Developing and piloting a Q-study on pedagogical challenges in problem- and project-based learning for first-year engineering students

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Abstract

Research highlights the benefits of Problem- and Project-Based Learning (PBL) for engineering education, but students face challenges with some of its pedagogical features. This pilot study uses Q-methodology to explore first-year engineering (FYE) students' learning challenges in a PBL environment. Based on literature, feedback from PBL experts, the University Student Counselling and Well-being unit, and students, 39 Q-statements was developed regarding different pedagogical challenges of students in PBL. Rather than simply identifying challenges, this study aims to identify the most predominant ones. Q-methodology is appropriate because participants rank statements in relation to each other, instead of rating individual statements. Our Q sorting question therefore asks FYE students to rank pedagogical features of PBL from most to least significant in terms of perceived challenge in relation to learning. To pilot the Q, we consulted two experts in PBL and Q-methodology and subsequently let 5 FYE students do the sorting activity. The results of this pilot are informative in themselves in further developing the tool. In the long term, this study is anticipated to provide knowledge about how students struggle with PBL which will help universities become aware of and remedy the situation.

Keywords: Problem based learning; Q-study; First-year engineering students; Pedagogical challenges

1 Introduction

1.1 Problem- and project-based learning for engineering students

Research in a variety of study programmes over the world has shown that problem-based learning (PBL) is a successful educational strategy (Du et al., 2009). At the university in which the study took place, PBL is usually understood as both problem-based and project-based learning, even though technically, PBL, only indicates 'problem'. PBL has been defined in various ways and implemented in different forms. One of the widely used definitions of PBL is "an instructional learner-centred approach that empowers learners to conduct research, integrates theory and practice, and applies knowledge and skills to develop a viable solution to a defined problem" (Savery, 2015, p.7). Project-based learning, on the other hand, describes students working in teams to solve a problem within a set timeline, resulting in end products (e.g. reports, designs, etc.) (Helle et al., 2006). Aalborg University (AAU) in Denmark has merged the characteristics of both problem- and project-based learning, and its curricula and teaching has been structured around the principles of PBL since its start in 1974 with six basic principles as guidelines (Askehave et al., 2015):

1. The problem as point of departure
2. Projects organized in groups
3. The project is supported by courses
4. Collaboration – Groups, supervisor, external partners
5. Exemplarity
6. Student responsibility for learning

A characteristic of PBL is that, ideally, the learning take outset in an ill-structured authentic problem which is contextualized. Students work collaboratively and are responsible for their own learning process. Hence, fostering student motivation by offering students ownership and multiple sources of learner agency are key elements of the PBL model (Jiang et al., 2023; Lyngdorf, Du & Lundberg, 2023). Such traits in the learner requires meta cognitive competencies, such as critical self-reflection, self-regulation, goal setting etc. (Bandura, 2006, 2008), which are less developed competencies among young learners (Knowles, 1978). Thus,

the transition to a PBL university, like AAU, in itself requires transformative changes in student identity and strategies which can be challenging for some. Furthermore, specific features of PBL, such as the strong emphasis on sociocultural learning processes, application, and transfer of knowledge for exemplarity and self-responsibility, might favour certain types of students over others. Therefore, AAU offers a mandatory 5 ECTS credit (1/6 of a semester) PBL course at the first semester bachelor for the students at the two engineering faculties. Despite the well-described advantages of PBL, Chen et al. (2021) document a concerning increase in challenges with students that are less prepared for student life in university or lack competencies in relation to academic achievement and a change in how students regard group work. This inspired us to find out more about these specific challenges for engineering students at AAU. Also, a subsequent literature review (Jiang et al., 2023) explored the multiple challenges that engineering students encountered when working in intercultural teams. By looking into the references in these studies, we learned how existing studies have identified and described specific challenges related to PBL environments. These studies provided us with inspirations and initial backgrounds to develop our Q statements. However, since these studies include many different types of challenges analysed in a non-holistic way, our study is also different since we focus on the pedagogical challenges only, and we also focus specifically on FYE students. We are also assuming that challenges may change over the years, and it is essential to learn more about the new FYE students' challenges to help retention and avoid drop-out. We are therefore not only interested in knowing what challenges are experienced, but also which are the most or least challenging from a student perspective. Therefore, it is necessary to apply a methodology that can approach this while at the same time offering a systematic and holistic approach with a specific focus on core PBL pedagogy elements.

1.2 Research Aim

While the principles and main features of the PBL-model at AAU University have remained virtually unchanged for a long time, the world around it has not. Therefore, we are interested in developing a tool that can uncover what pedagogical features of PBL challenge the new generations of FYE students. Some research (O'Brien & Reale, 2021) has found that introducing PBL in the first year of education can cause challenges and even lead to higher attrition rates due to the different expectations to students compared to what they are used to in lower levels of education. PBL provides students with more autonomy and freedom but also requires individuals to actively enact their agency. The transition to PBL pedagogics at university thus also requires students to transform their student role and rethink how to become a successful student (Brinkworth et al., 2009; Hagan & Macdonald, 2000). To understand the possible challenges in this transformation, we find Q-methodology to be relevant and valuable. This paper will present the work of developing a Q-study to study the above-described topic. In this sense, this study aims to address the following research question:

How can a Q-study be designed to study what pedagogical challenges FYE students experience in a PBL environment?

2 Methodology

2.1 Q Methodology

Methodologically, Q is used to study subjective opinions, values or beliefs (Watts & Stenner, 2012). It enables researchers to identify and describe the shared viewpoints that exist on a topic revealing areas of consensus and disagreement across these views (Brown, 2019). It combines the characteristics of quantitative and qualitative studies, using factor analysis to organize data from sorting activities and incorporating written reflections as post-sorting activities (Watts & Stenner, 2012).

Constructing a tool for data collection in Q-methodology can be regarded as a unique piece of work and contribution in itself since it can be shared and refined in a research community, which could lead to more studies and ultimately generalization of findings across studies. For example, it could be interesting to

compare how K-12 students experience PBL pedagogy and whether or not they are challenged by the same pedagogical elements as FYE students. Thus, this paper will present how we undertook the concourse development and Q-set construction (Lundberg et al., 2020) for studying FYE students' pedagogical challenges with the PBL model. We wish to emphasise that we focus on pedagogical challenges that are directly linked to PBL and therefore not challenges relating to other elements of student life such as feeling homesick, economic stress, etc. We have a system view of PBL (Kolmos, 2017) in the sense that we do not only focus on the projects, which directly applies PBL, but the education programme as a whole, including lectures which typically do not involve a lot of PBL in themselves, but they serve as support for the project.

2.2 Concourse development

To pilot Q, we followed the procedure of Tancredi et al. (2023), which includes the following steps: 1) concourse development; 2) construct the Q sample; 3) data collection (piloting) and 4) elaborate revisions.

Step 1: Concourse development

The concourse development includes the prework leading to the creation of a set of statements that participants will later rank to create their Q-sorts. The task here is to cover all existing knowledge in relation to the research question through various methods and formulate them into statements that research participants can sort. For this purpose, we inquired different sources as described in the following four steps, a-d:

a: Expert Insights. We sought input from local experts, namely the members of the research group of the authors, UNESCO Centre for PBL at AAU. At AAU, all FYE students have a first-semester course in PBL of 5 ECTS. The teachers of this course are all members of this research group as well as active PBL researchers. On 8 February 2024, authors Lyngdorf and Dahl gave a 10-minute presentation to this research group, followed by a 20-minute discussion with 10 research group members. We discussed our vision for the research and requested participants to write down suggestions to statements based on their experience as both teachers and researchers of PBL. In addition to the actual statements, it was also recommended to us that the term PBL should not in itself be used in the sorting question or in the statements as students may not always have a clear understanding of what PBL actually is, but they know when something is not working for them in this teaching environment. In total, this gave 8 statements.

b. Literature Review. We searched relevant literature to be better informed about student challenges in PBL. Here, the work by Chen et al. (2021) and Jiang et al. (2023) became central and inspired to the formulation of 26 statements. Other literature was also used (e.g., Bundgaard et al., 2021) for single statements.

c. Students' opinions. Author Dahl asked her students taking a 5 ECTS course in Mathematics Education to formulate statements on 18 March 2024. The class consisted of 13 students who were a mix of in-service and preservice mathematics teacher students for upper secondary level. The students were chosen as the authors assumed that, firstly, the students' particular interest in educational research would make it possible for them to come up with relevant statements from a pedagogical angle. Secondly, the students were experienced PBL-learners coming from either 4th or 6th semester of a Bachelor Programme in Mathematics, and for the in-service students taking the same class, they had graduated from AAU some years ago, hence they were considered able to also perceive their PBL education, and potential struggles, in a new light. Thirdly, even though the students were not engineering students, they are at the same faculty as the engineering students, hence experiencing a similar PBL model. During this process, it also became clear why it is a good idea to not mention "PBL" too specifically in the Q statements as the students here first thought that they were asked what they remember from their first semester course in PBL. Thus, many students, sadly, confuse PBL as the overall principles and structure of the education at AAU with a first semester course, also named "PBL". In total, this produced 15 statements.

d. Interview with staff: We arranged a meeting with the University Student Counselling and Well-being Unit to learn what kind of PBL related challenges students approach them with. Here author Lyngdorf interviewed

two experienced counselling staff that prior to the meeting had looked into data on types of challenges and frequency. They also helped by going through the already formulated statements to validate their relevance. Both the Mathematics education students and the Student Counselling and Well-being Unit emphasized that the group formation phase caused stress and worry. The student led group formation phase is a central part of PBL in most cases, but this can also be challenging for students. We have no explanation as to why this was not seen in any of the studies reported in the literature review other than, in our understanding, there is very little research done about group formation in PBL. In total, this validated 31 statements but did not produce new ones. 16 out of the 31 were identified as particularly relevant to the study as these reflected experiences that they encountered more frequently.

Step 2. Q-sample construction

The inputs were collected into a large excel-file, initially consisting of a collection of the 49 suggested statements from various sources described above. These were discussed and each of the three authors "voted" on the ones that were considered most suitable and checked for redundancy. This was done to ensure inter-reliability. Some of the statements were subsequently rephrased. For example, this challenge from Chen et al. (2021): "*Difficulties for new members in integrating into friend-knowing teams*" were phrased into the statement "*Creating an inclusive environment for all team members*" to make it more understandable for participants. We ended up with 36 statements (see Table 1).

Step 3: Data collection (piloting)

We did a piloting Q-sorting session on 25 November 2024 with five students from the first semester of the bachelor programme: Surveying planning and land management. We asked a project group to volunteer, offering them a free lunch, for piloting the q-statements which in total took one hour. This was done by authors Lyngdorf and Dahl. The piloting was a semi-structured session with room for participants to comment on the research design. Using Q as a group task is not what is usually done in Q, where participants sit individually and fill out the grid. However, since this was a pilot, and we assumed that having this as a group task, we would be able to hear how the students discussed the statements. In cases of doubts about how to interpret the statements, their thoughts would be open, and we were also able to discuss with the group and get various opinions about how a statement could be misunderstood. However, this method suffers from a weakness as some statements asked the participants to, e.g., make a decision about building trust among group members, which can be hard to agree on, if the group had trust-issues. Ergo, some of these statements might have had a much different place in the grid, had students filled out the grid by themselves. In any case, this was a pilot, which main purpose was to check the clarity and relevance of the statements.

Alongside the Q statements, we also needed the Q sorting question. This is the overall question used by the students to rank the Q Statements. The Q sorting question is the following: *Based on your own experience, which of the following statements describe the most significant challenges in your study at Aalborg University*? The students then rank the statements in order of significance in a sorting grid ranging from less significant to most significant. In Figure 1 below, it is shown how the students sorted the statements.

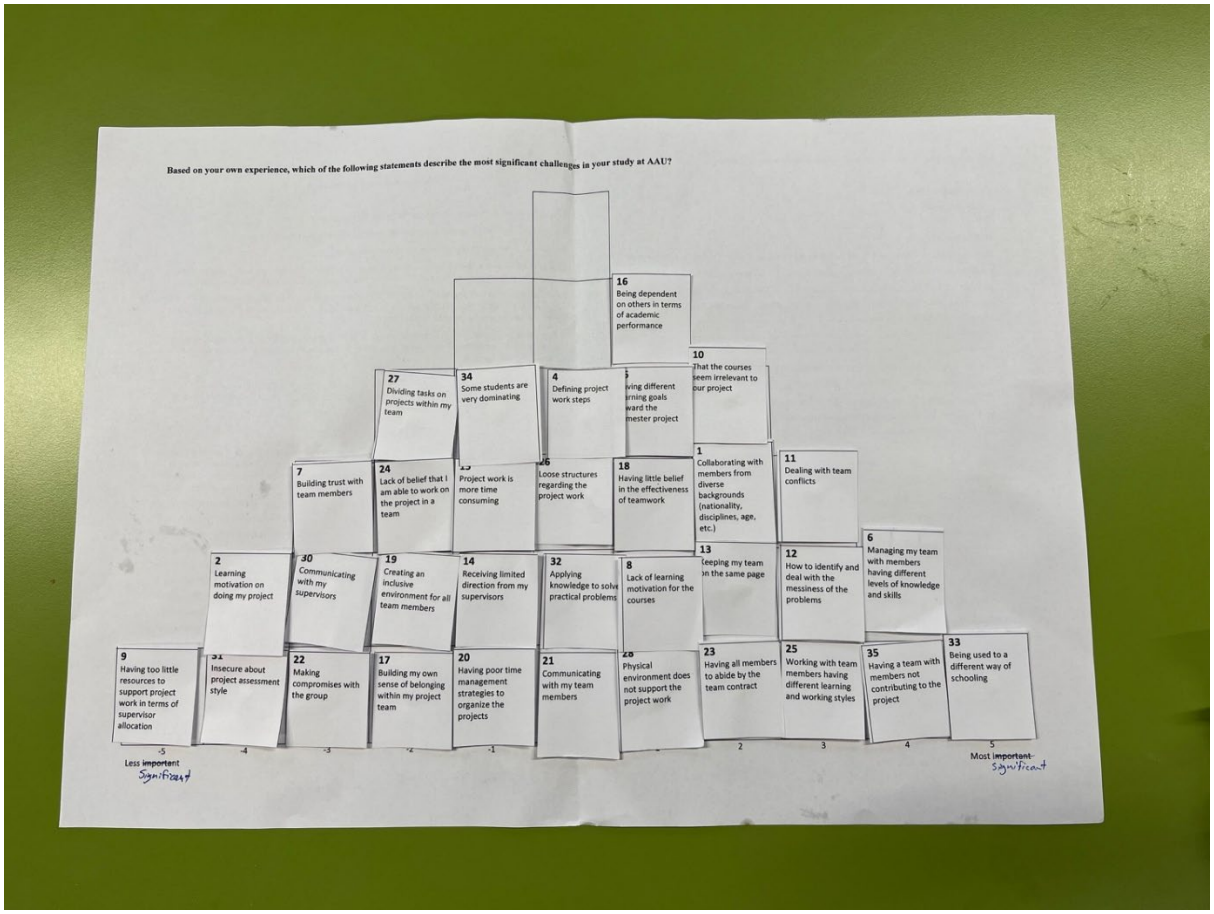

Figure 1: Student group's distribution of the Q statements

3 Results

3.1 The Q Statements

This section reports our Step 4 of Q piloting, as a result of the process described above, and the final Q set is presented in Table 1. Based on the piloting, several of the statements were adjusted to ensure better legibility and relevance to local practices. The results are shown in Table 1. As can be seen here, some statements were overlapping as several sources mentioned these. Also, two were from ourselves, for instance about the role of the physical group room, which some students have, others work in large office spaces. As examples, the statement "*How to identify and deal with the messiness of the problems"* was changed to *"How to identify and deal with the complexity of the problems".* In terms of relevance to local contexts, we found that three statements relating to group formation statements, e.g. *"Group formation is driven by social and not academic dynamics"* were not relevant, since our piloting participants were assigned in groups randomly by the study administration. As a result, which can be seen on Figure 1, these three statements were not placed on the grid. This points to the importance of adapting the Q-set to the local context and practices, which can differ even at the micro-level. As should be, PBL at AAU is not a one size fits all but rather implemented and adapted in a discipline and context specific way. Therefore, context responsiveness is important to consider, when using the tool across different contexts. In our piloting session we found that statement no. 3, 5, 29, are highly context dependent. The piloting also led to the formulation of three additional statements. These are *"Working in smaller teams isolates me from the rest of the course participants"; "Uneven motivation*

among team members"; "Loss of ownership feeling of the project when working in teams". These perspectives emerged through discussions with the group about missing statements.

Unlike in the design of a questionnaire, which is theory-driven, the process described above is rather a data-driven sampling task (Watts & Stenner, 2005) with the aim of generating a set of statements describing the most common pedagogically challenging elements of PBL. A Q set is typically around 40 statements as this is enough to capture diverse perspectives. Our concourse process resulted in 39 statements, which falls within the accepted range (Watts & Stenner, 2012).

Table 1. The Q-set. The origin of a statement is indicated as follows: L: Literature, R: Researchers/Experts, S: Mathematics Education students, U: Student Counselling and Well-being unit, X: Piloting results, ***** = Context sensitive statements, In bold = changed/new statements***

No.	Original statement + reference for literature	Source	Final statement
1	Collaborating with members from diverse backgrounds (nationality, disciplines, age, etc.) (Jiang et al., 2023)	LSU	**Collaborating with members from diverse backgrounds**
2	Learning motivation on doing my project (Lyngdorf, Du & Lundberg, 2023)	LU	Learning motivation on doing my project
3	Students not being included during group formation (Bundgaard et al., 2021)	L	Students not being included during group formation*****
4	Defining project work steps (Chen et al., 2021; Savery, 2015)	L	Defining project work steps
5	Group formation is driven by social and not academic dynamics	SU	Group formation is driven by social and not academic dynamics*****
6	Managing my team with members having different levels of knowledge and skills	S	Managing my team with members having different levels of knowledge and skills
7	Building trust with team members (Jiang et al., 2023)	SRLU	Building trust with team members
8	Lack of learning motivation for the courses (Lyngdorf, Du & Lundberg, 2023)	LS	Lack of learning motivation for the courses
9	Having too little resources to support project work in terms of supervisor allocation	R	Having too little resources to support project work in terms of supervisor allocation
10	That the courses seem irrelevant to our project	R(S)	That the courses seem irrelevant to our project
11	Dealing with team conflicts (Jiang et al., 2023)	LU	Dealing with team conflicts
12	How to identify and deal with the messiness of the problems (Chen et al., 2023; Savery, 2015)	L	**How to identify and deal with the complexity of the problems**
13	Keeping my team on the same page	U	Keeping my team on the same page
14	Receiving limited direction from my supervisors	R	**Receiving broad or ambiguous supervision to encourage independent problem-solving.**

15	Project work is more time consuming (Chen et al., 2021)	LU	**Project work demands a significant amount of time**
16	Being dependent on others in terms of academic performance	S(R)	Being dependent on others in terms of academic performance
17	Building my own sense of belonging within my project team (Jiang et al., 2023)	RLU	Building my own sense of belonging within my project team
18	Having little belief in the effectiveness of teamwork	U	Having little belief in the effectiveness of teamwork
19	Creating an inclusive environment for all team members (Jiang et al., 2023)	LSU	Creating an inclusive environment for all team members
20	Having poor time management strategies to organize the projects	S	Having poor time management strategies to organize the projects
21	Communicating with my team members	U	Communicating with my team members
22	Making compromises with the group	S	Making compromises with the group
23	Having all members to abide by the team contract	RU	Having all members to abide by the team contract
24	Lack of belief that I am able to work on the project in a team	SU	Lack of belief that I am able to work on the project in a team
25	Working with team members having different learning and working styles (Jiang et al., 2023)	LS	Working with team members having different learning and working styles
26	Loose structures regarding the project work	(S)	Loose structures regarding the project work
27	Dividing tasks on projects within my team (Du et al., 2009)	L	Dividing tasks on projects within my team
28	Physical environment does not support the project work	R	Physical environment does not support the project work
29	Lack of facilitation of group formation (Bundgaard et al., 2021)	LSU	Lack of facilitation of group formation*****
30	Communicating with my supervisors (Du et al., 2009)	L	Communicating with my supervisors
31	Insecure about project assessment style (Chen et al., 2021)	LR	**Insecure about project group exam style**
32	Applying knowledge to solve practical problems	U	Applying knowledge to solve practical problems
33	Being used to a different way of schooling	R	Being used to a different way of schooling
34	Some students are very dominating	S	Some students are very dominating
35	Having a team with members not contributing to the project	LRS	Having a team with members not contributing to the project
36	Having different learning goals toward the semester project (Lyngdorf et al., 2023)	L	Having different learning goals toward the semester project

Newly added statements			
37		X	**Working in project teams isolate me from the rest of the course participants**
38		X	**Uneven motivation among team members**
39		X	**Loss of ownership feeling of the project when working in teams**

3.2 Some conclusions based on the piloting

Since this was a pilot of our Q design, done as a group sorting, and not an individual sorting, we did not do any statistics on it. In addition, this would also have required more Q sortings.

Even though we cannot do statistics on how they sorted the statement, we found it interesting to discuss which six statements (2 times 3) the student group had placed at the two extreme ends of the grid. The ones placed as “least significant”, ergo pedagogical challenges that caused the least concerns were the following: "Having too little resources to support project work in terms of supervisor allocation”, “Learning motivation on doing my project”, and “Insecure about project assessment style”. It appears that they had adequate supervisor resources, are motivated to do their project, and are not insecure about the exam format in PBL. The two first statements are heavily influenced by not only the semester design and university allocation of resources, but the actual project the students are doing and the specific supervisor. The three statements the students indicated as “most significant” were the following: “Being used to a different way of schooling”, “Having a team with members not contributing to the project”, and “Managing my team with members having different levels of knowledge and skills”. It is unsurprising that students need to get used to a PBL learning environment, but that it is the “most significant” is still surprising, given the quite positive statements in the opposite end. One may speculate that the group may have had a hard start but nevertheless managed to formulate a project everyone was happy with. Perhaps with help from a supervisor. To what extent the two other statements are related, hence some students may not contribute due to lack of knowledge, is uncertain, but it could also be a general experience. These findings are mostly speculative since a Q sorting should be done individually and with enough sortings to achieve saturation. Furthermore, this piloting led to several reflections for us and in the end changes in several statements as described in this paper.

We expect the outcome of this study to contribute to develop PBL practices locally but also give recommendations and inspiration beyond. Learning is not supposed to be without challenges or difficulties, but students must not be left struggling without direction. The art is to scaffold learning at a balance where students are challenged but not lost and overwhelmed. This balance has been a central focus of educational research. Vygotsky (1978) developed the concept of the Z*one of Proximal Learning*, describing the limits of what a learner is capable of individually and what is achievable with a more knowledgeable peer. Similarly, Bjork and Bjork (2011) introduced the notion of *desirable difficulties* in learning reflecting that learning might not be intuitive and that making learning processes harder in the short term might lead to deeper understanding and retention over time. These difficulties can be regarded as desirable because they force the learner to engage more with material and processes. Having such research in mind, it will be of interest to explore what kind of challenges students perceive as unsurmountable and therefore destructive for learning at a given time of their studies in a PBL environment and what we as educators can do to better scaffold and support students in these aspects. A Q study might not be able to give all the answers to this but combined with qualitative methodology, such as individual and group interviews, and observations during a semester, we hope to find enough evidence to get a better understanding of students struggles with PBL pedagogy. In the end, this could create awareness among educators about specific PBL pedagogy related challenges, e.g. in FYE, where we need to design stronger scaffolding and student support in PBL

environments. This might also necessitate professional development among educators in certain areas of PBL pedagogy that shows to be especially challenging if not scaffolded sufficiently.

4 Next steps and Summary

The final Q statements will be used for approximately 50 first-year students in Energy and Engineering Science programme in the autumn semester of 2025. 50 participants are sufficient to ensure a diverse sample and achieve saturation, meaning that no new perspectives would emerge from additional participants. The Q study methodology also involves a more open inquiry step, where students can describe challenges that were not included in the statements.

The process outlined in this paper involved various experts such as students, and academic and technical staff as well as building on previous research. We are anticipating that by learning more about, which are the most prevailing PBL pedagogical challenges for FYE students, remedies can be made. We expect that the result of the development of the Q study will both inspire others to try this particular methodology but also that discussing it with colleagues would help us further validate the study. Finally, we expect that the results of the study will contribute with essential information to be used in improving PBL practices and in addition be inspirational for other institutions that have implemented PBL or are considering doing so.

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