USING DIGITAL CURRICULUM RESOURCES IN CHALLENGE-BASED EDUCATION: A CASE STUDY WITH APPLIED MATHEMATICS AND PHYSICS STUDENTS

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In this paper, we report on a study of 'applied mathematics and applied physics students' learning experiences' in the context of challenge-based education in a higher education CBE course aimed to understand the physics of social systems. Using a case study approach, we investigated how a team of five students used a digital curriculum resource (Dashboard) to identify and define a problem in a CBE course. Results point to the crucial importance of: (1) the design and use of the Dashboard so as to foster effective and efficient feedback from the three lecturers of the course and (2) student knowledge of Dashboard's affordances, that helped to structure students' activity and using it for their own purposes.

Keywords: Digital Curriculum Resource, Challenge-Based Education, feedback, technological agency

INTRODUCTION

From the new needs and concerns in society and industry, new approaches in university (mathematics) education have been developed to better prepare students for the important challenges of this century (e.g. global warming, sustainability, transport efficiency) (Pepin et al., 2021). In these student-centered approaches, learning takes place through open-ended collaborative inquiry, often combined with the design of a prototype solution to a problem (van Uum & Pepin, 2022). One of these approaches is Challenge-Based Education (CBE), a term used in this paper to refer to both teaching and learning processes. CBE seeks to help students acquire and deepen disciplinary knowledge and professional competencies and skills (e.g., problem resolution, ethical awareness) while interacting and collaborating with multi-stakeholders (Gallagher & Savage, 2020). In this pursuit of the CBE approach, we highlight two issues that are important to address, specifically related to the fundamental subjects of mathematics and physics: (1) the successful application of CBE is not obvious for these subjects (Dahl, 2018), even though in practice the CBE approach often involves significant physical-mathematical thinking and work (e.g., learning how to abstract a real-world problem in mathematical terms through the construction and application of models inspired by physics, and the use of theoretical concepts and techniques); (2) It is often difficult for students to identify and define a problem from a given broad challenge. This issue, in turn, highlights a pedagogical challenge in line with the new educational approach: how to make interactions between teachers and students more efficient and productive by providing short cycles of quality and effective feedback, guidance and support to help students in their self-defined projects.

To address these issues mathematics and physics need to be approached in a way that is in line with CBE, that is to say, in the context of the acquisition and development of knowledge, competencies, and skills (professional and mathematical) and the use of different resources which mediate the students and tutors activity. Niss and Højgaard (2019) point out that mathematical competence "is someone's insightful readiness to act appropriately in response to all kinds of mathematical challenges pertaining to given situations." (p. 12). In relation to the analysis of disciplinary knowledge in students (e.g., mathematical knowledge), we follow a cognitive approach oriented to the analysis of knowledge in practice in different situations. As Kynigos (2022) points out in relation to the way in which learning should be analyzed: "We should not be thinking of whether students learn how to factorize or learn how to solve a quadratic equation, but rather of situations resolvable by dense sets of concepts around a central one." (p. 15).

Thus, in this study we are interested in analyzing the use (by students and tutors) of a digital curriculum resource (DCR), to which we will refer in what follows as "the Dashboard", that can effectively support applied mathematics and applied physics students in CBE. To address this objective, we present a case study of a multidisciplinary CBE course at a Dutch university of technology in which students gained hands-on experience while encountering content from mathematics, physics, psychology and ethics.

We seek to answer the following research question (RQ):

What are the student learning experiences in a CBE course when using a digital curriculum resource to identify and define a problem?

THEORETICAL FRAMEWORK

Challenge-based education (CBE)

CBE is one of the student-centred approaches that have been developed under the umbrella of inquiry-based education (Martin et al., 2007). Malmqvist et al. (2015) state that problems in the context of CBE, being social challenges, involve a greater complexity than those structured, for example, in problem-based learning. Regarding the learning experience, they point out that besides being typically multidisciplinary it "takes place through the identification, analysis and design of a solution to a sociotechnical problem." (P. 87). Hence, in many CBE courses, student groups are given a broad challenge, in which they identify a particular problem they want to address. Initial support is directed at helping student groups to cleary define this problem. CBE learning environments can be described using of a set of criteria that each learning environment fulfils to a greater or lesser extent. Van den Beemt et al. (2022) distinguish three dimensions of CBE, particularly in engineering education: (1) Vision/Challenge, (2) Teaching and Learning, and (3) Support, each with different "indicators".

Instrumental Approach and use of resources

Rabardel and Boumaud (2003) develop the instrumental approach (IA) in which they consider both the relevance of technology in the context of the development of cognitive processes and the fact that essentially every human activity is mediated by the use of artifacts. IA characterizes the interaction with an artifact, called Instrumental Genesis, as the conjunction of two processes: *instrumentation* and *instrumentalization*. For the purposes of this study, we take the notion of resources as "anything (digital, cognitive or material) likely to resource the students' mathematical practice such as a textbook or discussions with other students." (Gueudet & Pepin, 2018, p. 58). In particular, we consider a *digital curriculum resource* (DCR) as the "organized systems of digital resources in electronic formats that articulate a scope and sequence of curricular content" (Pepin et al., 2017a, p. 647). Thus, interaction with a resource corresponds to: (1) the instrumentation process, where the affordances of resources influence student practice and knowledge; and (2) the instrumentalization process, where students adapt the resources to their own needs.

Feedback

In the study, we also integrate feedback analysis considering the model proposed by Hattie and Timperley (2007). They conceptualize feedback as "information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding." (p. 81) and point out that effective feedback must address three major questions: *Where am I going?*, *How am I going?*, and *Where to next?* These questions are related to learning goals, the learner's progress and the learner's next step and work together at four levels: the level of tasks (how well tasks are understood/performed); the level of process (the main processes needed to understand/perform the tasks); the level of self-regulation (the way students monitor, direct, and regulate actions towards the goal); and the level of self (the person of the learner; the least effective type of feedback). Therefore, effective feedback needs to address questions about the learning goals, the learner's progress and the learner's next step.

METHODOLOGY

In this study, we used a qualitative case study approach. The study was conducted at a university of technology in the Netherlands, in a second-year bachelor course "Sociophysics 1".

Sociophysics 1 and the DCR "the Dashboard"

Sociophysics 1 is part of a Learning Line of three courses which as a whole follows the CBE approach and incorporates the Scrum framework. The latter was used as a project management framework that helps students to develop and organize collaborative work in an efficient and agile way. The main student learning goals (LGs) of this course were to gain experience in observing, describing, characterizing and measuring a social system, and, particularly, to identify and determine the problem addressed by the students themselves. They also had to consider the psychological aspects necessary to describe the behavior of the social system, and had to start thinking about the ethical implications of conducting a challenge with human subjects. To accomplish the LGs, the students teams, had to formulate an Essential Question (EQ) they are going to address with their team, and then come up with Guiding Questions (GQs), Guiding Activities (GAs) and Guiding Resources (GRs) which will guide them through the project. Other objectives of the course were to familiarise students with the CBE approach and the Scrum framework. The course lasted 8 weeks. The teams made an intermediate presentation and at the end presented a poster and submitted a written report. With the aim of helping students to accomplish the LGs, two academics involved in the course (also co-authors of this paper) designed a DCR: the Dashboard. With this DCR, the students were able to communicate with their tutors: lecturers (physics, psychology, and ethics) and teaching assistants (TAs) regarding the formulation of the EQ, GQs, GAs and GRs. Using this DCR the lecturers (and sometimes the TAs) gave written feedback, after which the students could post their revisions.

Data collection and data analysis strategies

The participants in the study were two teams (out of 15) of 5 students per team, and tutors (the 3 lecturers of the course: physics, psychology and ethics; and one TA per team). The data collection methods are summarized in Table 1 (below).

Data sources	Data collection methods

Students: 2 team of 5 students each	Observation, interviews, SRRSs (drawings), students' products (presentations, poster, and report)
Tutors: 3 lectures and 2 TAs (one per team)	Observation, interviews
Dashboard	Students' posts, tutors' feedback

Table 1. Data collection methods

The interviews were conducted at the end of the course. During the interview, each student was asked to make a drawing (Schematic Representation of Resource System (SRRS), Pepin et al., 2017b). These drawings provided schematic representations of how students used and integrated different resources throughout the course. All the data were coded into three categories of analysis related to student interaction with the Dashboard: feedback, instrumentation, and instrumentalization. To carry out the content analysis based on the RQ, first, we conceptualized *students' learning experiences* as the way students structure and develop their activity using and integrating different resources (including DCRs); second, we analyzed this activity through the conjunction of two processes: a process where different resources contribute to structuring the students' activity and a process where students adapt the resources to their own needs and objectives.

For this study, we have focused on the students' and lecturers' posts in the Dashboard and the student drawings in connection with the students' interview data.

RESULTS

We report results from one team of five students (S1-5) who worked on the challenge: *Design methods to optimally (not necessarily homogeneously) distribute passengers on a train platform to improve the boarding time*.

Feedback

Following the CBE approach students were not given a pre-defined question for their challenge. Instead, the team formulated an EQ, and five GQs, eight GAs, and five GRs. Through the Dashboard, the students received rapid feedback -from each lecturer- on each formulation in quick feedback loops that helped them develop their GQs, GAs, and GRs more quickly, and thus identify the challenge they aimed to solve (Figure 1).

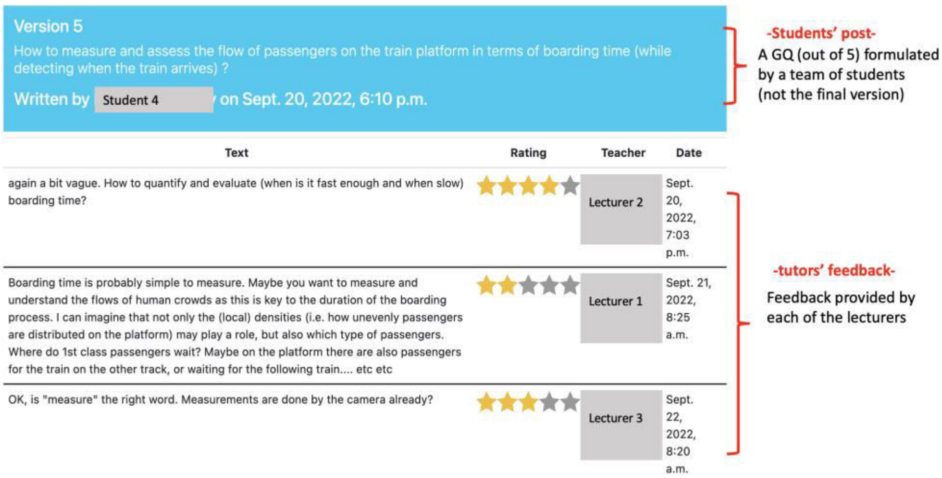

Figure 1. Display of the Dashboard interaction for the case of the fifth version of a GQ

Figure 1 shows how the interaction between the students and the three lecturers of the course developed through the Dashboard. This case shows that after the students' posts, the team received quick feedback on their GQ from each lecturer (one of them even responded in less than an hour). It also shows how the lecturers address the three major questions mentioned by Hattie and Timperley (2007): *Where am I going?* is addressed by Lecturer 3, who asks whether "measure" is in line with the objectives of the challenge; *How am I going?* is addressed by Lecturer 2 who gives information on the progress of the GQ and makes students notice that they need to be more precise ("again a bit vague") and with his question "How to quantify and evaluate (when is it fast enough and when slow) boarding time?" gives information on how they might proceed; and Lecturer 1 addresses *Where to next?* providing information looking for students having greater possibilities of learning from the challenge by also considering "which type of passengers" and contextualising this observation more broadly.

Regarding the number of interactions on the Dashboard, these were related to the expected development of the students' activity throughout the course. Students were expected to formulate their GQs during the first part of the course (first 2-3 weeks) to have enough time to formulate their GAs and GRs related to each GQ, as well as to work with the data they were provided with and with which they developed models (not analyzed in this article). Figure 2 shows the number of interactions on the Dashboard along the course.

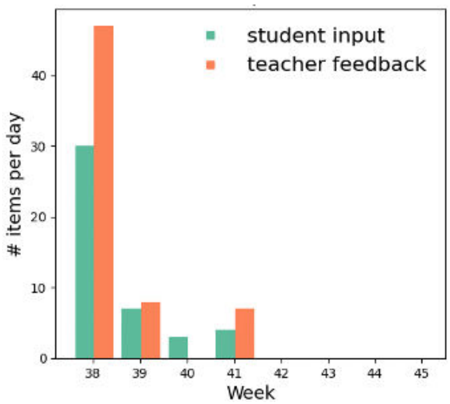

Figure 2. Number of interactions on the Dashboard during the course

We can observe that the number of interactions was highest in the first four weeks, with a peak at the beginning. These changes in the number of interactions per week are consistent with the way students were identifying their problem by formulating first their GQs and then their GAs and GRs that together defined their problem.

Instrumentation process

In Table 2 (below), we present excerpts from the interview in which students expressed some of their views on the Dashboard regarding the instrumentation process.

	Instrumentation: knowing the Dashboard and its influence on students' activity
S1	Once I get used to it, I found some features that I didn't know where they were, then I found it useful.
S2	I think is really nice to keep everything organized and have a nice interaction with the teachers easily through the comments that they can give from the guiding questions and because otherwise you would just have document with questions and many different

	versions of it and now it's all the organized in one place.
S3	That's pretty good outcome, like in connecting with the tutors and the professors as well.
S4	I didn't really like dashboard at the start because it was new concept to me, but it grew on me over time. I like the way it's centralized and it's personalized just for sociophysics.
S5	I like the dashboard because there's just a lot of interaction. You're able to conversate with your teachers and they give feedback relatively quickly. (…) this is a very feedback centered course, in that sense I think the dashboard is definitely essential.

Table 2. Students' remarks on interacting with the Dashboard

Table 2 shows that it is important that students first recognise the characteristics of the DCR in the context of their activity and the course (S1 and S4). Among the features of the DCR and the opportunities it offers, S2 points out that it helps in the organisation of their work and helps in the development of GQs. S5 identifies that the DCR is aligned with the course features "this is a very feedback centered course, in that sense I think the dashboard is definitely essential".

Instrumentalization process

Figure 3 shows how one of the student used the Dashboard for their own/team purposes.

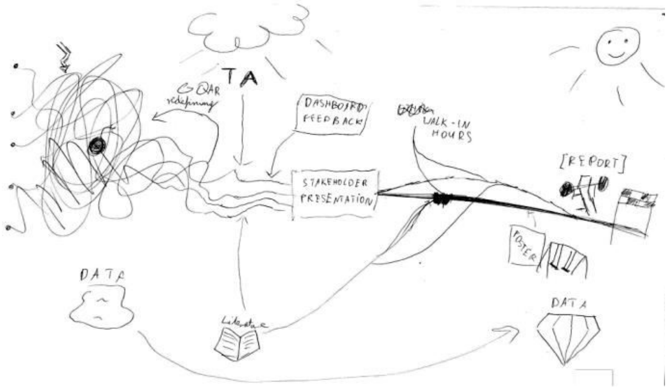

Figure 3. Example of a Schematic Representation of Resource System (SRRS) from S1

We observe that the student perceives that the Dashboard helped them particularly in the formulation of their GQs, which they had to formulate and reformulate based on the rapid feedback received from the tutors via the Dashboard. Explaining their SRRS, S1 said during the interview:

S1: At first there was chaos (…) then the teaching assistant [*TA*] help us very much, especially with redefining the guiding questions. Then, the dashboard feedback came, which got us into some right track.

What is expressed by S1 corresponds to the instrumentalization process insofar that the DCR, in addition to the feedback received personally by the TA, was used with the aim of having the students formulate their GQs. In the representation of S1 we can see that it was in the first part of the course that work was mainly done on the formulation and reformulation of GQs, which is consistent with Figure 2 and the expected progression of the course.

CONCLUSION AND DISCUSSION

This paper investigated the question of what are students’ learning experiences in a CBE course when using a digital curriculum resource (the Dashboard) to identify and define a problem. For answering our RQ, we define the *students' learning experience* and relate it to our theoretical framework. Thus, the interaction with the Dashboard and its use were analysed through the feedback received by the students and two processes: instrumentation, and instrumentalization.

The students considered the Dashboard as an important DCR (e.g., S5: "the dashboard is definitely essential") and helped them in the development of their challenge through the quick and effective feedback they received from the tutors to formulate their GQs (Figures 1 and 3). We observed that most of the interactions on the Dashboard took place in the first 3-4 weeks of the course (Figure 2). This is consistent with what is expressed by S1 (Figure 3), where it is observed that it is in the first part of the course that students have more difficulties in identifying and defining their problem. We identify that the feedback received by the students was effective in that it addresses the three major questions stated by Hattie and Timperley (2007): Where am I going?, How am I going?, and Where to next?

Finally, regarding students' interaction with the Dashboard, we place our discussion in the context of IA and mediation. Rabardel and Bourmaud (2003), drawing on Vygotski's work developed in the 1930s, point out that one cannot ignore that our actions are shaped by cultural tools. These cultural tools (e.g., the Dashboard), are oriented towards the goal of the activity, towards others and towards ourselves. And they help to shape our cognitive structures which, among other things, allow us to know and identify our objective (*epistemic mediations to object*). Thus, focusing on students' appropriation of DCRs, the results of our study show that the processes of instrumentation and instrumentalization do not take place in isolation between the resource and the student(s) but through the mediation with different agents (e.g., interaction with tutors and resources) who regulate these processes (Fig. 4). That is, the agents mediate between students and their objectives and in turn help to shape the way they reflect on their challenge both by themselves and as a team.

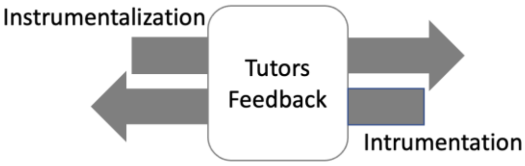

Figure 4. Student appropriation of resources

The results have implications for practice and are useful for course designers: e.g., the use and design of digital resources for providing effective feedback for CBL courses. Future research would deepen into how a DCR interacts with other resources (e.g., Teams and face-to-face sessions) as part of a broader resource system focused on providing effective feedback, and would also consider the students' comments after interacting with the DCR (e.g., likes or dislikes of some features of the Dashboard) for possible future developments.

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