. (T6)	4/7

Note. The table presents examples of expressions of for TSPCK components and identified themes within the components and the number of teachers with expressions in the identified themes.

4.2 Curricular saliency

Three themes emerged in this component: concepts, sequencing of the content and values. In the responses several concepts were identified as important, both for the topic itself (e.g. photosynthesis, cell respiration, energy, organic molecules, chloroplasts) but also for building understanding on how this topic is relevant in relation to other topics in biology and science (e.g. food chain, ecosystem). A logical and pedagogical sequencing of the content to enhance learning was discussed several times. How the content is sequenced is relevant for knowledge progression in lessons, courses and in different stages of schooling (primary, lower secondary and higher secondary education). As an example of the sequencing of concepts one teacher expressed perplexion when discussing that a textbook introduced chlorophyll (pigment found within the chloroplast organelle) instead of chloroplasts for younger learners (primary students) when presenting photosynthesis.

Relevant for this component is also the rationale for why the topic is important to learn. Several teachers expressed that this idea is important for future decision making linked to sustainable development. For instance, sustainable food production can be used as an example of energy efficiency at trophic levels and illustrate energy flow through the food chain. Insect pollination, on the other hand, was brought up as an example of environmental concern and as a link between autotrophic organisms and humans.

4.3 Learner prior knowledge

Learner prior knowledge was quite superficially discussed by the teachers; some misconceptions were identified but the general assumption was that difficulties in learning are a consequence of the complexity of the topic. While teachers successfully identified *what* was considered difficult by students, reasoning about *why* learners experienced difficulties were missing. For example, one teacher elaborated on photosynthesis as a recurring concept in biology curriculum and that learners doubt their own knowledge about the concept: ”it is mentioned here and there and when you want them to explain what it’s about, photosynthesis, greenhouse effect, they either can’t or dare say what they think”. Another frequent explanation for weak or missing prior knowledge was the abstract nature of the topic. Four themes emerged in relation to learner prior knowledge: food chains, biochemical reactions, chemistry as a learning barrier and misconceptions. Food chains and biochemical reactions were discussed as aspects that students have a basic understanding of but lack deeper knowledge for application on a system level. In other words, students in the lower and upper secondary schools have basic knowledge about ecological processes and principles that can be utilized as students advance in the curriculum.

A general student belief is that chemistry is a difficult subject, and this belief may function as a learning barrier according to the teachers. Symbolic representations of photosynthesis and cell respiration seem to trigger a negative reaction among some students, creating an anticipation for that the content will be challenging. Misconceptions on the biochemical level included student difficulties in separating energy and nutrients on a conceptual level and considering molecules to be living matter. Another misconception expressed by two teachers is that some students believe that fungi are autotrophic organisms.

4.4 What is difficult to teach

Aspects of what is difficult to teach can mainly be categorized as either content on the conceptual level, molecular level or system level. The biochemical nature of the topic is something that all teachers struggle with in the classroom as both the concepts and processes are abstract. Teachers find energy as a concept difficult to teach, as well as the transformation of energy between different forms (mainly from electromagnetic to chemical energy). Linked to this is the biochemical transformation of molecules between organic and inorganic forms, and biosynthesis. The concept of nutrients and identifying what makes a molecule a nutrient is also problematic. Although students have a basic understanding of the components of a good and nutritious meal, the difference between energy, nutrients and vitamins is unclear.

The other aspect of the topic all teachers identified as challenging is getting students to see the big picture. This means connecting different ideas and concepts within the topic and understanding how they interact on a system level. Several teachers expressed that going from photosynthesis and cell respiration as processes, to understanding their implications in the ecosystem is difficult. One teacher reflected on whether this difficulty might be a consequence of age-related cognitive immaturity.

4.5 Representation

This component yielded three main themes, and there was a considerable overlap between the teachers' responses suggesting similarities in teaching practices. Two of the themes were especially well represented: practical representations in the form of experiments or inquiry, and pictures. The third theme was symbolic representations in the form of chemical formulas.

Practical work was considered important to make the topic less abstract for students. Four specific activities were used by this group of teachers: creating closed (terrestrial) ecosystems, designing experiments about plant growth or seed germination, using yeast to demonstrate cell respiration and production of carbon dioxide, and last, using water plants to study oxygen production in photosynthesis.

Closed (terrestrial) ecosystems were mentioned by almost all teachers as an activity to encourage students to think deeper about the topic. Although this activity often was the first example to be mentioned, the instructions and learning goals varied between teachers. Students create their own ecosystems in a jar either as an exercise with little formal follow-up, or as a more extensive assignment including writing a hypothesis and lab report. The students of one teacher used sensors to measure levels of oxygen and carbon dioxide. The students then used the measured values for constructing graphs in a report.

Doing experiments about photosynthesis and cell respiration was considered a valuable learning opportunity. Designing experiments about plant growth and seed germination was described as an exercise to specifically challenge student thinking. Experiments with yeast and water plants were primarily used to demonstrate and measure the rate of photosynthesis and cell respiration. The yeast experiment was considered useful as it does not require a lot of material or equipment, and it generates good results within a reasonable amount of time (during a single lesson).

Pictures were considered an essential and necessary part of teaching the topic by all teachers, and for many this meant drawing the picture by hand together with the students. The pictures referred to describe the relationship between an autotroph and a heterotroph, food chains with at least three trophic levels and a picture of a leaf photosynthesizing. One teacher also used a picture of the snail (*Elysia* *viridis)* that incorporates chloroplasts into its cells from ingested plant material as a useful addition when distinguishing between autotrophs and heterotrophs.

Representations of the topic on a symbolic level include the chemical formula of photosynthesis and cell respiration. Even though symbolic representation and associations to chemistry as a subject were discussed as a possible learning barrier, only one teacher discussed the chemical formulas from a pedagogical perspective. This teacher reasoned that learning difficulties associated with the concept of energy, could be a result of how energy is included in the formula.

4.6 Conceptual and specific teaching strategies

Several different teaching strategies were found in the empirical material. However, most of them were not discussed in relation to another TSPCK component. Etymology, for example, was discussed by one teacher as a specific strategy to develop conceptual understanding. The lack of answers with component interaction could possibly be explained by the fact that the first author, conducting the interviews, has the same educational background as the informants. If the informants anticipated a shared understanding shorter answers might have been judged to be sufficient.

Conceptual teaching strategies were expressed mainly in the interviews. Interestingly, segments where teachers demonstrate the most pedagogical reasoning were when a teaching strategy was discussed in relation to difficulties in the content or as non-functional. Creating closed ecosystems was questioned and excluded by a couple of teachers representing the upper secondary as they sensed the activity failed to contribute to higher learning goals. One teacher motivated this decision by stating that even though the activity was pleasant and offered the students the possibility to do something different, the teacher did not experience that the activity enhanced students' learning. As students lack deeper theoretical knowledge of photosynthesis and cell respiration, the closed ecosystem functioned more as a model of the sun as an energy source and the circulation of gases in the system. Because of national changes in the course content and a general feeling of curriculum overload in the upper secondary, this activity lost its relevance according to the teacher.

Another teacher (T2) expressed frustration for students' design of their own experiments about photosynthesis or cell respiration. This activity was chosen specifically to challenge students' understanding and deepen knowledge, but students fail to carry out the activity as the teacher hoped:

> I let them do their own inquiry where they should manipulate one variable. One requirement is that they write and explain a hypothesis in their research plan. And that is difficult for them. They just write that the plant grows better when it gets more light, but they really

> struggle with going into detail. And I even give them time to do some research. (T2)

5 Discussion

The results of this study demonstrate that teachers develop professional knowledge about teaching a topic in interaction with the content and in the teaching context. Personal professional knowledge about teaching was evident as well as similarities in teacher knowledge between teachers. An American study confirms that experienced teachers enhance students learning, and that teachers learn from experience throughout their teaching careers (Podolsky et al., 2019). This study provides insight into teachers' professional knowledge both on an individual and a collective level, as well as insights into how teacher knowledge can be accessed in a more structured manner. Topic-specific teacher knowledge concerning the content, challenges and strategies that teachers encounter in teaching about autotrophy and heterotrophy can be used to stimulate pedagogical reflection among both experienced and student teachers. While the empirical material, gathered with CoRe, captures the teacher's pTSPCK, the results can be interpreted as a description of the collective topic-specific PCK (cTSPCK) of this group of teachers.

5.1 Topic-specific content knowledge

While the first prompt of the CoRe tool specifically targets the content, or the essence, of a topic, central concepts and ideas concerning the topic were identified and discussed by the teachers throughout their interaction with the tool and the researcher. Discussing teaching is more explicit and focused when it is mirrored against a content, and not surprisingly, *curricular saliency* was the most frequently expressed TSPCK component. As would be expected of a big idea in science (Harlen, 2010) autotrophy and heterotrophy were quickly recognized as core biology content, therefore it was easy for the teachers to identify its relevance for biology as a discipline as well as connections to other intradisciplinary topics. The topic's importance to developing citizenship and environmental awareness was also discussed by many of the teachers and is in line with previous research (i.e. Hartley et al., 2011; Schramm et al., 2018).

Two different areas were identified and discussed for which the topic is crucial within biology: understanding of biochemical processes on a subcellular level, as well as implications on an ecosystem level. Connections to other topics such as climate change were also discussed, which implies that teachers consider the interdisciplinary nature of the topic. Being able to jump between scales and understanding how the same principles apply in different contexts builds scientific literacy and reasoning (Doherty et al., 2025; Hartley et al., 2011).

5.2 Topic-specific challenges

As already concluded in previous research content related to autotrophy and heterotrophy is non-intuitive and challenging to teach and learn. The topic is simultaneously fundamental to understanding biology and complex and interwoven with the other natural sciences. Higher cognitive thinking skills and a capacity for scientific abstraction is required for complex topics, and photosynthesis have conceptual aspects linked to biology, ecology, physiology, biochemistry, molecular biology and physics (Jancarikova & Jancarik, 2022).

The teacher's reflections on *what is difficult to teach* in relation to the topic are supported by previous studies. The abstract concepts of photosynthesis, cell respiration and energy are complex and deeply rooted in the topic. What further complicates the matter is that the interactions between these concepts are also abstract and complex (Kampourakis & Reiss, 2018). Many students believe that plants grow by absorbing matter from the soil, and according to Brown (2013) the concept of food is problematic for students. This can be compared to difficulties in separating between vitamins, nutrients, and energy as one teacher reported. Food is along with concepts like gas and energy important for understanding photosynthesis as a process (Brown, 2013). Lubkowitz et al. (2017) argue that without including carbohydrate partitioning in the teaching of photosynthesis, energy flow remains unconnected to the process of photosynthesis. Connecting carbohydrate transport to different parts of the plant could strengthen the understanding of the plants' acquisition of nutrients.

Energy is a concept that children come across early as an everyday concept associated with food, physical activity, mood, and societal energy sources. As all the teachers concluded, energy is a problematic concept, and contributing to the problem is the use of multiple different metaphors and analogies to explain the concept (Lancor, 2014). Energy is far too abstract to be described with a single metaphor, and as different metaphors highlight different aspects of an abstract concept, the complexity of the concept increases (Lakoff & Johnson, 1980). In biology, energy is typically handled as a substance (Lancor, 2014), which can cause confusion, as it implies that energy can be produced or destroyed, contradicting lessons taught in physics.

The abstract and blurry nature of the concept energy is also enhanced by linguistic aspects. For instance, the concept of cell respiration, used in biology, is equivalent to the concept of slow combustion in chemistry. Different concepts for the same phenomena might cause confusion for students that still develop basic content knowledge. Further, it is important that students understand that respiration is not equivalent to breathing (Brown, 2013).

The teachers repeatedly spoke about difficulties in transferring the concepts between different levels, from the symbolic via the macroscopic to the ecosystem level. One teacher suggested that system thinking requires cognitive maturity that students of this age are still developing. This indicates another inherent challenge with the topic autotrophy and heterotrophy: that it builds on the capacity of system thinking. An understanding of molecules is necessary for scaling up and down from the macroscopic level (Hartley et al., 2011) but is cognitively challenging.

The suggestion that topic-specific challenges are not only of pedagogical nature poses an interesting addition to the discussion. The ability to think on system level requires deep content knowledge and sufficient help and support from teachers. Most students attending secondary education think mainly on a macroscopic level. According to a quantitative study by Jin et al. (2017) only 36 % of American middle and high school students were able to demonstrate higher levels of learning progression of ecosystems. A marginal amount (3 %) of the students were able to provide sophisticated responses to questions regarding ecosystems, using system thinking concepts, and 33 % were able to provide responses that demonstrated knowledge of relationships and patterns (Jin et al., 2019). This suggests that the topic is challenging to teach regardless of teaching experience (Brown, 2013) and further implies that a multidisciplinary approach could be productive.

Besides the fact that the topic contains difficulties and challenges from the teachers' perspective, the student perspective seems to be weak among teachers. Knowledge about learner understanding could be limited due to cultural reasons; based on the first author's own observations from classrooms most upper secondary students adopt a very passive role in the classroom. Passive students make it more difficult for teachers to benefit from the learning context for developing personal TSPCK, and in particular, knowledge about student prior knowledge is hard to attain (Carlson et al., 2019). A lack of communication between teachers and students leads to teachers determining preconceptions based on performance. Developing knowledge of the learning progression of a concept or a phenomenon could take different routes but requires active effort. A teacher could do systematic inquiries and observations in the classroom and develop pTSPCK by interacting with students. Another way is to benefit from cTSPCK either by reading literature or engaging with other teachers in professional development.

Using the TSPCK components as an analytical framework was not always straightforward. Although the authors initially thought that the components were distinct and clearly defined the expressions of the teachers did not always fall neatly into these categories. Learner prior knowledge and what is difficult to teach were frequently alternative components in the analytical process and had an impact especially on the quantitative summary. Difficulties in categorizing teacher expressions could also be a result of expressions where indeed knowledge from both components are utilized, suggesting richer TSPCK and reasoning.

5.3 Topic-specific strategies

The *representations* that were brought up as valuable teaching resources had a considerable overlap between teachers. All representations were mentioned by more than one teacher, which can be interpreted as evidence of a shared knowledge base. Practical work in the form of experiments was considered useful representations and *teaching strategies* to clarify the topic. Most of the experiments can be categorized as step-by-step demonstrations of the processes linked to the topic, both on a molecular and ecosystem scale. These were chosen to make the topic less abstract for the students, i.e. demonstrating cell respiration by carbon dioxide production by yeast.

Several teachers discussed two representations with teaching potential: closed terrestrial ecosystems and an experiment about cell respiration with yeast cells. These representations were, however, considered to be best used when students have deeper content knowledge; the teachers referred specifically to the flow of energy through the ecosystem, photosynthesis and cell respiration. This reflection suggests that teachers are indeed striving to use representations for more than demonstrational purposes; a teaching goal is also to provoke system thinking skills. Merely building a model of an ecosystem brings no added value and was considered a repetition of prior knowledge by some of the teachers. One teacher had solved this pedagogical dilemma by making the activity more advanced: the students documented the levels of gas production in a closed system. By adjusting the execution and learning goals representations can therefore be used for different purposes.

There were two apparent reasons for actively choosing to skip a representation in the upper secondary education: lack of time and lack of sufficient content knowledge among students. A general sense of curriculum overload leads to more teacher-centered teaching as practical activities consume more lesson time. A solution to the problem was to move the activity to other courses in the upper secondary, where optional courses offer more flexibility for the teacher. The negative outcome of this solution, however, is that not all students take part in this kind of teaching and develop practical skills.

Strategies for teaching were quite similar between different teachers. This reflects both similarities in the teaching context as well as a shared or collective understanding of the topic. The occurrence of specific teaching strategies in the written material and conceptual teaching strategies in the transcripts suggests that reflection is triggered by an oral format. Choosing representations and teaching strategies can, however, be pedagogical decision-making based on routine.

Inquiry is considered important in teaching both biology as well as the topic itself by the teachers, as well as by scientific literature (Lubkowitz et al., 2017; Schramm et al., 2018). The practical work chosen by the teachers is often, however, done as step-by-step activities. Building ecosystems is more easily done as an open assignment but due to time limitation open assignments are quite rare. O'Connell (2008) argues that creating a mystery of germinating peas stimulates authentic inquiry about the germination process. Solving a mystery appears to have generated fruitful circumstances for genuine inquiry, however, the study does not discuss learning outcomes. Another example is provided by Lubkowitz et al. (2017); a question-based approach with experimental modules for teaching photosynthesis and carbohydrate partitioning is presented to follow energy flow in organisms and stimulate deeper understanding.

Drawing as a method of clarifying concepts and ideas was also considered essential by the teachers. A drawing constitutes a representation or a model that highlights certain aspects of the topic and can be used to develop understanding when incorporated into a lesson (Rybska et al. in Korfiatis et al., 2024). The teachers referred to pictures as an activity that was done as a joint activity; the teacher draws a picture on the board, and the students copy the picture in their notes. Students' drawings of photosynthesis can function as modelling-based learning for deeper conceptual understanding (Rybska et al., in Korfiatis et al., 2024).

5.4 CoRe as a reflection tool

Overall, the teachers seemed to appreciate CoRe as a reflection tool. Some prompts were experienced as more difficult than others by the teachers, but the general impression was that the tool was efficient for reflecting on teaching. The possible use of CoRe in didactical courses was discussed and several teachers even made suggestions on how the tool could be used or developed to enhance professional development. One suggestion was to include a prompt that would focus on how to visualize the topic in a picture as visual representation was considered essential in biology teaching.

The empirical material was gathered in two formats: as written answers to the prompts and as oral expressions in the interview. While the written documentation was easier to categorize, and most of the articulations can be found in this format, the interviews generated more examples of pedagogical reasoning which is indicated by the increased number of articulations of conceptual teaching strategies. Some teachers clearly preferred the interview and did not engage in the written format.

None of the teachers had previously encountered CoRe. A presentation of the tool could have generated an increased number of articulations in the empirical material, nevertheless the similarity in the empirical material suggests that the prompts were understood in a similar way. Not every prompt was however self-evident, especially the prompt concerning other difficulties or limitations that must be taken into consideration was omitted. Apart from generating additional examples of TSPCK all the interviews developed into discussions about teaching, teacher education and curriculum, and therefore functioned as a catalyst for pedagogical discussions in general. One of the teachers even addressed this in the interview, referring to the interview as another dimension of knowledge sharing.

The study, in line with others (i.e. Loughran et al,, 2012; Park et al., 2018) shows that the PCK and TSPCK frameworks are helpful when portraying teacher knowledge. The empirical material produced by teachers' interaction with CoRe did however contain numerous segments where teachers expressed teacher knowledge that was not however compatible with the TSPCK components chosen for this study as in Sannert et al. (2025). These were not coded as their nature was too general, but their occurrence demonstrate that teachers easily identify content as well as teaching and assessment strategies. In this study specific teaching strategies was added as a component as the content was considered important for describing TSPCK. A study by Sannert et al. (2025) confirms that CoRe can be used to document a variety of teacher knowledge bases such as pedagogical, content and general assessment knowledge. Park and Chen (2012) used CoRe to document orientation of teaching science, knowledge of student understanding and knowledge of instructional strategies. Using the same tool to discuss different knowledge bases shows that teacher knowledge is multifaceted and that these are interconnected. As with the concept of energy, maybe one way of defining PCK is not enough to portray the abstract nature of practical knowledge?

5.5 Implications and suggestions for further research

CoRe appears to be a sensible reflection tool for and on teaching, on both an individual level and a collective level. In a teacher education context, the tool could offer a structure for reflection pre- and post-lesson as well a means to track progression in the development of teacher professional knowledge. In-service teachers could use the tool to share and develop knowledge within the teaching community. While pedagogical reasoning was found more extensively in the interviews, the tool could be more productively used in an interactive manner.

The teachers repeatedly brought up the close connection to chemistry and physics. As many aspects of the topic is abstract and multidisciplinary an interesting aspect to study would be to investigate how teachers from these subjects jointly address the inherent difficulties in the topic. What kind of representations and conceptual teaching strategies could be used to create synergies between the subjects and enhance student learning? Developing teaching strategies that incorporate inquiry to deepen knowledge without being too time consuming could also be a productive research area.

Judging from this group of teachers', knowledge about the root of misconceptions and difficulties from a student perspective would help teachers to include tailored activities and resources. A pedagogical dilemma that can be sensed in the expressions of the teachers is that there seems to be a consensus regarding the importance of practical work and inquiry for teaching and learning the topic, while these strategies at the same time fail to meet the expectations of the teacher.

5.6 Limitations

Conducting this study was done under some important limitations. In the study the TSPCK framework was used as an analytical tool. With a deductive setup follows that researchers approach the data with an informed perspective, but also with bias. Researchers might be more likely to find evidence that is supportive rather than non-supportive of the theory (Hsieh & Shannon, 2005). An overemphasis on the theory can blind researchers to contextual aspects of the phenomenon.

The findings of the study must be interpreted with some reservation as the study context is very specific and limited. The results are based on a very small convenience sample of a group of relatively homogenous biology teachers in the Swedish-speaking minority in Finland. It is not possible to draw any statistical generalizations from the study. Expressions of pTSPCK are not to be considered as full descriptions as the teachers were unfamiliar with the CoRe tool, and additional pTSPCK could be extracted from classroom observations or teachers eTSPCK.

Another important possible limitation is the quality of the empirical material. The participating teachers were all unfamiliar with CoRe as an instrument, and it was their first encounter with the prompts in the instrument. This could potentially have affected the responses, and some familiarity or background literature could have generated more elaborate responses. In the interviews, on the other hand, familiarity with the researcher might have influenced the teachers to leave parts of their reasoning out as a shared understanding might have led them to think this was redundant.

Research ethics

Author contributions

Jessica Sundman: conceptualization, data curation, methodology, validation, visualization, writing—original draft preparation.
Ann-Sofi Röj-Lindberg: methodology, supervision, writing – review and editing.
Pia Sjöblom: formal analysis, validation, writing—review and editing.
All authors have read and agreed to the published version of the manuscript.

Artificial intelligence

Artificial intelligence has not been used in any part of the research process.

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Informed consent statement

Informed consent was obtained from all research participants.

Data availability statement

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Conflicts of Interest

The authors declare no conflicts of interest.

Appendix A

CoRe prompts

Prompt 1	What do you intend the students to learn about this big idea?
Prompt 2	Why is it important for the students to know this?
Prompt 3	What do you know about this big idea that you do not intend students to know yet)?
Prompt 4	What difficulties/limitations do you think are connected with teaching this big idea?
Prompt 5	What knowledge do you have about students' thinking that influences your teaching of this big idea?
Prompt 6	Are there other factors that influence your teaching of this big idea?
Prompt 7	What teaching strategies do you use to engage students with the big idea, and why have you chosen these?
Prompt 8	How can students' understanding or misconceptions about this idea be determined?

Note. CoRe consists of eight prompts that are addressed in relation to a topic or a big idea.

References

Bassey, M. (2000). *Case study research in educational settings*. Open University Press.

Berry, A., Friedrichsen, P., & Loughran, J. (2015). *Re-examining pedagogical content knowledge in science education*. Routledge.

Brown, C. R. (2013). *The effective teaching of biology*. Routledge.

Buldu, E., & Buldu, M. (2021). Investigating pre-service early childhood teachers' cPCK and pPCK on the knowledge used in scientific process through CoRe. *Sage Open*, *11*(2), 21582440211025564. https://doi.org/10.1177/21582440211025564

Carlson, J., Daehler, K. R., Alonzo, A. C., Barendsen, E., Berry, A., Borowski, A., Carpendale, J., Kam Ho Chan, K., Cooper, R., Friedrichsen, P., Gess-Newsome, J., Henze-Rietveld, I., Hume, A., Kirschner, S., Liepertz, S., Loughran, J., Mavhunga, E., Neumann, K., Nilsson, P., … Wilson, C. D. (2019). The Refined Consensus Model of pedagogical content knowledge in science education. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77–94). Springer Nature Singapore. https://doi.org/10.1007/978-981-13-5898-2_2

Cochran-Smith, M. (2004). Taking stock in 2004: Teacher education in dangerous times. *Journal of Teacher Education*, *55*(1), 3–7. https://doi.org/10.1177/0022487103261227

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge.

Doherty, J. H., Todd, K. A., Wenderoth, M. P., Van der Slik, A. L., & Cole, E. J. (2025). Biological principles successfully guide students' generative mechanistic reasoning. *CBE—Life Sciences Education*, *24*(4), ar51. https://doi.org/10.1187/cbe.24-12-0298

Forsler, A., Nilsson, P., & Walan, S. (2024). Capturing and developing teachers' pedagogical content knowledge in sustainable development using content representation and video-based reflection. *Research in Science Education*, *54*(3), 393–412. https://doi.org/10.1007/s11165-023-10149-y

Gotwalt, E. S. (2023). Putting the purpose in practice: Practice-based pedagogies for supporting teachers' pedagogical reasoning. *Teaching and Teacher Education*, *122*, 103975. https://doi.org/10.1016/j.tate.2022.103975

Harlen, W. (2010). *Principles and big ideas of science education*. Association for Science Education.

Harms, U., & Bertsch, U. (2018). Energy, photosynthesis, and respiration. In K. Kampourakis, & M. J. Reiss (Eds.), *Teaching biology in schools* (pp. 139–152). Routledge.

Hartley, L. M., Wilke, B. J., Schramm, J. W., D'Avanzo, C., & Anderson, C. W. (2011). College students' understanding of the carbon cycle: Contrasting principle-based and informal reasoning. *BioScience*, *61*(1), 65–75. https://doi.org/10.1525/bio.2011.61.1.12

Hattie, J., & Zierer, K. (2018). *10 mindframes for visible learning: Teaching for success*. Routledge. https://doi.org/10.4324/9781315206387

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

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. https://doi.org/10.1007/s11165-010-9168-3

Jančaříková, K. I., & Jančařík, A. (2022). How to teach photosynthesis? A review of academic research. *Sustainability*, *14*(20), 13529. https://doi.org/10.3390/su142013529

Jin, H., Shin, H. J., Hokayem, H., Qureshi, F., & Jenkins, T. (2019). Secondary students' understanding of ecosystems: A learning progression approach. *International Journal of Science and Mathematics Education*, *17*(2), 217–235. https://doi.org/10.1007/s10763-017-9864-9

Kahn, R. R., & Nyamupangedengu, E. (2022). Investigating opportunities for integrating methodology when teaching a life science topic (meiosis) to fourth-year pre-service teachers: A case study. *Journal of Education*, *86*, 64–84. https://doi.org/10.17159/2520-9868/i86a04

Kampourakis, K., & Reiss, M. J. (Eds.) (2018). *Teaching biology in schools: Global research, issues, and trends* (1st ed.). Routledge. https://doi.org/10.4324/9781315110158

Kind, V. (2009). Pedagogical content knowledge in science education: Perspectives and potential for progress. *Studies in Science Education*, *45*(2), 169–204. https://doi.org/10.1080/03057260903142285

Korfiatis, K., Grace, M., & Hammann, M. (Eds.). (2024). *Shaping the future of biological education research: Selected papers from the ERIDOB 2022 Conference*. Springer Nature Switzerland; European Researchers in Didactics of Biology.

Lakoff, G., & Johnson, M. (1980). The metaphorical structure of the human conceptual system. *Cognitive Science, 4*(2), 195–208. https://doi.org/10.1207/s15516709cog0402_4

Lancor, R. (2014). Using metaphor theory to examine conceptions of energy in biology, chemistry, and physics. *Science & Education*, *23*(6), 1245–1267. https://doi.org/10.1007/s11191-012-9535-8

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, 4*(4), 370–391. https://doi.org/10.1002/tea.20007

Loughran, J., Berry, A., & Mulhall, P. (Eds.). (2012). *Understanding and developing science teachers' pedagogical content knowledge*. SensePublishers. https://doi.org/10.1007/978-94-6091-821-6

Lubkowitz, M., Koch, K., Weil, C., & Braun, D. M. (2017). A question-based approach to teaching photosynthesis, carbohydrate partitioning, and energy flow. *The American Biology Teacher*, *79*(8), 655–660. https://doi.org/10.1525/abt.2017.79.8.655

Mapulanga, T., Ameyaw, Y., Nshogoza, G., & Sinyangwe, E. (2023). Improving secondary school biology teachers' topic-specific pedagogical content knowledge: Evidence from lesson studies. *Journal of Baltic Science Education*, *22*(1), 20–36. https://doi.org/10.33225/jbse/23.22.20

Mavhunga, E. (2016). Transfer of the pedagogical transformation competence across chemistry topics. *Chemistry Education Research and Practice*, *17*(4), 1081–1097. https://doi.org/10.1039/C6RP00095A

Mavhunga, E., & Rollnick, M. (2013). Improving PCK of chemical equilibrium in pre-service teachers. *African Journal of Research in Mathematics, Science and Technology Education*, *17*(1–2), 113–125. https://doi.org/10.1080/10288457.2013.828406

MConnell, D. (2008). An inquiry-based approach to teaching photosynthesis & cellular respiration. *The American Biology Teacher, 70*(6), 350–356.

Oliver, D. G., Serovich, J. M., & Mason, T. L. (2005). Constraints and opportunities with interview transcription: Towards reflection in qualitative research. *Social Forces*, *84*(2), 1273–1289. https://doi.org/10.1353/sof.2006.0023

Park, S., & Chen, Y.-C. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms. *Journal of Research in Science Teaching*, *49*(7), 922–941. https://doi.org/10.1002/tea.21022

Park, S., Suh, J., & Seo, K. (2018). Development and validation of measures of secondary science teachers' PCK for teaching photosynthesis. *Research in Science Education*, *48*(3), 549–573. https://doi.org/10.1007/s11165-016-9578-y

Podolsky, A., Kini, T., & Darling-Hammond, L. (2019). Does teaching experience increase teacher effectiveness? A review of US research. *Journal of Professional Capital and Community, 4*(4), 286–308. https://doi.org/10.1108/JPCC-12-2018-0032

Rybska, E., Wojtkowiak, J., Chyleńska, Z., Karnaou, P., Constantinou, C. P. (2024). Where do plants get their mass from? Using drawings to assess adolescent students' modelling skills and their ideas about plant growth. In K. Korfiatis, M. Grace, & M. Hammann (Eds.), *Shaping the Future of Biological Education Research. Selected Papers from the ERIDOB 2022 Conference* (pp. 147–162). Springer. https://doi.org/10.1007/978-3-031-44792-1_11

Sannert, R., Van Driel, J., & Krell, M. (2025). Can Content Representation (CoRe) accurately capture key components of science teachers' PCK? A methodological perspective. *Journal of Science Teacher Education, 37*(1), 109–133. https://doi.org/10.1080/1046560X.2025.2516293

Schramm, J. W., Jin, H., Keeling, E. G., Johnson, M., & Shin, H. J. (2018). Improved student reasoning about carbon-transforming processes through inquiry-based learning activities derived from an empirically validated learning progression. *Research in Science Education*, *48*(5), 887–911. https://doi.org/10.1007/s11165-016-9584-0

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. https://www.jstor.org/stable/1175860?origin=JSTOR-pdf&seq=1

Taber, K., & Akpan, B. (2017). *Science education: An international course companion*. Sense publishers.

TENK. (2019). The ethical principles of research with human participants and ethical review in the human sciences in Finland. https://tenk.fi

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. *The Electronic Journal of Science Education, 3*(4).

Veal, W. R., & Kubasko Jr., D. S. (2003). Biology and geology teachers' domain-specific pedagogical content knowledge evolution. *Journal of Curriculum & Supervision*, *18*(4), 334.