Research article

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Student experiences of project-based learning in an analytical chemistry laboratory course in higher education

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Abstract: This study describes students' experiences in project-based learning (PjBL) incorporated as part of a revised undergraduate analytical chemistry laboratory course. We examined which phases were the easiest as well as the most challenging and what student skills developed during the research project. The research data were collected between 2016 and 2018 via two questionnaires. They were analyzed both quantitatively and qualitatively. One questionnaire focused on the whole course (in 2016–2018, $n = 127$) of which only the answers on the research project questions were analyzed. The other questionnaire focused on only the research project (in 2018, $n = 42$). Based on the results of our study, students felt that the research project was useful for their future laboratory experiments. Several sets working life skills as well as self-assessment skills were also developed during the project. These included skills related to laboratory work, group working, planning the research, problem solving and data collection. The students named the easiest phases to be the concrete laboratory experiments, making the seminar presentation, drawing up the research plan and reporting the results. As the most challenging phases, they named the design phase of the project, challenges related to experimental works and data collection. For example, students experienced uncertainty when gathering information and the whole project appeared challenging during the design phase. However, when students started to work, they saw that the work progressed smoothly if they had designed it well. When students have an opportunity to create their own research project, they acquire meaningful learning experiences.

Keywords: analytical chemistry laboratory course; project-based learning; research project; students' experiences.

Introduction

Project-based learning (PjBL) is a widely researched area (Egilmez, Sormaz, & Gedik, 2018; Kokotsaki, Menzies, & Wiggins, 2016; Wurdinger, Haar, Hugg, & Bezon, 2007; Wurdinger & Qureshi, 2015). PjBL is a model that organizes learning around different projects (Thomas, 2000) and in which students create projects that result in meaningful learning experiences (Wurdinger et al., 2007). It is a teacher-facilitated, student-driven approach to learning where the genesis of the project is an inquiry (Bell, 2010; Chandrasekaran, Stojceyski, Littlefair, & Joordens, 2013; Dole, Bloom, & Kowalske, 2016). Due to the large number of PjBL studies, its definitions vary widely. In this study we use the definition of PjBL created by Wurdinger, Haar, Hugg, and Bezon et al. (2007): "a teaching method where teachers guide students through a problem-solving process

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which includes identifying a problem, developing a plan, testing the plan against reality, and reflecting on the plan while in the process of designing and completing a project" (p. 151). The literature uses the abbreviation "PBL" for both problem-based and PjBL. However, in this study we also use problem-based learning (PrBL), so the abbreviations PrBL and PjBL will differentiate the two. PrBL is an effective learning approach where a problem is introduced and solved before the generalizing concept is provided (Egilmez et al., 2018). PrBL allows for free inquiry and it is considered to be a student-centered teaching method where students work together to solve problems (Gao, Wang, Jiang, & Fu, 2018; Savery, 2006). In PrBL, the tutor is a facilitator of learning, learners are self-directed, and they self-regulate their own learning. PjBL is said to be similar to PrBL in that the learning activities are organized around achieving a shared project or goal. In both aspects, the role of the instructor is emphasized because students can now access a massive amount of information and it may lead to the problems of choosing the subject of the project work (Savery, 2006). On the other hand, these learning approaches keep instructors up to date because they have to create and define new problems and projects (Egilmez et al., 2018). For example, the key to PrBL is to design a suitable problem scenario related to the real lives of students (Gao et al., 2018).

PjBL and PrBL are both effective learning approaches. Robinson (2013) states that the incorporation of project-based and problem-based laboratories is a potential solution when students lack motivation and engagement. Gao, Gao, Wang, Jiang, and Fu (2018) have come to the same conclusion when they studied PrBL in a public basic course for students from non-chemistry majors at Northeast Agricultural University. Their study indicated that although there were some negative evaluations, the vast majority of students were willing to accept the PrBL method. According to Gao et al. (2018), PrBL could remarkably improve the motivation of students.

The Analytical Chemistry Laboratory course at the University of Jyväskylä, has been taught since the 1960s. It was updated in 2014 (Matilainen, Koliseva, Valto, & Välisaari, 2017). The course is part of the subject studies in chemistry. After the course was revised in 2014, it contained more cooperation, student-centered activity, and inquiry-based learning along with PjBL. In the revised model (Matilainen et al., 2017), students are divided into groups of 7–10 students. The students choose the group time which best fits their timetable when they sign up for the course. Each group has its own instructor for the entire period. The course contains traditional laboratory experiments used to develop basic laboratory skills, in which both classic and modern spectroscopy methods as well as the laboratory environment become familiar to students. A research project is one part of the course, and it continues for the duration of it. As part of the project, students search for information how to do the analyses from different types of literature sources, familiarize themselves with various analytical chemistry research methods as well as with designing and conducting laboratory tests, and with analyzing and reporting research results. The student groups are self-directed, they divide tasks between themselves typically by the students' interest and the instructor evaluates the process of the project during the course and especially in the separate group meetings, which have their own goals and tasks which must be done. Students learn to take responsibility for their own work as well as the learning of others. The research project requires successful group dynamics and long-term, goal-oriented work. The PjBL approach used on the course includes some characteristics of PrBL. In this study, we focus on PjBL from a student perspective.

Structure of the research project

The course's new structure and feedback from the students and instructors has been reported previously (Matilainen et al., 2017). In this article, the focus is on the research project of the laboratory course from students' point of view. We have selected the subjects of five research projects: (a) analysis of elements in needles, (b) analysis of elements in water, (c) analysis of elements in soil, (d) quality assurance of inorganic fertilizer and (e) quality assurance of dialysis solution. In Table 1 these are referred to as *needles*, *water*, *soil*, *inorganic fertilizer* and *dialysis solution*, respectively.

In the first group meeting, the students are given the research problem by their group instructor. Each group has their own problem. The instructor also provides some literature and tips for finding further material

Table 1: Research problems and guiding questions for the research plan.

Research project	Research problem	Guiding questions
Needles	The goal of this project is to determine the elemental concentrations, such as accumulated heavy metals, in examined needles. After the analysis, the measured elemental concentrations should be compared to reference or limit values given for air quality or some other report considering the elemental composition of the needles.	Why are bioindicator studies needed and where can they be used? Why is the analysis of needles important? What methods can be used for the analysis of elemental concentrations of needles? Why did you select these elements for analysis? Can you find reference or toxicity limiting values for these elements in the literature?
Water	The goal of this project is to determine if the analyzed well water can be safely used for drinking water. After the chemical analysis, the obtained chemical parameters are compared to quality requirements and recommendations given by the Finnish Ministry of Social Affairs and Health for water for household consumption and a decision should be made if these criteria are fulfilled.	Why is water analysis important? Does the quality of used water have an effect on one's health or, for example, washing dirty laundry? What methods can be used to assess if water is suitable for household use and is there any legislation for water quality? Why did you select these elements for analysis? Can you find reference or toxicity limiting values for these elements in the literature?
Soil	The goal of this project is to determine the fertility category of the soil based on analysis of the selected elements. One of the analyzed elements should be a heavy metal. The elements are analyzed after three-step sequential extraction, after which the elemental composition and nutrient content of the soil can be estimated. The obtained results are compared to reference values given by Eurofins Acro Testing Finland Ltd.	What properties of soils can be found by using water, ammonium chloride and ammonium acetate extraction? What sample preparation steps are included in sequential extraction? Most metals in soil have reference values and limiting values. What do these values mean?
Inorganic fertilizer	The goal of this project is the quality control of inorganic fertilizer using different analytical methods, in other words, does the fertilizer contain elements in the concentrations indicated on the package?	Which kind of fertilizers exist and why are fertilizers used? How much fertilizer is produced in Finland, Europe and the world? What instances control the quality of fertilizers and what criteria is used for quality assurance? What main and trace elements are important for fruit trees, berry bushes, plants and corns?
Dialysis solution	The goal of this project is the quality control of dialysis solution using different analytical methods. The obtained results are compared to limit values given for dialysis solution. A decision should be made if the solution can be used in the care of patients.	Why is the analysis of drug ingredients important? What methods can be used for the analysis of elements in dialysis solution? Why did you select these elements for analysis?

regarding the research problem. The group decides how to work in the laboratory to solve the given research problem. The students can bring and analyze their own samples if it is possible for the selected research project. They should decide on sampling, sample preparation, elements to be measured, measurement methods to use and the importance of the obtained analytical results. The instructor gives a list of elements from which at least three elements are selected for analysis. One element is analyzed with two different methods, one of which should not be an instrumental method. Typically, the students use those analytical methods which they learn during the course, but they may use any other methods found in the literature that may be performed with the reagents and equipment available in the laboratory. The group draws up a research plan with the aid of the guiding questions and the research problem given in Table 1. The guiding questions help the students draw up the research plan, see what kind of analytical methods can be found from the literature and determine what elements are analyzed. They also are exposed to content which connects their

Table 2: Schedule and goals of the research project.

Week	Goal of the research project meeting
1	Research problem
	Guiding questions for the research plan
	Appropriate literature
4	Purpose of the project
	Decision of the elements to be analyzed
7	Determination methods for selected elements and timing of the research
10	Complete analytical process (sampling, sample preparation, elements to measure, measurement methods to use)
11–13	Laboratory part of the research project
	Analysis of the selected elements with different methods
14	Course seminar in lecture hall
	Seminar presentation of the selected methods and the results of each project group and act as an opponent for another project group
	Outside specialist in the field of analytical chemistry from the industry comments on each seminar presentation and gives a presentation

project to real life and helps them understand why these kinds of projects are done. The guiding questions also help instructors direct the research plan.

To keep the group on schedule, there are three separate group meetings with the instructor during the course, and each meeting has its own goal, as shown in Table 2. The course concludes with a seminar session during which each group gives a presentation of their research project in the lecture hall and also act as an opponent for another group.

The students' competence in analytical chemistry was evaluated during the course by comparing the results of the analysis to the values found in the literature. Each project had their own samples and it was possible to, for example, compare students' results to the official reference values given by the manufacturers or to the values given by the environmental authority. The basic laboratory work also included some analysis (e.g., for iron and nickel) in which the analytical precision of the results was evaluated (Matilainen et al., 2017).

Research questions

The main research questions were as follows:

1. How did students experience the course research project?
   1.1 What were the easiest phases of the research project?
   1.2 What were the most challenging phases of the research project?
2. What skills did students improve during the research project?

Methods

Students' questionnaires

Students' experiences and opinions concerning the research project were obtained anonymously using two questionnaires (see Appendix 1 and Appendix 2). The first questionnaire (Q1) collected specific information about the research project in 2018 and the second questionnaire (Q2) included more questions about the presentation of the research project as well as about the whole course (between 2016 and 2018). Both questionnaires were distributed at the last meeting of the course (the seminar day) and both questionnaire forms included a Likert scale and open questions. The scale questions used a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Participants

Data from Q1 were collected in the fall semester of 2018. The number of respondents was 42 and the response rate was 100%. The participants were students majoring or minoring in chemistry. Background questions asked about their gender and major. The gender was divided equally. Chemistry was the major subject for 36 out of 42 respondents (86%) and it was the minor subject for 6 out of 42 respondents (14%). Data (n = 127) from Q2 were collected between 2016 and 2018 and the response rate was 100%. The annual variation of the participants was as follows: 51 participants in 2016, 34 participants in 2017 and 42 participants in 2018. The annual gender variation of the participants was as follows: in 2016, 28 were men, 23 were women; in 2017, 16 were men, 18 were women; in 2018, 20 were men, 21 were women and one did not answer this question. From Q2, only the questions related to the research project were used. All the respondents that completed the questionnaires were active course participants.

Data analysis and research quality

The quantitative survey data were analyzed with descriptive statistics using SPSS 24. Means, frequencies, standard deviations and Cronbach's alpha coefficients were calculated for both questionnaires. The Cronbach's alpha coefficient indicates scale reliability. The Cronbach's alpha coefficient was 0.89 for Q1 and 0.86 for Q2, meaning the scales displayed good internal consistency.

Data-based qualitative content analysis was used to analyze the open questions. All participants' names are presented using the following format: Student 1, Student 2, Student 3, etc. In the data-based content analysis of the participants' answers to the open questions, qualitative interpretations were constructed gradually. In the first phase, the participants' answers were analyzed, itemizing the words and concepts they used. In the second phase, categories were generated to determine the meanings of concepts. Two authors were involved in this process. All three authors read the answers. They analyzed the answers independently and discussed the results. The few disagreements that emerged were resolved through discussion and the authors arrived at a consensus (Patton, 2015), which contributes to the reliability of the analysis. Patton (2015) suggests that in a consensus-based theory of truth people can create truth by arriving at a consensus. In the analysis tables, example quotations from the data are presented to make the analysis more transparent. The use of multiple coders in the research analysis phase can be seen as a form of triangulation.

Results

Scale questions

The research project valuation was performed using Likert scale questions. The variations in the number of respondents in the research results were due to the lack of respondents' answers for every question. Based on Q1 (Appendix 3), students (n = 42) reported that that the knowledge they gained from the research project will help them design laboratory experiments in the future (avg. 4.02), in conducting the laboratory experiments (avg. 4.26), and in the analysis of research results (avg. 4.05). Students found that the research project helped them in reporting research results (avg. 3.84). The students also liked how they were able to devise the research plan (avg. 3.81) and implement it themselves (avg. 4.00). The research project included various analytical chemistry research methods, which was seen as a positive aspect because students became familiar with them (avg. 3.79). The research project was considered a motivating form of learning (avg. 3.74).

The courses' instructors received positive feedback from the students as they received good support from the instructors during the project (avg. 4.47, n = 42). This was also reflected in the answers to Q2 (Appendix 4) between 2016 and 2018 (averages varied between 4.21 and 4.41, n = 127). Additionally, students (n = 127) saw that the instructors were interested in what they were teaching (avg. 4.26–4.58) and provided enough guidance for the research project (avg. 4.31–4.40).

In 2018, most of the students considered themselves an active group member (avg. 3.98, n = 42, Appendix 3). This is a positive result because the groups were large (7–10 students) and so their functionality was challenging. This is also reflected in the answers to the open questions presented in the next section. Additionally, students felt that working in a group was meaningful for them (avg. 3.74, n = 42, Appendix 3) and they received support from their project group members (avg. 3.74–4.25, n = 127, Appendix 4). Students also liked the research project as a whole (avg. 3.67–4.31, n = 127, Appendix 4) and they learned a lot about conducting the project (avg. 4.03–4.10, n = 127, Appendix 4).

Open questions

All of the following citations of answers to open questions are from Q1.

Reported experiences during the research project

Most of the students found the research project to be interesting, pleasant, and rewarding (frequency, $f = 25$), even though the project appeared challenging at first when starting to perform unfamiliar tasks on one's own ($f = 5$).

> *"The implementation of the project was interesting but also challenging." (Student 10)*

> *"At first, a little daunting when you did not know what was happening and what to do. But when I got caught up with the project, doing so went well." (Student 6)*

Some of the students found the research project to be laborious and challenging ($f = 14$). They felt that the research project was large, time consuming and contained many new things and new analytical methods with which they were unfamiliar.

> *"At first, it seemed like a big deal, but because everyone was involved, it was a complete job." (Student 14)*

> *"There were quite a few new things, such as the use and features of all devices, which we still didn't remember." (Student 21)*

The research project was seen to be useful and instructive ($f = 10$). The students felt that they learned about analytical process, they could conduct the real research including data acquisition and they had the opportunity to use new analytical instruments. Overall, while doing the project, students' skills and the methods needed in analyses developed.

> *"A useful and inducing introduction to analytical research. Learned about new equipment and analysis design. I felt it was very useful." (Student 3)*

The students also commented on the experiments ($f = 9$). Students felt they received enough instructions and the research project progressed well. The experiments performed in the course supported the research project. Yet they also noted that they lacked the time to conduct the research project and absorb all the information gained from it.

> *"Adequate guidance was given for the project and it was easy to implement." (Student 1)*

> *"Too little time for carrying out the project compared to how early planning of it was started." (Student 31)*

The students worked in a group of 7–10 people. Although the group size was seen to be large ($f = 3$), working in the group was pleasant, cooperation practical and one had the right amount of responsibility for completing the project ($f = 4$).

> *"The group was good and cooperation worked well." (Student 2)*

> *"In groups of more than two people there will always be communication difficulties. I do not like working in large groups at all, but I gain experience from it." (Student 11)*

What were the easiest phases of the research project and the most challenging?

The students indicated what they viewed as the easiest phases of the research project. Most of the students (70%) felt that the concrete laboratory experiments were the easiest phase for them (Table 3). Students

supported their answers by mentioning the need to follow a prepared plan only, the good instructions, and familiar topics.

> *"The easiest thing to do was the laboratory experiment itself, since it was easy to work when the research plan had already been carefully made and you had a chance to focus solely on problem solving." (Student 1)*

According to the students, other easy phases were related to making the seminar presentation, drawing up the research plan, frequently repeating analysis methods of the course and reporting the results.

When opinions about the most challenging phases of the research project were asked for, the design phase, experimental work, and data acquisition were mentioned, as shown in Table 4. Although students felt insecure about the design phase of the research project, on both questionnaires the students reported that they learned a lot about research design (avg. 4.02, $n = 42$, Appendix 3; avg. 3.88–4.06, $n = 127$, Appendix 4).

Students reported that initially it seemed challenging to start to make a research plan but it became easier as the project proceeded. Then it became easier to understand the project itself. Students also mentioned that when they conducted laboratory experiments, they experienced several problems when the methods did not work as they were intended to.

The literature and information search and sources at the beginning were generally seen as challenging. Additionally, students considered it difficult to compile the results and complete the final report. Other challenges were related to the large group size. Students criticized the 10-person group as too large because it was difficult to divide the tasks within a group. However, the amount of comments related to size were few ($f = 5$).

What skills improved during the research project?

When asked what skills improved during the research project, students most often mentioned the skills related to laboratory work, teamwork and planning (Table 5). They indicated that their laboratory work skills, knowledge of equipment, and analytical precision and accuracy developed (e.g., Reid & Shah, 2007; Robinson, 2013). Students described how their group working skills improved: they found that, for example, their communication and collaborative skills and ability to share the tasks grew. Between 2016 and 2018, students saw that they learned to work in a group with the help of the research project (avg. 3.74–3.98, $n = 127$, Appendix 4). Students' feedback also included planning skills, such as research or analysis design. A smaller group of students mentioned that their data acquisition skills, stress tolerance and problem-solving skills improved.

Table 3: Categories of the easiest phases of the research project.[a]

Topical category code	Frequency	Illustrative student comment
Concrete laboratory working	32	*Doing laboratory work. Because we had a well-designed research plan, we did not have to think so much in the lab. (Student 26)*
Planning the seminar presentation	3	*Planning the seminar presentation, because at that point things were clear. (Student 29)*
Making the research plan	3	*The easiest thing to do was to make your own plan as long as all the material had been found. (Student 8)*
Frequently repeating analysis methods of the course	3	*Analysis which were practiced earlier in the course. (Student 34)*
Reporting the results	3	*Reporting results and conducting lab work. (Student 18)*
Data acquisition	1	*Finding information – it was not a problem. (Student 38)*
There were problems in every phase	1	*I can't say, there were unexpected problems at every phase. (Student 12)*

[a]The frequency with which they were reported, and an illustrative example of a student comment representative of each code. From the 42 respondents, 46 discrete responses were identified.

Table 4: Categories of the most challenging phases of a research project.[a]

Topical category code	Frequency	Illustrative student comment
Challenges related to the design phase of the project	20	*Planning the practical phase of the method (i.e., how much pipetting, how to dilute), because the different sources varied so much, it was difficult to determine what the best way was (Student 16)*
Challenges related to the experimental works	14	*Solubilization of the needle sample. (Student 43)*
Data acquisition	12	*Finding new literature. (Student 20)*
Reporting	7	*Collecting results. (Student 11)*
Challenges related to getting started with the research project	7	*Getting started was the most difficult phase because I didn't really know where to go and my thoughts were a bit confused. (Student 8)*
Challenges related to group work	5	*I felt it was challenging working in a group of 10 people. (Student 16)*

[a]The frequency with which they were reported, and an illustrative example of a student comment representative of each code. From the 42 respondents, 65 discrete responses were identified.

Table 5: Categories of reported skills that improved during the research project.[a]

Topical category code for learned skills	Frequency	Illustrative student comment
Laboratory work	20	*Use of equipment, analytical methods and their use in research. (Student 3)*
Group working	17	*Communication and collaborative skills. (Student 28)*
Planning	13	*Making the laboratory work plan. (Student 4)*
Data acquisition	5	*It helped to find research methods. (Student 42)*
Stress control	4	*Tolerance of stress and uncertainty. (Student 10)*
Reviewing the results	4	*Critical review of your own work. (Student 8)*
Problem solving	2	*Problem-solving. (Student 36)*
Applying a new theory	2	*I got a lot of new information. (Student 21)*

[a]The frequency with which they were reported, and an illustrative example of a student comment representative of each code. From the 42 respondents, 67 discrete responses were identified.

> *"I learned to find suitable research methods." (Student 42)*

> *"I learned to tolerate stress and pressure." (Student 10)*

A total of 67 discrete responses were received from 42 respondents to this open question, which can be seen as a good result. Students also assessed, on a Likert scale, the development of four different skill sets: problem solving skills (avg. 3.53), interaction skills (avg. 3.51), self-evaluation skills (avg. 3.19), and stress tolerance skills (avg. 2.98) (see Appendix 3).

Conclusions

In this research, we were interested in how the students experienced the course's research project and what skills were developed during the project. In PjBL, students learn through the research project as a whole. When students have an opportunity to create their own research project, they obtain meaningful learning experiences (see Wurdinger et al., 2007). This was one of the goals of the course, and it was reflected in the results of this study. The students viewed the concrete laboratory experiments as the easiest phase of the research project. Other easy phases were the seminar presentation, drawing up the research plan, frequently repeating analysis methods of the course and reporting the results. The research also explored what students considered as the most challenging phases of the research project. They identified the design phase, experimental work and data acquisition as the most difficult parts. For example, when students conducted laboratory

experiments, they encountered a number of problems when the methods did not work well enough. Although students mentioned that initially it seemed challenging to start to make a research plan, it became easier as the project proceeded.

Students gave a wide range of feedback on the course's research project. In their opinion, the beginning of the project was the most difficult phase. For example, students experienced uncertainty in the acquisition of information and the whole project appeared challenging during the design phase (e.g., Cavinato, 2017). However, when students started to work they saw that the work progressed smoothly if they had designed it well. Students gained confidence in conducting laboratory experiments with different analytical instruments (e.g., Cavinato, 2017; Robinson, 2013). As a whole, students felt that the research project was useful for their future laboratory experiments. Despite the large group sizes, the students considered the members of their research group to be active and that their group supported its members. According to Robinson (2013) in PjBL approach in the laboratory, students gain valuable skills. For example, students learn how to do accurate laboratory work, they learn to solve problems, and they learn to collaborate with team members.

There was a contradiction between the responses to the statements and the open answers. For example, in their answers to the open questions the students described how their skills improved during the research project. All the skills mentioned related to the working-life skills. For example, skills related to laboratory work, group working, planning the research and data acquisition, developed. The averages of the answers to the Likert scale questions about four sets of skills (problem-solving, interaction, self-evaluation and stress tolerance) indicated that students were more neutral about their development.

In the future, attention should be paid to guiding instructors before the research project. All of the instructors should have similar instructions on how much students are allowed to design their own project because the element of choice is an important factor for students' success in PrBL (Bell, 2010). According to Wurdinger and Qureshi (2015), some instructors are more student-centered with PjBL than others who allow students to create projects based on their own interests. These different approaches were also reflected in the teaching they provided. In addition, the workload of projects should be unified. Some of the students in the course experienced their workload to be large, but some of the students felt that it was small. However, group-by-group feedback varied on different annual courses.

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