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Mathematics students' self-reported learning experiences in a challenge-based course

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In this paper, we report on a study of 'students' learning experiences' in the context of challenge-based education in a higher education mathematics course. Using a case study approach, we investigated (1) how students perceive the role of the existing resources to help them solve their challenges during a one-week challenge-based course; and (2) how students experienced their learning in terms of mathematics and professional skills. Results point to (1) the crucial importance of human resources (e.g. problem owner) for such learning environments to link the mathematics to an authentic situation and develop the skills of an 'applied mathematician in the real world', and (2) a deeper understanding of appropriate methodological tools and their use for researching the concept of 'student learning experiences' in mathematics education.

Keywords: University engineering education, challenge-based education, innovative course, resources, students' learning experiences.

INTRODUCTION AND BACKGROUND

There are concerns in society, business, and industry that presently university engineering education does not sufficiently prepare students for the challenges of this century (e.g., societal problems, global warming, and sustainability), as indicated by the National Academy of Engineering (2018). In this context, an increasing number of universities are developing and implementing educational approaches that move from traditional teacher-centered teaching and learning processes to student-centered approaches (van Uum & Pepin, 2022). This shift, in turn, is related to forms of engineering education that become more relevant by contributing to the solution of societal problems through collaboration between industry and universities. One of these approaches is Challenge-based Education (CBE), which seeks to promote in students both the acquisition and production of disciplinary knowledge and the development of professional competencies (e.g., problem resolution, design capacity, ethical awareness, and multidisciplinary collaborative work). In this paper, we use the term CBE to include both learning and teaching processes. In CBE, students develop their knowledge and competences by collaboration on the solution of real-life problems derived from 'grand challenges' in society, often in a multidisciplinary setting. However, there are still several challenges in implementing CBE at the higher education level (Gallagher & Savage, 2020), in particular for fundamental disciplines such as mathematics and physics. In the case of mathematics, research is needed to understand what and how students can learn in line with a CBE approach and how they can be supported in their learning. Thus, we set out to understand students learning experiences in CBE, that is, to investigate the needs and benefits of this approach from

the students' perspective. For this, we carried out a case study in a Dutch university of technology with the aim to develop a deeper understanding of students' perceived learning experiences in an innovative master's course in mathematics: the modelling week. We are interested, in this paper, in (1) students' use and integration of resources when facing real-world problems and working with problem-owners from business and industry; (2) how students perceive their learning in such CBE environments. On the use of resources, we draw on the Instrumental Approach (Rabardel & Bourmaud, 2003; Trouche, 2004) to analyse students' learning through their interaction with different resources (Gueudet & Pepin, 2018; Pepin & Kock, 2019), particularly “when the curriculum changes from a teacher-centred to a student-centred one” (Pepin & Kock, 2021, p. 325). We ask the following research questions:

RQ1: How did students perceive the role of existing resources to help them solve their challenge during a one-week challenge-based mathematics course?

RQ2: How did students experience their learning in terms of mathematics and professional skills?

THEORETICAL FRAMEWORK

Challenge-based Education

In the transition to student-centred education, different approaches have been developed under the umbrella of inquiry-based education (Martin et al., 2007). One of these is CBE. Malmqvist et al. (2015) define learning experiences in CBE (by them termed challenge-based learning) as:

A challenge-based learning experience is a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable. (p. 87)

These authors add that problems in the context of CBE involve a greater challenge and complexity than those structured, for example, in problem-based learning. Challenges in CBE are linked to social challenges and often involve large open-ended problems (e.g., global warming), in which students have to define their distinctive challenge that they want to solve; this means that students experience greater uncertainty. Moreover, CBE challenges are inherently multidisciplinary. However, no agreed upon definition of CBE exists (Gallagher & Savage, 2020). Rather, a CBE learning environment may be compared to a range of criteria that it fulfills to a greater or lesser extent. The characteristics of a particular learning environment should then be considered holistically when determining whether it may be described as CBE (van den Beemt et al., 2022). For this reason also monodisciplinary courses or courses in a non-international context could, depending on their other characteristics, still be considered as CBE.

CBE is claimed to be motivating for students, because of the real-world character and the relevance of the challenges. Through CBE, it is said, students acquire and develop disciplinary knowledge, transversal competences while interacting and collaborating with multi-stakeholders (Gallagher & Savage, 2020; Membrillo-Hernández et al., 2019). Two relevant aspects of CBE are the definition of the problem, and the design and implementation of prototype solutions.

Additionally, we also consider it necessary to extend the definition of CBL-experience given by Malmqvist et al. (2015) by first pointing out what is meant by 'learning experience' and considering the different ways in which students are affected (e.g., depending on the communication with academic supervisors and other students) and what feelings they expressed (e.g., frustration, liking, interest in the activity) during the solution of a problem in the context of CBE. Thus, to consider the different facets of and agents in student learning experiences, we propose a first conceptualisation of 'mathematics students' learning experience' as the conjunction of two processes: A process of being affected and getting knowledge or skills (e.g., from tutors) from doing, seeing, or feeling things depending on learning goals; and a process of developing and applying knowledge or skills through the use of resources and different forms of collaboration.

The lens of resources

This study draws on the Instrumental Approach (Rabardel & Bourmaud, 2003; Trouche, 2004), to address the question of student learning experiences and development of competencies in CBE when they use different types of resources while solving problems. For engineering students in applied mathematics, we assume that the development of competencies is related to students' strategies when orchestrating and integrating different types of resources. This integration involves two processes: (1) instrumentation, where the affordances of resources influence student practice and knowledge; and (2) instrumentalization, where students adapt the resources to their own needs. In this way, this study draws on the categories of resources as outlined by Pepin and Kock (2021): curriculum resources (e.g., textbooks, teacher curricular guidelines, worksheets), social and cultural resources (e.g., conversations with tutors, peers, and friends), cognitive resources (e.g., concepts and techniques), and general resources (e.g., software, internet, and other digital resources).

THE STUDY

A case study approach (Cohen et al., 2007) has been used for this study, where the unit of analysis is the case of the modelling week in the mathematics department.

The context: University and modelling week

The study took place at a Dutch technical university that offers different educational programs in science, core engineering studies and social engineering studies. As part of its educational vision towards 2030, this university is in the process of shifting towards a student-centred education following the CBE approach as one of its main

educational strategies. Through this strategy, the institution seeks for the future engineers to have a deep understanding of their discipline and to be able to work collaboratively in real world complex situations in multidisciplinary settings.

The study participants took part in a ‘modelling week’ for first year master’s students, which is part of a compulsory course in the Applied Mathematics Master's program. The ‘modelling week’ allowed students to work for a week on problems designed by stakeholders from outside the university (problem owners hereafter); these came from regional businesses and industry. The whole course consisted of three moments: (1) Kick-off, where information about the course was given by the problem owners and the creation of different teams (by the course leaders and university tutors) was carried out according to the areas of interest of each student; (2) Lego workshop, where students got to know each other and team dynamics were performed; and (3) Modelling week, where during one week (Monday to Friday) students worked in teams to find a feasible and effective solution to the problem, guided by university supervisors and problem owners. The modelling week ended with the presentation of the results of each team. Eight teams of 5-7 students each participated in the course and four of them agreed to participate in our research.

Data collection

Data were collected through non-participant observation of students working together and with their tutors (problem owner, mathematics tutor) during their meetings. These resulted in fieldnotes from these meetings and photos (e.g. of student writings). In addition, the following data collection strategies were used (Table 1):

Participants	Instrument
Students	Exit Cards, interviews, drawings, and surveys
Tutors	Interviews
Problem owners	Interviews

Table 1: Instruments for data collection from participants of modelling week

The exit cards were filled out by the students at three different data points (Monday, Wednesday, and Friday), and consisted of five questions to be answered by students: (Q1) Select the smiley that best describes your overall feeling about your work today and explain why you selected this smiley; (Q2) describe the most interesting things you learned today; (Q3) describe the activity you liked best today, and explain why; (Q4) describe the most important hurdle/difficulty you came across today for your progress, and explain why; (Q5) On the axes provided, sketch how you feel you have progressed towards your goal so far and use a few words to explain what you have drawn. The interviews were conducted at the end of the week, based on students' drawings of their resource system (Schematic Representation of Resource system-SRRS; Pepin et al., 2017). The SRRSs are a schematic representation of how students used and integrated

different resources throughout the week. During the interview, each student was asked to explain his or her drawing.

Analysis strategy

To carry out the analysis of results, and in accordance with the objectives of this article, we focused on the analysis of the students' learning experience through exit cards, and students interviews in combination with SRRSs. The interviews (with problem owners and tutors), observation notes and surveys were backgrounded and not considered for the analysis reported on in this paper. For data analysis, we drew on Grounded Theory (Walker & Myrick, 2006) as it allowed us to organize and categorise the data collected into themes that in turn supported the descriptions and analyses, and fed the theoretical approaches used. Thus, we established two main categories of analysis with subcategories in each category: (1) Kinds of resources and support for: identifying the problem, guidance, and making choices. (2) Student perceptions of their learning experiences (including difficulties experienced): applying mathematics in the real world, and social skills. Through these categories we identified both the process of being affected and the process of developing and applying knowledge or skills; both processes in relation to the different resources mentioned by the students. To identify resources, we qualitatively analysed the sentences with words referring to resources (material, concepts, actors) to determine the beliefs, ideas, or motives guiding students' activity, as well as the contexts and situations in which they are used.

DISCUSSION OF RESULTS

Here we report results from a team of students (S1-7) involved in the problem entitled 'stochastic durations in taxi route planning' (referring to a non-deterministic process of transportation service). In making taxi transfers more efficient for elderly and disabled people, the students addressed the problem of "how do stochastic boarding times affect the quality of the realization of the planning compared to the constructed (deterministic) planning?"

For answering *RQ1*, we analyzed the interviews/SRRSs and exit cards (see Table 2). Due to space limitations, we present the SRRSs of two students: S2 and S7.

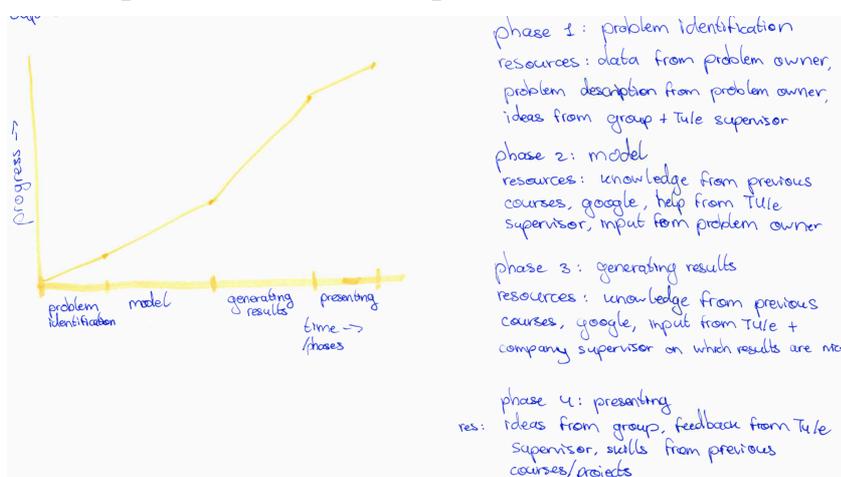


Fig 1: Schematic Representation of Resource system-SRRS from S2

S2 represents his/her experience in the modelling week divided into four phases. This diagram allows us to identify more precisely the resources that S2 used and incorporated in each phase. It can be seen how the problem owner appeared important for the identification of the problem and giving “inputs”; the supervisor was also relevant for giving “feedback”. Other resources available to the student were: the use of "knowledge from previous courses", "google", “ideas from group”.

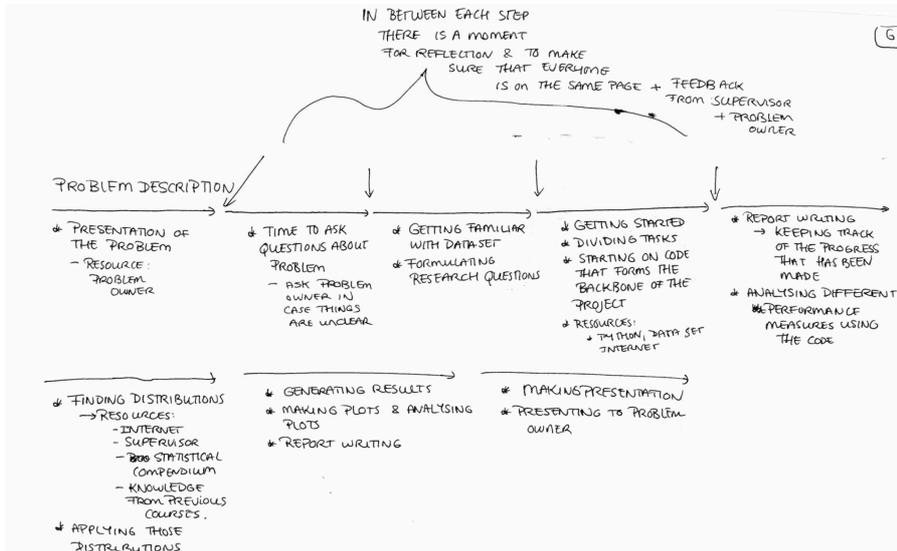


Fig 2: Schematic Representation of Resource system-SRRS from S7

S7 represents his/her experience in a continuous manner and specifies the different activities the group carried out. Two relevant resources that S7 perceived that helped them solve the problem were the problem owner and the supervisor through their feedback, which allowed the transition through the different stages. Other resources used were: “pyhton”, “data set”, “internet”.

The SRRSs are complemented with information from the exit cards in relation to the first category of analysis. The number in parentheses corresponds to the question number on the exit card and the day it was filled out (M-Monday, W-Wednesday, F-Friday).

	Identifying the problem	Guidance	Making choices
S1	We discussed the problem with our group in an organized manner (Q1.M)	The problem owner saying our results were valuable for their company and that they will use them (Q3.F)	brainstorming the problem and hearing everyone’s ideas (Q3.M)
S2		Discussing them with the problem owner and then changing our model according to the feedback (Q1.W)	Discussing with the problem owner and making sometimes difficult choices in modelling (Q2.W)

S3	I feel like we have got the problem clear, and know what we have to do (Q5.M)		
S5		Meeting with problem owner, a lot of insight (Q3.W)	
S6		Our meeting with the problem owner we got a lot of new insights, as well as meaningful feedback (Q3.W)	
S7	We were well organized and made concrete plans to tackle the project (Q1.M)		

Table 2: Exit card responses for "Kinds of resources and support" category

Table 2 shows that for four students (S1, S2, S5 and S6) in this group the role of the problem owner was essential as a guide. To identify the problem, group discussion was important (S1, S3 and S7). For decision making, the brainstorming (S1) amongst the group and discussions with the problem owner (S2) appeared crucial.

From the interviews/SRRSs and exit cards (Table 2), we can summarize the role of the available resources in the following way: (1) The importance of the problem owner: as guide through the process; answering questions related to the problem; assessing the solution and presentation. (2) The role of the tutor: giving tips with the mathematics/modelling, also in terms of resource availability and giving feedback on what they have done. (3) Importance of other social resources (e.g. group discussions) and general resources (e.g. google, python, internet).

For answering *RQ2*, we analyzed the exit cards (see Table 3) in relation to the second category of analysis.

	Applying mathematics in real world	Social/professional skills
S1	In terms of mathematics: what a simulated annealing algorithm is (Q2.M)	I did not really learn anything new. We just applied our knowledge. So you could say we gained more experience in applying theory to real life (Q2.W)
S2	How to present your results in a way that they are most interesting and understandable for the project owner (Q2.F)	making a plan of work together. Also including all team members, also the ones that are less active (Q4.M)
S3	I got a better idea of what mathematicians do in the real world and industry (Q2.M)	the skill of reading/understanding other people's code (Q2.W)
S4	To understand the meaning of the question and how to convert a question from reality problem into a math question (Q4.M)	how to extract the effective information from the questions (Q2.M)

S5	Starting coding. There were many places to start and deciding where is something difficult (Q4.M)	Not being to critical of your own work (Q4.F)
S6	The most difficult obstacle is to write the program (Q4.M)	to get the final results ready for our presentation (Q4.F)
S7	How we should interpret some part of the data (Q4.W)	new ways of comparing the results and new distributions and additions we could add to our code (Q2.W)

Table 3: Exit card responses for “Student perception of their learning” category

The learning that students perceived they acquired came from Q2 of the exit cards (see Table 3). Here we observed learning related to mathematics, for example, "a simulated annealing algorithm" (S1) or "coding" (S5); as well as professional skills, for example, "to get the final results ready for our presentation" (S6). The difficulties perceived by the students come from Q4 of the exit cards. Among the difficulties we note: “How we should interpret some part of the data” (S7), “to write the program” (S6) or “how to convert a question from reality problem into a math question” (S4). From the exit cards (Table 3), we can summarise the student perception of their learning experiences under two important points: (1) Some students pointed out aspects related to mathematics (e.g., a simulated annealing algorithm). However, it was striking that others said that they did not learn anything new in terms of mathematics. Vergnaud (2009) points out that the mathematical competencies that students acquire and develop are not restricted to linguistic and symbolic expressions (predicative form of knowledge) but are also required to consider actions in the physical and social world (operational form of knowledge). (2) About professional skills: they said that this was the main outcome, that they worked like ‘real engineers’ with authentic problems, and in a pressurised situation.

CONCLUSIONS

In terms of theory, we developed insights into students' learning experiences in relation to their own perceptions of what they learned and with which resources they learned. This, in turn, allowed us to approach a better understanding of the notion of "students' learning experiences" at the conjunction of two processes.

Coming back to our proposal to (re)conceptualize 'the mathematics students' learning experience': referring to RQ1, the results show the importance of considering a process in which students are affected by the PO and the tutor; at the same time, referring to RQ2, results show the second process in which students develop and apply both knowledge and skills to face their challenge. As we can observe, these two processes are in turn closely related to the use of resources, where two processes are involved: instrumentation and instrumentalization.

In terms of methodology, (1) we made a link between different methodological tools (SRRSs and exit cards) for grasping students’ reflection on their development (operationalisation of the mathematics in an authentic situation), and the resources that

they need for such development; (2) we found the usefulness of exit cards (as new tool) and SRRSs as “deepening tools” for receiving richer data; and SRRSs in combination with interviews as useful tools for examining integration of resources.

Finally, the results have implications for practice and are useful for course designers: e.g., choice of problem/project; support of students by tutor and problem owner; alignment of support by problem owner and tutor.

At the curricular level and in the context of the transition to a student-centered approach through the CBE approach, from the results we observe that this transition is not only moving away from traditional teaching, but it also entails a reflection on the new roles expected by tutors and the impact of their interaction with students. Thus, it is important to continue with research that accounts for: (1) how tutors and POs help, guide, and establish the balance between not leaving students completely alone and not solving problems for them; and (2) how this interaction is perceived by the students themselves through the use of resources.

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