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Research article

Engagement through experiments: Experiences from online kitchen chemistry courses

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Abstract: The experimental nature of chemistry education is highly challenging in online teaching and the lack of practical assignments prevents online science education from reaching its full potential. This study investigates how student engagement can be achieved by implementing experiments in online teaching. Two asynchronous self-paced online courses were developed and offered to broad audience. The courses taught chemistry in the kitchen chemistry context and included phenomenon-based learning through practical assignments related to food preparation. Analysis of the course participants' responses to various surveys shows that according to the students, they were able to observe the connection between theory and experimentation in each assignment. Also, 85% of students who completed the first practical assignment were motivated enough to finish the whole course. These findings highlight the importance of behavioural, emotional and cognitive engagement created by meaningful learning tasks.

Keywords: engagement, home experiments, kitchen chemistry, online education, science education

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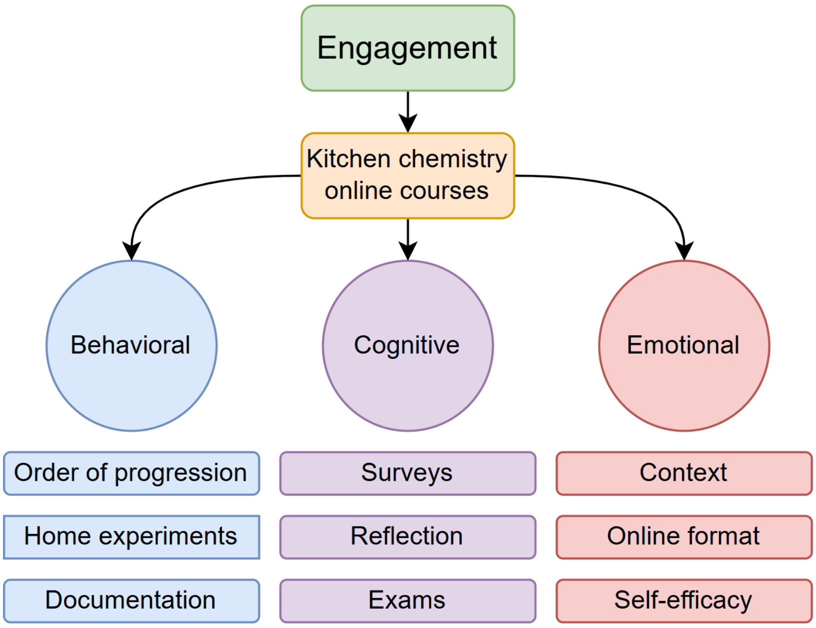

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1 Introduction

The COVID-19 pandemic forced all schools to transition from physical contact teaching to online education, giving schools very little time to prepare (Dhawan, 2020; Nguyen & Keuseman, 2020). All teaching, both theoretical and practical, had to be transferred to online environment (Díez-Pascual & Jurado-Sánchez, 2022). This caused problems especially in natural sciences, because science courses containing practical assignments had major challenge of finding alternative ways for students to gain necessary practical skills without being in school (Díez-Pascual & Jurado-Sánchez, 2022; Nguyen & Keuseman, 2020). For example a study conducted for first and second year chemistry students reported that the most commonly addressed challenge, during COVID-19 online learning was the inability to do experiments in teaching labs (Huang, 2020).

Not only was the practical course work missing from COVID-era, but the lack of preparation also made the online teaching challenging in quality. Compared to traditional teaching, it responded insufficiently to students' basic needs, causing more mental health problems and was associated with many learning and teaching difficulties. Students described such teaching as stressful and challenging. (Spinks et al., 2023) Despite the drawbacks, it showed that most if not all curricula could be taught online. This left behind the need to invest in quality online education and the question is no longer whether online education is needed, but rather how it could be implemented (Dhawan, 2020).

In this study the goal was to evaluate the feasibility of promoting student engagement by including practical experimentation in an online course.

1.1 Online learning

Implementing online learning requires unique pedagogical solutions, time, abilities and the right attitude. Because of this, the hasty transition to the internet during COVID-era should not be used as a starting point for evaluating online learning. (Spinks et al., 2023) One of the major challenges for teachers is figuring out how to transform well-received in-person active teaching methods to online environment and it is still under debate whether online learning can provide the same learning outcomes as traditional contact teaching (Cavinato et al., 2021; Hong et al., 2021).

Usually, online education is seen as lower quality compared to contact teaching, although research has examples showing otherwise (Spinks et al., 2023). One study compared the students' course grades from several courses offered both as contact and online formats. Students in the online courses achieved the same or better grades compared to the contact teaching in 16 out of 17 courses. For some courses, even when the online version offered less support for students, the students got better grades in increasing numbers. According to student feedback, the one online course with lower student performance had misalignment with course material and assessment and the course expectations were not clear. (Zheng et al., 2021)

Online learning is not meant to imitate contact teaching, but rather provide unique form of learning with its own strengths and challenges (Spinks et al., 2023). Some of these strengths include enhanced flexibility in choosing time and location for studying, accessibility to a wider audience and immediate feedback (Dhawan, 2020; Zheng et al., 2021). For some students written communication might be less intimidating than speaking in class, which may increase participation and reduced traveling to classes offers more time for sleeping and other self-caring, which is beneficial for mental health (Zheng et al., 2021). Online environments also provide opportunities to innovate new pedagogical and technological solutions in education (Cavinato et al., 2021).

Despite having some benefits, online learning might not be suitable for all learners since it requires physically and mentally much more from the learner compared to face-to-face teaching. Typical classroom teaching has clear scheduling, necessary equipment for learning and a specific place to keep external distractions to a minimum so students can concentrate on the topic at hand (Huang, 2020). In online education this is not always the case, making student's ability to self-regulate their own learning critical (Sun & Rueda, 2012). The online format might lack communication, collaboration and other personal interaction and when students are left alone without support, various learner-specific aspects might hamper the learning process (Zheng et al., 2021). The lack of confidence in one's own skills might lead to negative feelings such as frustration, anxiety, confusion and feelings of isolation. The lack of skill might lead to digital illiteracy and difficulty in understanding objectives and learning goals. (Dhawan, 2020) Various external factors such as personal responsibilities, available time, places to study and outside distractions might affect the learning process as well (Cavinato et al., 2021).

In addition to these learner-specific challenges, the technological nature of online learning makes it also vulnerable to various hardware and software problems, such as outdated equipment, poor connectivity, incompatible file formats, login and installation errors and power outages (Cavinato et al., 2021; Dhawan, 2020; Miltiadous et al., 2020).

The vast number of various challenges associated with online learning raises concerns about equity and accessibility, since learners have different opportunities to participate in it (Cavinato et al., 2021). These concerns are usually not a problem in contact teaching, where students are all in the same classroom sharing the resources. Some of these previously mentioned issues, especially technological problems, can be alleviated by asynchronous course materials and giving plenty of time to complete assignments. Asynchronous studying offers online learning even more flexibility, since the learner is free to choose the most suitable time, place and pace for their learning This kind of flexibility is especially useful for people with strict schedules and other responsibilities. (Vai & Sosulski, 2011) Alas, most of the learner specific challenges mentioned may be caused by online learning being an unfamiliar format. Usually, the more learners engage in online learning, the more satisfied they are with their learning effectiveness (Hong et al., 2021).

1.2 Chemistry education

The objective of science education has shifted from ensuring adequate numbers of competent scientists to the scientific literacy of the people. Inquiry-based-learning is now an overarching theme in science curricula worldwide. It focuses on giving students their own experiences with a chance of active learning and reflective thinking, instead of presenting scientific phenomena as mere facts and theories. (Jegstad, 2023)

In chemistry education, scientific reasoning is related to the three levels of chemistry knowledge (Jegstad, 2023; Johnstone, 2000). One concern is that chemistry education puts too much attention on the sub-micro and symbolic levels, when students often struggle making connections to macro level. Even though inquiry-based chemistry education puts emphasis on 21st century skills like creativity, critical thinking and collaboration, many teachers' implementations of it prioritize topic knowledge and ready-made science. (Jegstad, 2023) Different authors have tried to mitigate this problem by expanding the levels of chemistry knowledge into models that highlight various aspects of purpose and real life relevance in chemistry education (Sjöström et al., 2020). Science education should focus more on these social and epistemological (i.e. nature of science) aspects, since only then can learners get the full picture of science knowledge (Jegstad, 2023).

Experiments are major part of chemistry education, since chemistry is an experimental science (Díez-Pascual & Jurado-Sánchez, 2022). Experimenting enables students to take part in phenomenon-based-learning, which is a systematic observation-based approach emphasizing direct interaction with true natural phenomena. It focuses on student's own research and experiences to be used as a basis for learning and understanding. (Adipat, 2024; Nuora & Välisaari, 2019) In experimental courses students participate in hands-on activities and gain experience by operating scientific instruments and observing scientific processes and objects (Díez-Pascual & Jurado-Sánchez, 2022). Such course contents are usually well received by the students as they stimulate students' curiosity and creativity since well-designed laboratory experiments with clearly defined learning objectives can increase student's learning experience and outcomes (Hong et al., 2021; Nguyen & Keuseman, 2020). In addition, inquiry-based experiments are known to improve student engagement for enhancing learning, critical thinking and understanding of scientific methods (Nguyen & Keuseman, 2020).

Experiments alone do not guarantee useful learning activities. In order for an experiment to be pedagogically effective, it should have a clear vision of 1) what students are expected to learn, i.e. what the learning objectives are, 2) what teaching methods are used to achieve the learning objectives and 3) how learning is assessed. (Seery et al., 2024) Typical learning goals for experimentation include learning subject-specific content and new working methods, developing scientific thinking and cultivating interest (Hofstein, 2015). The time reserved for practical work is usually spent almost entirely to perform various activities, leaving very little time for actual reflection on one's own performance. Actual learning is unlikely to happen if students simply perform tasks without internalizing what they have done. (Seery et al., 2024) One of the central goals of science teaching is meaningful learning or learning with understanding (Hofstein, 2015). Teaching aimed at understanding can be promoted by creating opportunities for students to consciously connect new things with what they already know. Student's interest, motivation and commitment also have an impact on the internalization process, and these aspects have been fostered by context-based learning and using real societal problems as a starting point for teaching. (Seery et al., 2024)

Courses containing experiments are typically organized as contact teaching, so majority of online teaching does not include any experimental work (Hong et al., 2021). This lack of practical training prevents online learning from reaching its full teaching potential (Dhawan, 2020). One solution to improve this aspect of online learning might be for students to conduct experiments at their home, but some see such approach as expensive, risky and less practical (Díez-Pascual & Jurado-Sánchez, 2022).

1.3 Theoretical framework: engagement

Engagement is a multifaceted concept, which can be used to describe the quality of effort learners make to achieve desired outcomes (Miltiadous et al., 2020; Sun & Rueda, 2012). It manifests itself as learners' attendance, active participation, meaningful interaction with resources and completion of tasks (Hong et al., 2021; Miltiadous et al., 2020). Three distinct dimensions can be found in engagement: behavioural, emotional and cognitive. Behavioural engagement describes learner participation and consists of what students do in practice. Emotional engagement describes learners' feelings towards the topic, and it's affected by attitudes, interests, values and experiences. Cognitive engagement describes how much mental capacity learners invest on their learning and how it is affected by motivation, self-control and utilization of study strategies. (Fredricks et al., 2004) Out of these three dimensions, behavioural and cognitive engagement require effort on learner's part: physically performing a task or mental capacity to process information (Sun & Rueda, 2012). Every type of engagement seems to improve learning outcomes, but studies have shown that behavioural engagement is more important to learning effectiveness than the other two aspects (Fredricks et al., 2004; Hong et al., 2021; Miltiadous et al., 2020).

1.4 Kitchen chemistry

Kitchen chemistry as a real-life context can be used effectively to teach scientific principles (Nuora & Välisaari, 2019). In addition to being inexpensive to implement, the context of kitchen chemistry can increase interest and enthusiasm in studying chemistry, because it: (Grosser, 1984)

- presents science applications in familiar and safe contexts

- uses techniques that most of the target group is already familiar with (everyone has cooked something). The target group realizes that they act as chemists whenever they prepare food
- is well suited for self-directed experimentation at home with instructions
- is suitable for popularizing science to the public, and provides practical examples in the academia
- can explain a vast number of cooking recipes with a few scientific principles, giving learners sense of control and experiences of success.

Kitchen chemistry has been used as a context in chemistry education in various forms with generally positive results. By connecting chemistry to everyday things like cooking, the learning experience can be made more engaging, especially for non-science majors as shown by Nguyen and Keuseman (2020). They presented 10 week kitchen chemistry themed online course for university students, which included dish preparation experiments and writing reports of them. Student-driven approach with the experiments allowed the students to control their own learning without direct guidance and the authors assessed that the relatable nature of cooking made independent work possible. The course was well received. Many students did the experiments together with their family members and students indicated how also their relatives were looking forward to the weekly experiments, because they enjoyed talking about the dishes and trying new ones.

Schultz et al. (2020) compared students' work sheet scores in activities offered as a traditional laboratory work, as an online video, and as kitchen chemistry experiments. The recorded student work produced significantly lower test scores compared to traditional contact teaching. One of the kitchen chemistry implementations produced slightly lower test scores compared to contact teaching and the other produced scores comparable to videos. Even though the authors claimed that these scores were not directly comparable, the study highlighted the importance of concrete hands-on activities for students and how kitchen chemistry experiments are not automatically a guarantee for better academic performance.

The approach described in this article differs from other kitchen chemistry implementations in that these courses were designed from the beginning to be completed and managed fully independently by the online course learners. The practical course work had a significant role in the courses, and their functionality was the main research focus in this study.

2 Methods

This study was conducted as part of the development of online courses, and the data used was obtained from these courses. The following sections present the guidelines for the course development and their contents.

2.1 Building the online courses

Kitchen chemistry context has been repeatedly and successfully used at the University of Jyväskylä in chemistry teacher training (Nuora & Välisaari, 2019). Previous implementations have been relying on contact teaching. Here, the plan was to bring the same context to online format. Based on previous experiences, it was understood that kitchen chemistry context includes much more than just cooking, where the fundamentals of natural science can be seen. These include, for example, food packaging, E-codes and cleaning. Consequently, the main topics guiding the design of the online courses presented here became:

1. What are kitchen chemistry and molecular gastronomy?
2. Different forms of cooking food
3. Acids and bases in food preparation
4. Various food preservation methods and packaging materials
5. Chemistry in kitchen cleaning and hygiene needs
6. Sustainable development in food production and manufacturing

The goal was to build self-paced online courses that would teach chemistry in easily understandable contexts and make connections between chemistry and everyday phenomena. This kind of phenomenon-based learning is one of the central cross-disciplinary themes in Finnish national curriculum principles for both middle and upper schools (Schaffar & Wolff, 2024). Another major part of the courses were food-themed assignments which were designed to enable the students to conduct scientific experiments in their own homes.

The courses were created as a part of the University of Jyväskylä's open university's continuous learning program. The learning platform, Moodle, is commonly used at the university, so it was known to be reliable and already familiar to the students. Technical support was also readily available in case of problems. The courses were primarily targeted at high school students to offer a glimpse into university studies but as a part of continuous learning offering of the open university, they are available to anyone interested.

From previous experiences, others' implementations and learning theories it is known that in asynchronous online courses students usually need more guidance. This led to some pedagogical prerequisites when designing these courses. Communication between teachers and students was handled through a discussion forum which were used by students to ask questions and by teachers to send messages about course-related matters. The logical progression of the studies was ensured by keeping some subsections locked until completion of previous ones. Practical course assignments were followed by surveys, which served as a data collection method but at the same time directed students to reflect upon their own working, making the overall experience more meaningful than the experiment just being a chore. Model solutions after the experiments provided students a point of reference to compare with their own ideas.

The courses were built entirely from scratch, excluding the main topics and most of the experimental assignments. This made it possible to study the themes from various perspectives and build the course material from the most appropriate sources. Theory sections were written using numerous publications and official websites as sources. There are plenty of publications which view cooking from a scientific perspective, such as the books used to build these courses, presented in Table 1.

Table 1. Books used as background information to build the online course material

Cheung, P. C. K., & Mehta, B. M. (Eds.). (2015). Handbook of Food Chemistry (2015 edition). Springer.
Damodaran, S., & Parkin, K. L. (Eds.). (2017). Fennema's Food Chemistry (5th edition). CRC Press.
Farrimond, D. S. (2017). The Science of Cooking: Every Question Answered to Perfect Your Cooking (Illustrated edition). DK.
Kelly, A. L., Lavelle, C., This, H., & Burke, R. (Eds.). (2021). Handbook of Molecular Gastronomy: Scientific Foundations, Educational Practices, and Culinary Applications. CRC Press.
McGee, H. (2004). On Food and Cooking: The Science and Lore of the Kitchen (Updated edition). Scribner.
McGee, H. (2010). Keys to Good Cooking: A Guide to Making the Best of Foods and Recipes. Penguin Press.
Potter, J. (2015). Cooking for Geeks: Real Science, Great Cooks, and Good Food (2nd edition). O'Reilly Media.
Provost, J. J., Colabroy, K. L., Kelly, B. S., & Wallert, M. A. (2016). The Science of Cooking: Understanding the Biology and Chemistry Behind Food and Cooking. John Wiley & Sons.
Richards, E. H. & Elliott, S. M. (1907). The chemistry of cooking and cleaning; a manual for house keepers. Whitcomb and Barrows.
Sikorski, Z. E. (Ed.). (2007). Chemical and Functional Properties of Food Components (3rd edition). CRC Press.
This, H. (2006). Molecular Gastronomy: Exploring the Science of Flavor. Columbia University Press.
This, H. (2007). Kitchen Mysteries: Revealing the Science of Cooking. Columbia University Press.

At first the plan was to build a single course, but as the amount of course material kept growing, it was decided to split the main topics and two courses with slightly different focus were made. The first course, KEMY1001 (*Chemistry in Kitchen*, n.d.) puts greater emphasis on theoretical chemistry and the latter, KEMY1002 (*Applied Kitchen Chemistry*, n.d.) deals more with everyday life applications of chemistry. The learning objectives for both are presented in table 2.

Table 2. Main sections and learning objectives for the courses

Course	KEMY1001 (Chemistry in Kitchen)	KEMY1002 (Applied Kitchen Chemistry)
Main sections	What are kitchen chemistry and molecular gastronomy? Different forms of cooking food Acids and bases in food preparation	Various food preservation methods and packaging materials Chemistry in kitchen cleaning and hygiene needs Sustainable development in food production and manufacturing
Learning objectives	Understand the importance of chemistry in food preparation Identify the most common food macromolecules and know their chemical nature Know the reasons for cooking and most common cooking methods Understand browning reactions and factors affecting them Be able to explain cooking related changes in food at molecular level Know the meaning of acids and bases and their uses Manage the independent execution and reporting of simple experiment	Know factors affecting the shelf life of food Understand food preservation methods and their principles Understand the importance of hygiene in food handling Know how to apply chemistry in cleaning the kitchen Understand sustainable development and the environmental effects of food production. Manage the independent execution and reporting of simple experiments

Engagement was sought from its all three dimensions. The courses' overall themes and contents were meant to spark interest and therefore emotional engagement. Every major topic included hands-on experiments, which aimed to engage students behaviourally. Cognitive engagement was achieved with various questions, questionnaires and exams, which made students reflect on their own work and direct their thinking to course themes.

2.2 Courses' structure

Both courses were individually worth 1 study credit, corresponding to approximately 27 hours of work for students. The courses were structured in sections for introduction, course material and conclusion. The introduction welcomed the students to the course and offered guidance for completing the course. It included an introduction video, starting questionnaire, discussion forum, general tips for online learning and external link to the instructions of the learning platform. The conclusion part included a video to wrap up the course and a final survey for those completing the course.

Course material for both courses consisted of three main sections, made by splitting the previously mentioned (see Table 2) six main topics between the courses. All the sections had the following structure: Theory, experiment, survey about the experiment, model solutions for the experiment and finally exam about the section. The surveys, model solutions and exams were locked and opened only after the previous module was finished. This was done to make sure students completed the sections in order and couldn't just go take the exams straight away.

Theory involved consisted of 3-7 individual webpages of various scientific principles related to the main section. Each page had a list of references used at the end, allowing anyone interested to learn more about the topic. Theory was followed by practical experiments somewhat related to the previous theory. After that, there was a survey recording students' reception of the previous experiment and it also made students reflect on their work during the practical part. After responding to the survey, students received the model solutions for the previous experiment, allowing them to check their own answers within a short period of time after completing the practical assignments. Each main section ended with a multiple-choice exam, which the course automation graded immediately after the student completed it. The course was graded pass / fail and to pass the course, students had to complete all questionnaires, experiments and exams.

2.3 Practical course work

Both courses involved three hands-on experiments, which students were expected to perform independently in their home kitchens. Such independent assignments might not be suitable for every student, since the lack of teacher's support puts greater emphasis on the student's own self-management. However, they allow students to make genuine choices without the teacher's expectations affecting them and the independent nature offers more flexibility and autonomy for learners, which mimics the authentic decision-making process of a chemist working in a laboratory.

Five out of the six courses practical experiments were developed by the authors in kitchen chemistry context before the online courses. They had to fulfil a few criteria to be suitable for independent work, making them also usable in online education:

1. Work steps had to be relatively simple and the required equipment and raw ingredients to be easily available
2. Clearly noticeable changes had to occur during the experiment
3. Experiments had to relate to authentic cooking situations so that the students would learn cooking related practical skills for their own use (for example, how to make mayonnaise from basic ingredients).

Based on these criteria, the preparation of five different food items were chosen as experiments: fried egg, kissel, mayonnaise, butter and caramel. In addition, red cabbage indicator was chosen as the sixth experiment so that each online course section would include one practical assignment. The experiments and their contents are shown in Table 3.

Table 3. Experiments in the courses

Course	Experiment	Subject matter
KEMY1001	1. Frying an egg	amino acids and proteins, denaturation, density, frying
	2. Making caramel	carbohydrates, caramelization, volume measuring, boiling
	3. Red cabbage indicator	acidity, indicator, extraction
KEMY1002	4. Making kissel	carbohydrates, gelatinization, solubility, thickening
	5. Making mayonnaise	mixture, emulsion, polarity, mixing
	6. Making butter	emulsion, polarity, phase inversion, foam

The work instructions were offered as PDF documents. They consisted of a short introduction to the topic, the chemical background of the phenomenon, work steps and finally questions related to the experiment. To ensure that students did the practical exercises, they were asked to document their own work by taking pictures from different stages of the experiment. Students could submit their documentation and answers to the return box in the learning environment and after that they would receive model solutions with correct answers and images showing the work process for comparison.

2.4 Research questions and methods

The purpose of this study was to find ways to promote student engagement in online courses. As mentioned in the introduction section, engagement improves learning effectiveness (especially behavioural engagement) but most online courses lack experimental work. To alleviate this issue, one goal of this study was to find ways to increase experimenting in chemistry online courses. The approach presented here takes advantage of kitchen chemistry context and the first major research question was "*How well students manage to do independent kitchen chemistry experiments?*". The independent role of the learner put focus also on the rest of the course, therefore the second major research question was "*How does a self-paced online course function?*" These overall evaluations were approached by various minor questions about specific aspects of the course such as "what do students learn from the course?", "were the experiments difficult?" and "how automated multiple-choice exams work?". The point of interest was participants' experiences during the course instead of their academic achievement.

Design-based research was chosen as a research method. It combines theory and practice in a continuous iteration process, with three distinct stages (Edelson, 2002). Problem analysis maps the issues the research is meant to focus on, design procedure creates solutions to the needs that emerged from problem analysis and design solution is the resulting concrete output for the whole process, which can then be used as a starting point for new problem analysis. It is particularly popular method in education research, since it responds to actual needs and the iterative nature ensures that the design solutions are tested, making them readily available for teaching purposes.

Research orientation guided the course design process from the beginning and surveys consisting of Likert-scale statements and open-ended questions were prepared by the authors for the courses. Courses opened with an initial survey, which was used to clarify a student's background on the topic and motivation for taking the course. Each experiment had an individual survey to study the practical assignment. Courses ended with a final survey, which was used to collect thoughts about the perceived effectiveness of the course from those who had completed the course.

2.5 Data collection

The material used in this study consisted of students' answers to the various surveys in the courses. It was collected from both courses over the period of 1 August 2023 – 1 September 2024, during which both courses were offered twice. 145 responders answered the initial surveys, 225 practical assignments were returned along with their respective surveys, 224 exams were passed, and 70 answers were received in the final surveys.

2.6 Data analysis

Content analysis was chosen for this study for its flexibility in handling various forms of data. It can be defined as a research technique for identifying and recording relatively objective and valid inferences from messages and other meaningful matters with a goal to provide new insights by summarizing findings from larger data sets. (Krippendorff, 2019; Neuendorf, 2017) Due to the relatively small data set and to ensure everything was read for course development purposes, all student responses for the questions chosen in this study were included in the analysis. The analysis was performed manually to allow for a more in-depth look at the method used and student responses.

The students' answers were read and copied to a spreadsheet. Frequencies were calculated from the Likert-scale statements for comparison and open-ended questions were analyzed qualitatively using emergent coding, in which the different categories emerge from the data being analyzed. The analysis proceeded straightforwardly, as the analyzed data consisted of answers to questions, leaving no ambiguity about their context or meaning.

The reliability of the analysis was enhanced by repeating the coding process several times and performing numerical check calculations during the process to make sure the numbers added up. One of the authors made the preliminary classification and this was verified by team discussions to find the consensus of the final classification to be used. Table 4 presents some of students' responses and their categorization.

Table 4. Examples of student responses to the question “What did you learn about chemistry in this course?” and their final classification.

Student’s responses	**Chosen category for the content analysis**
For example, the difference between baking soda and baking powder, the acid-base cooking of fish, or the processes that occur when cooking meat. Maillard reaction, how heat affects proteins	Theory
I learned that cooking, which I thought was a completely ordinary everyday chore, is actually incredibly fascinating. How chemistry is intrinsically related to everyday life	Comprehension
- - I learned how to do simple experiments and write about chemistry-related topics. Washing burnt caramel is more challenging than ordinary washing.	Practical skills
Pretty much everything So much, it's hard to even list it all.	Everything

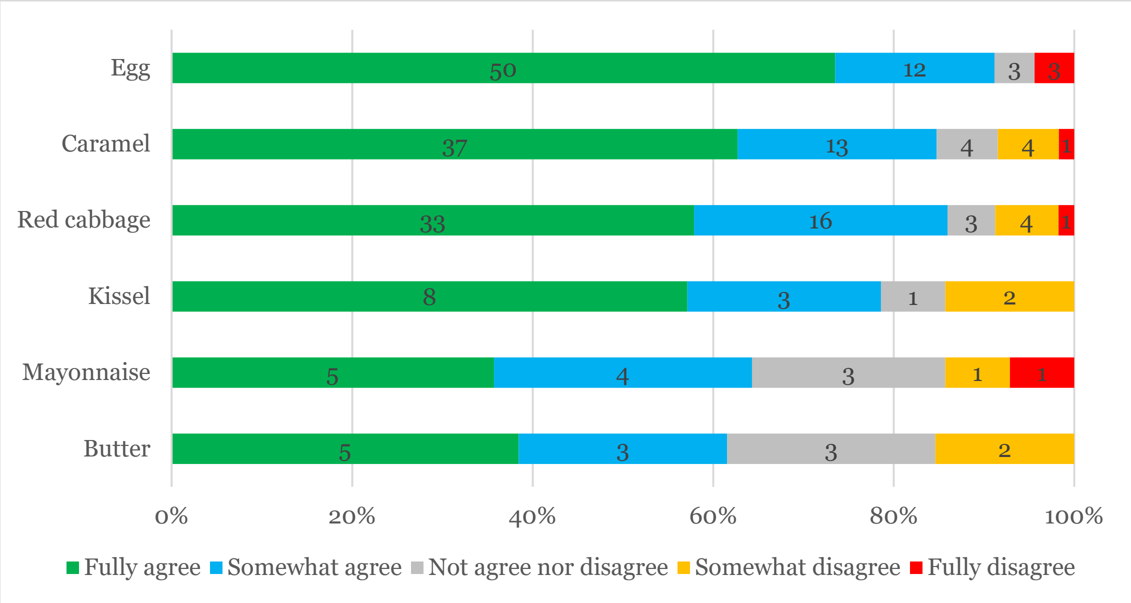
3 Results

These kitchen chemistry courses had a positive reception and attracted participants from different age groups from all over the country. Out of 145 participants, 63 left the courses without doing any experiments and 82 completed at least one experimental course work. A total of 70 course completions were registered. The effectiveness of the courses was assessed based on the following responses collected at different parts of the courses.

3.1 Assessment of course work

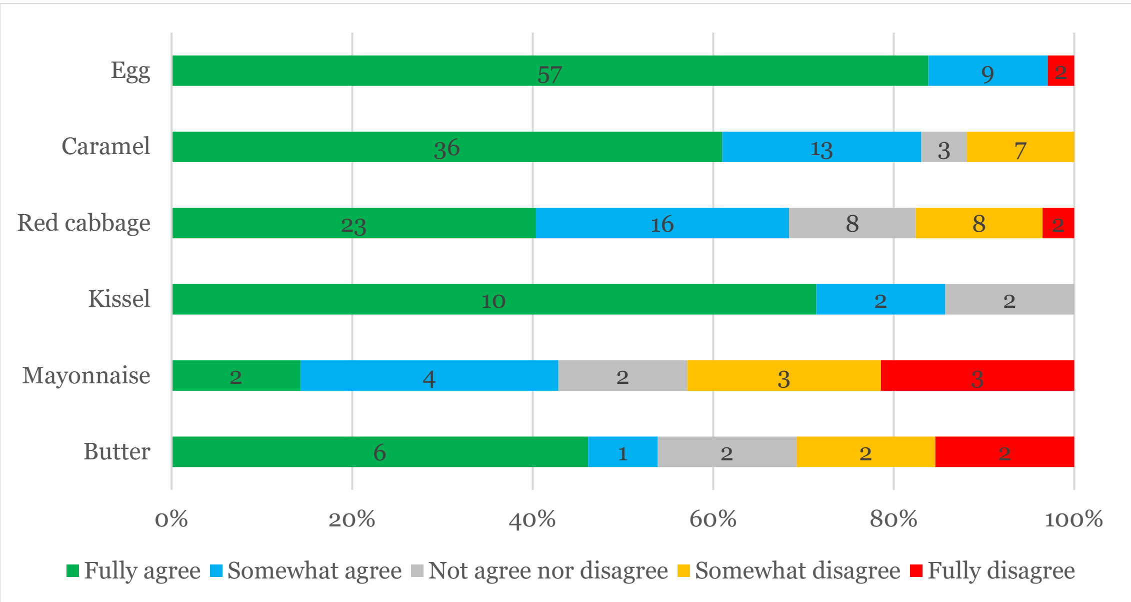
The survey answers regarding courses’ experiments are presented in Figures 1-6. All results are given in percentages for each experiment performed. The numbers in the beams in Figures 1-6 are the actual numbers of responses involved from the two courses given. Both courses had three experiments, which had to be done in order (1. egg, 2. caramel, 3. red cabbage and 1. kissel, 2. mayonnaise, 3. butter). The results also indicate that 11 students dropped out from the first course, and one student dropped out from the second course after completing at least one course experiment.

Figure 1. Responses to the statement: "The assignment was easily approachable".



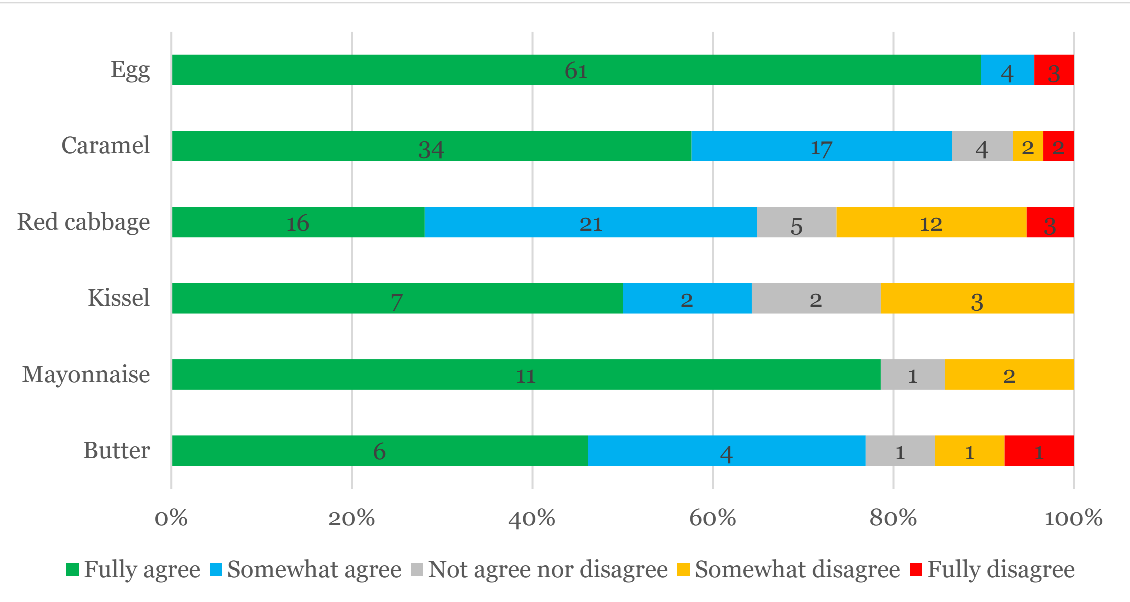
The statement "the assignment was easily approachable" was used to determine the threshold for doing the experiment and how naturally the experiment fit into the online course, i.e. whether the students thought it logically connected to other content in the online course (see Figure 1). Based on the responses for each experiment, a clear majority of students completing the experiments agreed at least somewhat that the experiment was easy to approach, i.e. doing it did not feel disconnected from the topic or unnecessarily pretentious. The proportion of those who agreed with this statement varied between the experiments, from 61% (8/13) to 91% (62/68). Based on this result, it can be stated that short independent experiments can fit well into the online course work, if they support the overall context of the course.

Figure 2. Responses to the statement: "I was already familiar with the work methods".



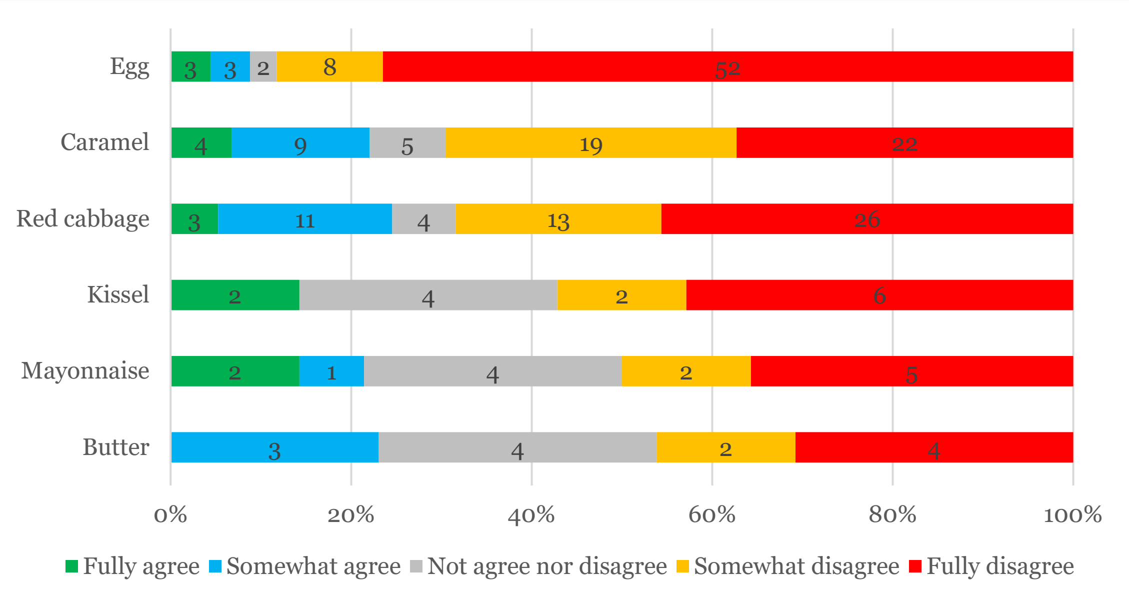
The statement "I was already familiar with the work methods" (see Figure 2) investigated two things. Firstly, whether the experiments were casual enough, so that they would be relatively simply to complete, and students could also make use of them again in the future. Secondly, we wanted to find out whether the practical nature of the course would make it possible to teach students new methods suitable for cooking. The proportion of positive responses to this statement varied from 43% (6/14) to 97% (66/68). For almost all the experiments the majority considered the working methods familiar. The exception was preparation of mayonnaise, where the same number of respondents 43% (6/14) considered the working methods both familiar and new. That specific coursework was also ranked the least familiar among all. Based on these results, it can be stated that almost all the course assignments were already familiar to the majority of course participants, but in almost every assignment there were also students for whom the work methods were new.

Figure 3. Responses to the statement: "The required ingredients and equipment were easily found".



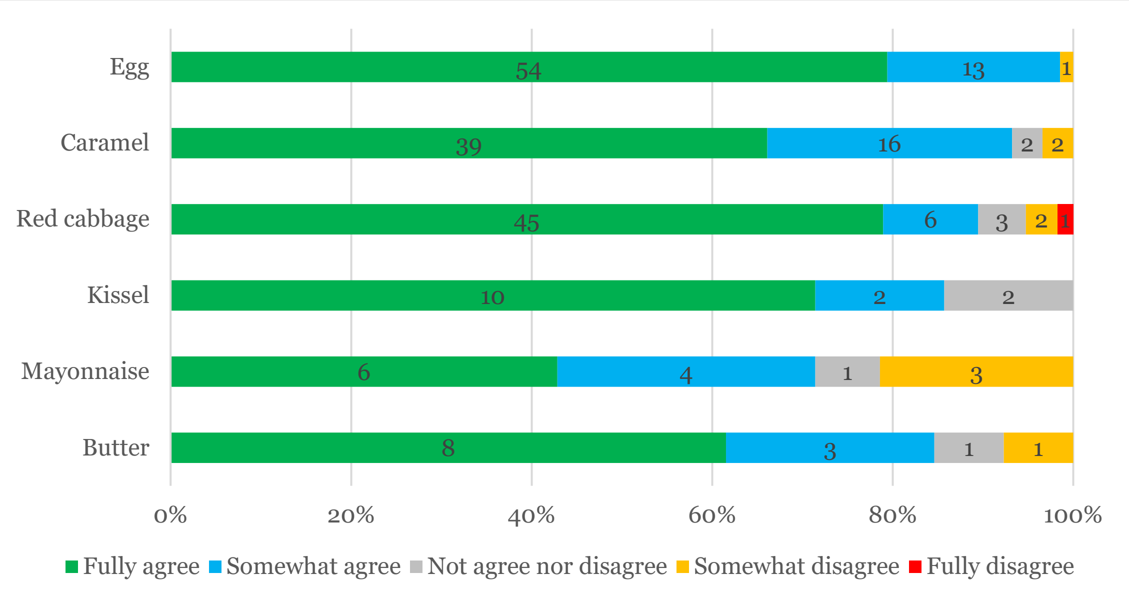
Independent completion of the experiments requires that the students find the necessary ingredients and equipment themselves or that they are easily accessible. Based on the responses received (see Figure 3), the situation was like this in all experiments of the course. The percentage of responses that agreed with the statement was between 64% (9/14) and 96% (65/68). Based on the responses, the most challenges in finding ingredients occurred in the red cabbage indicator assignment, where 26% (15/57) of the respondents disagreed with the statement. The students didn't know the requirements before starting the experiments, so they could not prepare for them in advance. In the case of the red cabbage indicator, the responses are probably explained by the fact that, unlike the other experiments, it was not an actual food preparation task, so the red cabbage used in it was not a raw ingredient commonly found in households. Based on these results, it can be stated that food-themed experimenting can be accomplished in students' homes without much advance preparation.

Figure 4. Responses to the statement: "I had difficulties during the experiment".



The statement employed in Figure 4 was used to find out how challenging the experiments were. Unlike the other statements, this one specifically asked for opinions about negative experiences and challenges. The purpose was to find out whether the students read the statements presented to them or whether they just randomly chose one of the options. Judging from the answers, the students understood what they read, as this statement has the most disagreements out of all surveys. The proportion of those who completed the experiment without challenges varied between 46% (6/13) and 88% (60/68). The majority therefore had no challenges in completing the course assignments.

Figure 5. Responses to the statement: “The work instructions were sufficient”.



The data on statement “the work instructions were sufficient” shown in Figure 5, was used to scrutinize the usability of the work instructions, i.e. whether potential challenges were due to inadequately written instructions. Most respondents considered the work instructions to be sufficient, as the proportion of positive responses ranged between 71% (10/14) and 99% (67/68). The only response that completely disagreed was in the red cabbage indicator work. In the final feedback of the course, one student wanted tips on alkaline foods for this experiment, so presumably this criticism concerned the fact that the work instructions did not directly state which food ingredients found at home should be investigated. Based on these responses, it can be stated that the ordinary work instruction’s structure also seems to work in independent experimenting.

Figure 6. Responses to the statement: "There was a clear connection between the observations made during the experiment and the theory dealing with the topic".

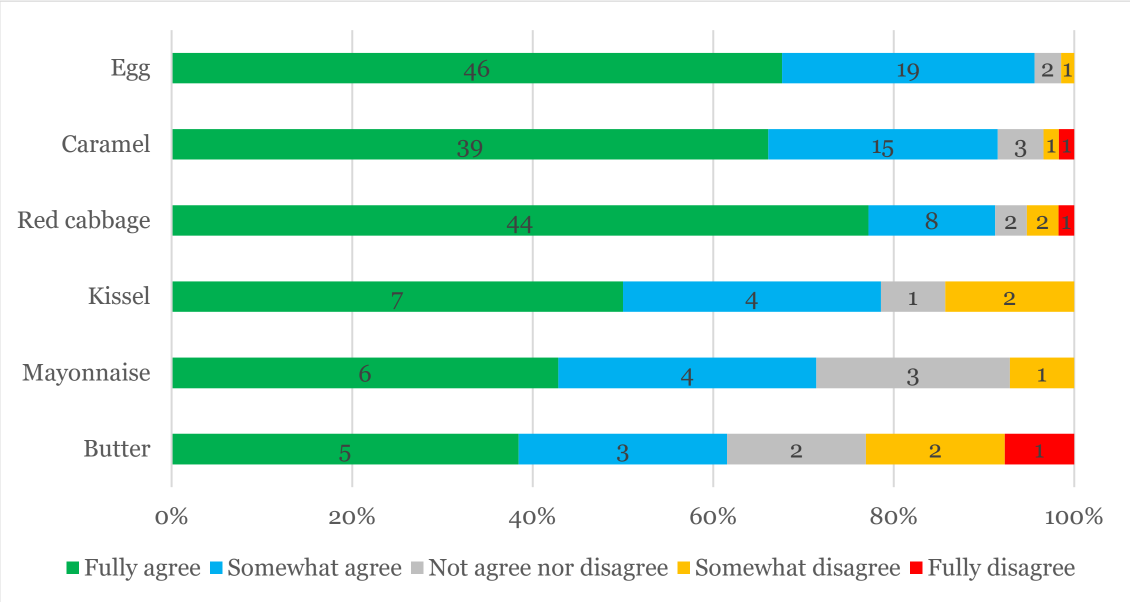


Figure 6 shows data on questionnaire statement "There was a clear connection between the observations made during the experiment and the theory dealing with the topic". This statement was used to determine whether the course's experimental work could create an understandable connection between chemical theory and a natural scientific phenomenon. At the same time, it guided students to think again the work-related chemical theories more in-depth and, in general, to see the connections between theory and practice more clearly. Most respondents considered the connection between the theory of experiment and the observations to be clear, as the proportion of positive answers ranged between 62% (8/13) and 96% (65/68). Based on this, it can be stated that simple experiments can help students observe natural scientific phenomena.

3.2 Students' perceptions on the course

Table 5 presents the open-ended questions selected for the study and a summary of the responses received. A total of 70 course completions were registered during the data collection period, but not everyone answered all the open-ended questions, making the total number of answers vary by question.

Table 5. Summary of answers for open-ended questions

Would you have liked more content to support learning?	No (47)	Yes (19)			
Did you do the experimental work alone or with someone else?	Independently (56)	With others (12)			
How well did you do in completing the course's experimental work?	Great (64)	Fair (2)	Poorly (2)		
What did you learn about chemistry in this course?	Theory (41)	Comprehension (25)	Practical skills (9)	Everything (5)	
What was interesting about the course?	Experiments (42)	Learning (17)	Everyday context (11)	Whole course (4)	Theory (3)
How could the course be improved?	Good as is / No suggestions (30)	Changes to experiments (19)	More videos (14)	Changes to the course format (4)	Changes to the theory sections (3)

Three out of four respondents (47 / 66) felt that they did not need additional support for the course, while 29% of respondents (19 / 66) would have liked some learning support. The desired additional content mentioned included videos (7), clearer theory sections (6), summaries at the end of sections (3), less theory per section (2), and additional written material (1). These results indicate that the choices made in the course design worked quite well. All the mentioned desired content seems to be related to the growing population who don't like reading and prefer videos over text.

Most respondents (56 / 68) did experimental work independently. The rest 18% of the respondents (12 / 68) said that they did at least some of the work with others. Other people mentioned were their children (4), spouse (3), parents (2), siblings (1) and family members in general (1). One of the respondents said they made caramel with their students. Only four of these twelve respondents said they directly received help from others, such as advice on preparations or perceiving colors when the course participant themselves was color blind. Based on these answers, it can be stated that the course work can be done independently and that experiments done at home can also engage family members. The themes and experiments of the courses can also be utilized more widely in teaching, as demonstrated by the one respondent who worked with his students and the following feedback on the course:

> *"I got exactly the ideas for my own teaching that I came looking for and I even learned something new and got information that I can use with my own food and restaurant students, thank you, a really nice course that would have also worked with secondary school students."*

Almost all respondents (64 / 68) considered doing well in the experiments, 3% of respondents (2 / 68) reported that they had performed moderately and another 3% stated they had done poorly. Those who had done well wrote that the experiments were straightforward and reasonably simple, the instructions were easy to follow and for some the methods used were already familiar. Students who had managed moderately or poorly did not elaborate on the challenges they had encountered. The large proportion of well-performing students suggests that the course's experimental assignments were not too challenging for most students and thus suitable for an online course.

Since the courses were mainly intended to encourage the study of chemistry and to teach some chemistry and chemical thinking, they were evaluated with pass/fail scale and learning outcomes were not actually measured. Nevertheless, those who completed the courses were asked what they felt they had learned about chemistry. 59% of respondents (41 / 69) stated that they had learned about chemical theory, such as acidity, the Maillard reaction or food macromolecules from the course. Alas, 36% of respondents (25 / 69) said the course increased their understanding of the role of chemistry commenting on this as follows:

> "*I learned to understand chemical concepts and what they really mean in practice. One could say that chemistry opened in a whole new way*"
>
> "*I already knew the chemical theory, but its connection to cooking wasn't clear or I hadn't thought about it as deeply before the course.*"
>
> "*I learned to see chemical reactions, which I have already encountered in previous studies, from a more concrete perspective, which deepens my understanding.*"

Some (13%) of respondents (9 / 69) described that they learned practical skills and mentioned individual experiments and their preparation methods as new things. 7% of respondents (5 / 69) reported learning a little bit of everything. According to one respondent, there were so many new things that they couldn't list everything in the answer box and another respondent said they learned "a lot of everything, for example interesting experiments for elementary school chemistry classes."

All respondents thought they had learned something new. Even though the courses were self-paced and did not have an instructor always present, more than half of the students reported acquiring chemistry subject matter, and a good third reported learning about chemical thinking. The course also emphasized learning by doing, however few students reported learning new working practices. This might be because the coursework was designed to be as straightforward as possible, so the techniques used in the experiments, such as boiling and frying, were likely familiar to most of the course participants, and therefore they didn't learn new practical skills.

When asked about the course's most interesting aspects, 61% of respondents (42 / 69) mentioned experimental assignments. These responses praised the courses' concrete approach, which allowed students to create the dishes themselves, and several claimed the coursework was easy to understand. Learning about the subject was ranked as second most interesting, with 25% of responses (17 / 69). 16% of respondents (11 / 69) found the course's everyday relevance fascinating. 6% (4 / 69) of respondents liked the course in total. One closely related course feedback comment to this was saying:

> *"I think it's a really nice and interesting whole. I think the theory sections were nice and short and concise. The model solutions/answers that came after the experimental work were good and clear. It was nice that I got the answers almost immediately after I had returned the experimental work, so I had my own answers in good memory!"*

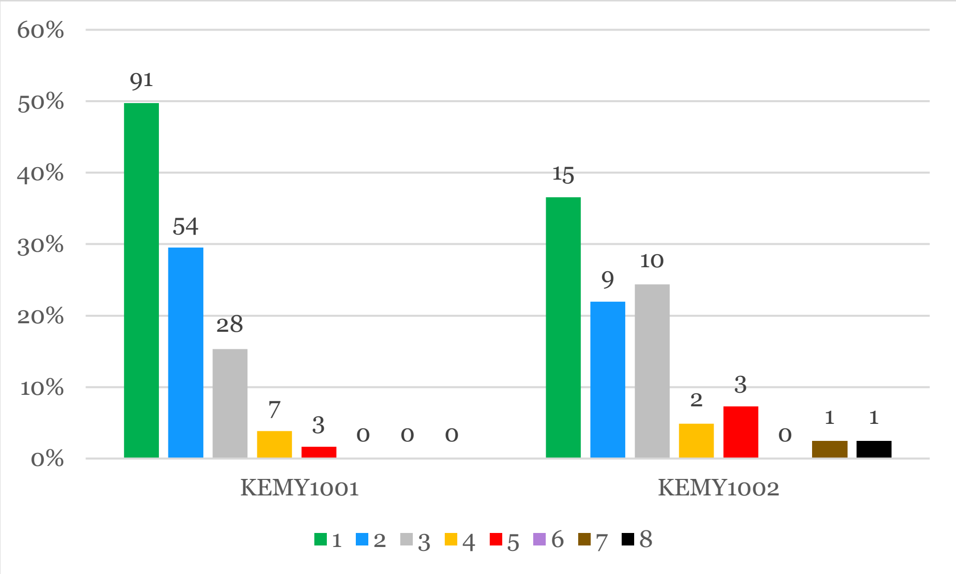
These results show that the experimental work was regarded as the most intriguing aspect in the courses, even though, based on previous results, the methods utilized in them were already familiar to most participants.

Almost half (43%) of the respondents (30/70) indicated that the course was satisfactory as it was or that they had no suggestions for improvements. 27% of participants (19/70) expressed a desire for changes to the experimental assignments, such as more and varied experiments or more comprehensive work instructions. 20% of participants (14/70) wished for additional video content for the course. 6% of respondents (4/70) wished changes to course format, such as having the theory sections as downloadable files or not having the section exams locked behind previous modules. 4% (3/70) of respondents wanted changes to theory sections, such as more variety in course material and less chemical formulas. These results indicate that the students acknowledged the importance of practical course work and probably liked the experiments, since many proposals were targeted at the coursework.

3.3 Usability of automated exams

Both courses had three multiple-choice exams, one at the end of each section. These exams consisted of five multiple-choice questions with each having at least four different choices. Each question was worth one point and passing the exam required at least four points. The questions were arranged randomly so there was no correct order for students to memorize. Due to the independent nature of the courses, exams could be taken without limitations. The students were not informed about this, instead they were told that they could retake the exams if necessary. Considering the multiple-choice nature and the small scale of these exams, passing them on first try can be seen as desirable, on second try acceptable and on third or more attempt questionable, since increasing number of tries indicates poor preparation or guessing. Therefore, the number of attempts students needed to complete the exams was analyzed and the results shown in Figure 7.

Figure 7. The number of attempts needed to pass the exams



Course KEMY1001 had 183 passed exams, of which 50% (91/183) were passed on the first attempt, 30% (54 / 183) on the second attempt, 15% (28/183) on third attempt and 5% (10/183) on four or more attempts. Course KEMY1002 had 41 completed exams, of which 37 % (15/41) were passed on first attempt, 22% (9/41) on the second attempt, 24% (10/41) on the third attempt and 17% (7/41) on four or more attempts.

Both courses have a downward trend as the number of attempts increases and majority of exams were passed within two attempts. Even though students completing exams with first or second try may be an indication that learning has occurred, it might also be the result of the exams being too easy to complete. Some of the students, however, criticize these exams for being too challenging and indicate that in multiple-choice exams guessing is always an option.

> “- - - some of the questions on the final tests were so difficult that I couldn't find the answers to them at all, even though I think I went through the course material really carefully.”

> “Chemical reactions were difficult exam questions, I had to guess because I couldn't find the answers in the material.”

Overall, the results seem to be as expected. The second course had relatively more attempts of three or more, making it a more challenging course, which could be explained by its focus and less familiarity of the students on applied chemistry issues included in the study material.

4 Discussion

Kitchen chemistry context has been used in chemistry education with favourable results (Nguyen & Keuseman, 2020; Nuora & Välisaari, 2019; Schultz et al., 2020). The cooking-related contexts seem to attract wide audience, engaging learners emotionally and in practice. This study built upon this general interest, focusing on behavioural and cognitive dimensions of engagement in kitchen chemistry and online learning in a previously known and well-relatable context. All the three dimensions of engagement defined by Fredricks et al. (2004) were taken into account. Every major topic included hands-on experiments, which aimed to engage students behaviourally as well as emotionally by inspiring self-efficacy in inquiry. Cognitive engagement was initiated with questions, questionnaires and exams, to make students reflect on their own work and direct their thinking to connect experimenting with chemistry theory.

The goal of these self-paced online courses was to teach chemistry and scientific thinking and to enable students to conduct independent experiments. The context of kitchen chemistry made it possible for students to carry out experimental work using their own equipment and reagents while also connecting the chemical phenomena to readily approachable everyday life in a concrete manner.

One major research question was “How well students manage to do independent kitchen chemistry experiments?” According to the open-ended answers, the students were able to do the experiments independently and managed them well. The practical assignments were also the most often mentioned interesting part of the course, and most course development suggestions were related to the experiments. The experiment-specific assessments revealed that the practical assignments were easy to approach, some were more or less familiar to the students, the necessary equipment and ingredients used in the assignments were generally easy to find, the majority of students completed the experiments without major challenges, traditional recipe-type instructions were considered sufficient by the students and most importantly, the students were able to observe the connection between theory and experimentation in each assignment.

Out of 145 participants, 82 completed at least one experimental course work and the rest 63 left the course without doing any experiments. Out of these 82, 12 did not finish the courses. These numbers reveal that 85% (70/82) of participants who completed the first experiment were motivated enough to complete the whole course. This indicates that the first module is important to engage the learners and to give them a sense of achievement and self-efficacy regardless of their background in chemistry skills. It also suggests that to increase the course passing rates, it would be beneficial to give students meaningful hands-on activities as early as possible.

The second major research question was “How does a self-paced online course function?” The results indicated that most course participants didn’t need any additional support, and the rest wished for more videos or less reading. Videos were only used at the beginning and at the end of the courses. Other videos were not deemed necessary, since the theory sections were intended to be kept as concise and informative as possible. Also, text was considered more suitable for mobile device users. Every participant claimed to have learned something, mostly theory and thinking skills, which were two of the primary course objectives. Besides theory and comprehension, students refer to experimenting and everything as learning outcomes (see Table 4). Everything can be understood as versatile learning of various course contents.

The main purpose of the automated course exams was to make students recall what they had learned, i.e. engage them cognitively. They were also used to assess the overall functionality of the courses and make student performance visible to teachers. Based on the results, it can be deduced that the exams worked as expected, as most participants passed them in a reasonably number of attempts. They were not too intuitive to master without familiarizing themselves with the course material, but still directive and informative enough to act as learning tools as well.

Participation in the courses was voluntary, and participants were not selected in any way. Participants were from different age groups and from different regions of the country, which might enhance the generalizability of the results. The geographical variation might also enhance the validity of the results, since respondents were not interacting with each other and truly independent learners might give more diverse and valid results (Taber, 2019). However, since only people who were motivated enough to participate in the courses gave data for this study, the results might be skewed in a more positive direction.

The final survey was restricted only to those students who had completed all the other course sections. The students who dropped out were not able to provide their final feedback which might leave some valid criticism out of this review. From a course development perspective, however, it is more valuable to receive feedback from people who have completed the whole course, as they have knowledge about all the individual course components.

It is possible that some of the course satisfaction is due to the attraction of novelty. Humans tend to pay more attention when something new and out of ordinary is happening. Novel teaching methods might seem to work at first because of this, but later when the novelty wears off, students' interest fade as well. (Taber, 2019) However, novelty itself is not a bad thing, and teachers are encouraged to use a variety of teaching methods to support different types of learners. The online format and kitchen chemistry context almost certainly contributed to the novelty factor for these courses, but as previously discussed the practical experiments were strongly engaging themselves.

Students usually mention only one thing in open-ended questions. In the future it would be worthwhile to ask students to mention at least three things to get a deeper insight into all the factors involved with engagement and meaningful learning targets when applying experimenting in online settings. It could also be wise to include some identifying questions in the final surveys to get information about which demographic is most likely to finish the courses.

5 Conclusions

Everyday processes contain many natural science phenomena to study, and the real-life connections of studies seem to be of interest to a wide range of people. This study shows that cooking related home-experiments were well received by the students and they could be implemented successfully with a relatively simple resources and instructions without any advance preparations needed from the students, making them one viable way to include experimental work to online courses.

Overall, the two online courses fulfilled their goal to provide an easy-access introduction to chemistry, introduce phenomenon-based approach to connect chemistry with everyday context, and provide the possibility of experimenting as a tool for learning chemistry in non-formal educational settings. Based on this research, the devised education approach employed here is a novel model that provides chemistry educators with the possibility to apply experimenting in online teaching surroundings. It shows how to combine behavioural, emotional and cognitive engagement by meaningful learning tasks without losing target-oriented scientific literacy skill development initiatives. Moreover, the approach implemented here can be adopted to various educational levels of learners in experimenting-related science education.

Research ethics

Author contributions

A.R.: conceptualization, investigation, data curation, formal analysis, visualization, writing—original draft preparation, writing—review and editing
J.V.: conceptualization, methodology, validation, writing—review
J.L.: conceptualization, methodology, validation, funding acquisition, supervision, project administration, writing—review

All authors have read and agreed to the published version of the manuscript.

Artificial intelligence

Artificial intelligence (Google NotebookLM, MS Copilot) was only used to create summaries of background research articles for comparison with researchers' own notetaking.

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Informed consent was obtained from all research participants.

Data availability statement

Data is available from authors upon collaboration.

Conflicts of interest

The authors declare no conflicts of interest.

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