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Birgit Pepin and Zeger-Jan Kock

Eindhoven University of Technology, Eindhoven, The Netherlands, b.e.u.pepin@tue.nl

In this study we used qualitative methods to investigate which kinds of resources students used, and how they used them, in two programmes: (1) Challenge-Based-Learning projects (CBL), and (2) Calculus and Linear Algebra courses (Pepin & Kock 2019). The main data collection strategy consisted of focus group interviews with student groups working on the CBL projects. Results show that students working on CBL projects used resources outside the realm of curriculum resources offered to them in traditional courses, including internet resources and digital modelling and signal processing tools. The supervisor appeared important to provide feedback, which for some students led to an iterative Actual Student Study Path. This may have implications for the development of a CBL curriculum.

Keywords: Actual Student Study Paths, curriculum resources, higher education mathematics, challenge-based learning.

INTRODUCTION

In traditional university mathematics courses, students orchestrate different resources and follow various *Actual Student Study Paths* (ASSPs) depending, amongst others, on the course organization and their preferred ways of studying (Pepin & Kock 2019). We have shown this to be the case for first year engineering students studying Calculus (CA) and Linear Algebra (LA) (ibid). Digital resources (e.g. the university's Digital Learning Environment - DLE) constitute part of the resources used by students in these courses (Pepin & Kock, 2019). However, universities of technology tend to move towards more challenge-based projects (Malmqvist, Rådberg, & Lundqvist 2015), in which groups of students work, interdisciplinary, on authentic engineering tasks.

Typically, studies on the use of resources include the curriculum resources made available or recommended as part of mathematics courses. For example, in a review study Biza, Giraldo, Hochmuth, Khakbaz, and Rasmussen (2016) have described the opportunities afforded by introductory university mathematics textbooks, and their actual use by students in traditional lecture/tutor group courses. However, in these courses there are also *social resources* (e.g. lecturers, tutors, peers) that students tap into, and *digital* and other resources mobilized by students themselves. In challenge-based courses students have to develop their own learning/study strategy, including their learning trajectories (i.e. what to do to learn). Subsequently they have to build the resources into the challenge-based project development according to their needs. Hence, we expect that student needs regarding the selection and use of resources in a challenge-based learning environment differ from those in traditional lecture/tutor group courses.

We ask the following research question: What kinds of resources were selected by students, and how did students' ASSPs unfold in CBL projects, as compared to traditional courses?

THEORETICAL FRAMES

In this study we use the theoretical frames of (a) Re-sources, (b) Actual Student Study Paths, and (c) Challenge-Based Learning for our purpose of comparing ASSPs in traditional mathematics courses versus studying mathematics in innovative approaches, such as CBL.

Several studies lean on the notion of *resource* to study what kinds of resources and materials students have access to, use, and orchestrate for their study of mathematics and engineering (e.g. Anastasakis, et al., 2017). To clarify the concept of curriculum resources, Pepin and Kock (2018) referred to mathematics curriculum resources as "all the resources that are developed and used by teachers and pupils in their interaction with mathematics in/for teaching and learning, inside and outside the classroom." Curriculum resources would thus include text resources (e.g. textbooks, teacher curricular guidelines, worksheets); other material resources, such as manipulatives and calculators; and web based/digital resources (e.g. the DLE, videolectures). Digital resources are generally distinguished from digital educational technologies (e.g. digital geometry software) (Pepin & Gueudet, 2018). General resources are the non-curricular material resources mobilized by students, such as general websites (e.g. google Scholar, Wikipedia, YouTube). Cognitive resources are the mathematical frameworks and concepts students work with. In terms of social resources, we refer to formal or casual human interactions, such as conversations with friends, peers or tutors.

Using the lens of resources, we (a) investigated students' own perceptions of how they manage their learning/studying, and (b) coined a term that linked to the patterns we observed in these perceptions. We drew on Simon and Tzur's (2004) Hypothetical Learning Trajectory approach, and other works in this field. However, when investigating students' study trajectories, we considered: (1) the alignment and orchestration of resources, not of tasks or activities; (2) the students' perspective, that is, how they actually orchestrated the resources for their own learning (and not how it was done by teachers/lecturers) and how they gave meaning to these self-created/orchestrated paths. In an earlier study we called these *Actual Student Study Paths* (ASSP- see Pepin & Kock 2019) and outlined selected study paths for the first-year courses of CS and LA.

Malmqvist, Rådberg, and Lundqvist (2015) have defined challenge-based learning (CBL) in the following way:

> Challenge-based learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, involves different stakeholder perspectives, and aims to find a

collaboratively developed solution, which is environmentally, socially and economically sustainable. (p.1)

Often mathematics is the content area where students struggle to see its value, until they arrive at an engineering problem/challenge that typically cannot be solved without mathematics. Therefore, one way to stimulate students to appreciate the value of mathematics is to frame the mathematics learning around engaging, authentic problems related to a 'real' challenge (Rasmussen & Kwon 2007). These learning environments aim not only to foster student learning, but also to promote collaboration between university, business and the public sector and to create societal and technical prototype solutions to difficult, strategic challenges. Students play a key role in these environments, not only in problem-solving, but also in driving a collaborative, multi-perspective dialogue on defining the problem to be solved. In addition to a physical arena, the CBL labs typically provide a set of methods for addressing a societal challenge, from problem identification to solution concept.

THE STUDY

In the Innovation Space (IS) of a Dutch engineering university, groups of 4-5 bachelor students worked together in multi-disciplinary teams (e.g. industrial design, mechanical engineering, innovation sciences) on a challenge, set by a stakeholder from outside the university. The projects were unstructured but the students had to fulfill Bachelor End Project (BEP) requirements of their respective disciplines. This setup provided students with opportunities to investigate and analyze an authentic situation and to develop a (prototype) solution in the form of an artefact. Different projects included various degrees of mathematics in the form of mathematical modelling and signal processing with the help of digital tools. No particular resources were stipulated/provided, except that each group had a supervisor (from one of the university departments) and an outside stakeholder, who supported the projects. Earlier, students had followed lecture/tutor group based mathematics courses (e.g. CS, LA), where they were provided with particular resources.

In our previous study (Pepin & Kock 2019) we had used a case study approach to investigate 24 students' orchestration of resources (coming from nine different engineering departments) in two first year mathematics courses in the same engineering university. In the present study we explored 6 students' use of resources for their challenge-based Bachelor End Projects.

Our data collection strategy had a similar approach as in the previous study:

- Individual and focus group interviews with four student groups working on IS projects. In two of these projects mathematical knowledge was important for the students to understand, model, or solve the problem. In this study we focus on these two groups, the *Parkinson project* and the *Garden of Resonance* project. The interviews were conducted in English, which was a second language for most students.

- Students were asked to draw Schematic Representation of their Resource System (SRRS - see Pepin & Kock, 2019), to illustrate the particular resources each student used, and how. During the interviews, students were asked to explain their resource use based on their SRRSs. The SRRSs served as a methodological tool, to help the researchers understand the use of resources.
- Selected observations in the IS environment included observations of mid-term and end-of-project presentations; observations of student working places in the IS labs; observations of supervisor meetings where the projects were discussed (including assessment).
- Examination of documents/curriculum materials provided by the university and lecturers for the students: e.g. syllabi, resources provided by the different engineering departments (mainly to understand the contexts in which students were working in the IS as compared to their 'home departments'). Moreover, we examined two final student reports.
- Informal interviews/discussions with course leaders were conducted, in order to understand the context of and the way of working in the IS.

In terms of analysis, the interviews were first transcribed and interview quotes with a reference to mathematics and mathematics resources were selected and coded. Second, student drawings were compared with their explanations and the selected quotations (within case comparison): how they explained their identification of (for them) suitable resources and the orchestration of these resources; this resulted in selected resources and self-reported study paths. Third, these self-reported study paths were compared across the cases. This resulted in particular types of study paths for the interviewed IS BEP students who referred to mathematics resources. Fourth, the findings from the previous study were compared with the results from this study, taking-into-account the context and course organization.

RESULTS

In the Parkinson project the students focused on the so-called freeze of gait issue. During a freeze of gait episode, patients unexpectedly feel as if their feet are stuck to the ground while they are trying to take a step. Patients have an increased risk of falling as a result of a freezing episode. Present research is directed at understanding the occurrence of these episodes. In the project students were working on the development of a prototype sensor to detect a freeze of gait situation.

The students realised that some of their previous courses and learning experiences were useful as cognitive resources:

> Yea, calculus physics, modelling, and … Like, you have calculus mathematics and modelling, those are very important basic skills for an engineer I think. … I think for example when you want to calculate the stride length, you have to integrate. So, then you need to have had a basic of calculus. (Int Foc C)

Students mentioned the importance of mathematics as an important tool in the project. Students C and D specifically mentioned CS, and the techniques of double integration from an acceleration to a displacement. Moreover, the students were dealing with issues of measurement errors, the filtering of signals, and analysis in the frequency domain. For this, they mastered and employed digital tools, in particular Matlab/Simulink. Student D explained the resources he used to obtain the knowledge needed for the project, as shown in his SRRS (Figure 1):

> Because the double integration was really a hard thing (…) I contacted a master student who helped me further with the Matlab and Simulink part. I also asked my own supervisor or tutor. I also got in contact with another faculty staff member, …He helped me with the sensor part, and filtering signals. …And [the supervisor] helped me a little bit, but he didn't have the time to figure it out himself. So, I was all by myself and looking it up on the internet, and YouTube videos and Matlab documents and such. (Int Foc D)

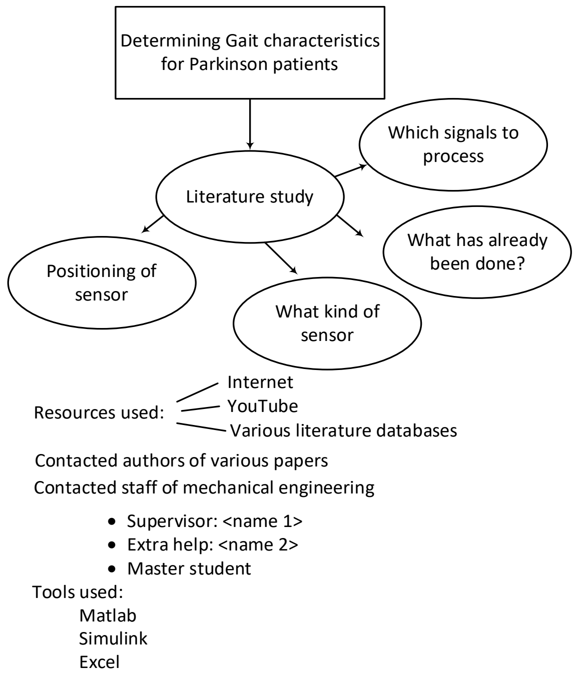

Figure 1. Student D SRRS. (Transcribed from original drawing for readability.)

From the SRRS and interviews, we identified particular self-reported study paths. for example, student D (see Figure 1) put a literature study at the centre of his work. He interacted with several social resources when he got stuck, including the authors of scientific papers, and knowledgeable peers. Student C built knowledge from university courses and knowledge he had developed following his own interests, using internet, literature, and social resources. He appeared confident that he could develop and add "another level of expertise" when needed.

In the *Garden of Resonance project* the students, under the guidance of an artist, assisted in creating a work of art consisting of huge sound scales, that made it tangible how all matter is constantly vibrating (see www.gardenofresonance.com). The students attempted to model and design sound scales producing a sound spectrum with frequencies that had a calming effect on the listener.

The students of this project appreciated the support of social resources: (a) their peers; (b) professors / supervisors; and (c) the artist originating the project:

> I helped [H] in working out a little bit of the calculations for his model. And I was not able to do that, I guess, when I didn't do any mathematics before. So, otherwise you really have to find out how the concepts work. (Int Foc V)

> Yea, and [what] she [the acoustics professor] kind of does is, she lets me go run in the wild with all the knowledge. And then tells me "It's good that you found all that, but you need to especially need to take care of that." And then I go back again, get up and do it again. (Int Foc H)

Digital mathematics tools, such as Matlab and its signal processing toolbox (e.g. Fast Fourier Transform - FFT), were important for the students to model the problem and analyse their data (see Figure 2).

Students referred to previous courses as resources for the project. However, they had wanted to see the relevance of the knowledge in those courses:

> Maybe the knowledge about that process, that takes time. (…) If I would have had my classes as I would have had now. And if I would have had my tests in a different way, in which I needed to use the knowledge that I had obtained into modelling something, or making something. But then making it by myself and not making it in a whole team that all get really specialized in one piece so that you still don't have oversight of what you are doing. That would have created a sense of, kind of a sense of how knowledge becomes. (Int Foc H)

The students explained the different ways of using (and learning) the mathematics in traditional courses and for the project:

> Like the calculus and the physics ones, those are essential. Because they actually teach you like the tools to handle some problems. But where I think like the project work, … like there would be a moment where you sit down with somebody, and actually sketch out the project. Actually, sketch out what steps you need to take, and what information you might want to research on that. (…) What the format is now [of the traditional courses], is that you get a lot of information that you might use sometimes. But because you get like information like "Here you got it." And then you don't do anything with it. "Yea, ok. I'm now just trying to pass the test, and then I'll forget it I guess". (Int Foc H)

In terms of different student study paths, we observed that student H (Figure 2) described an iterative path of developing knowledge using different material and social resources, subsequently being corrected by feedback from his professor/supervisor, after which the process started again. Students N and V drew SRRSs with categories of resources they had used, but without a specific sequence. Their categories contained curriculum materials from the university, but also social resources from within and outside the university and a range of general resources, often web-based. Digital software tools such as Matlab were important resources to shape the mathematical practice of the students and to help develop a solution to the challenge, based on the mathematical concepts involved.

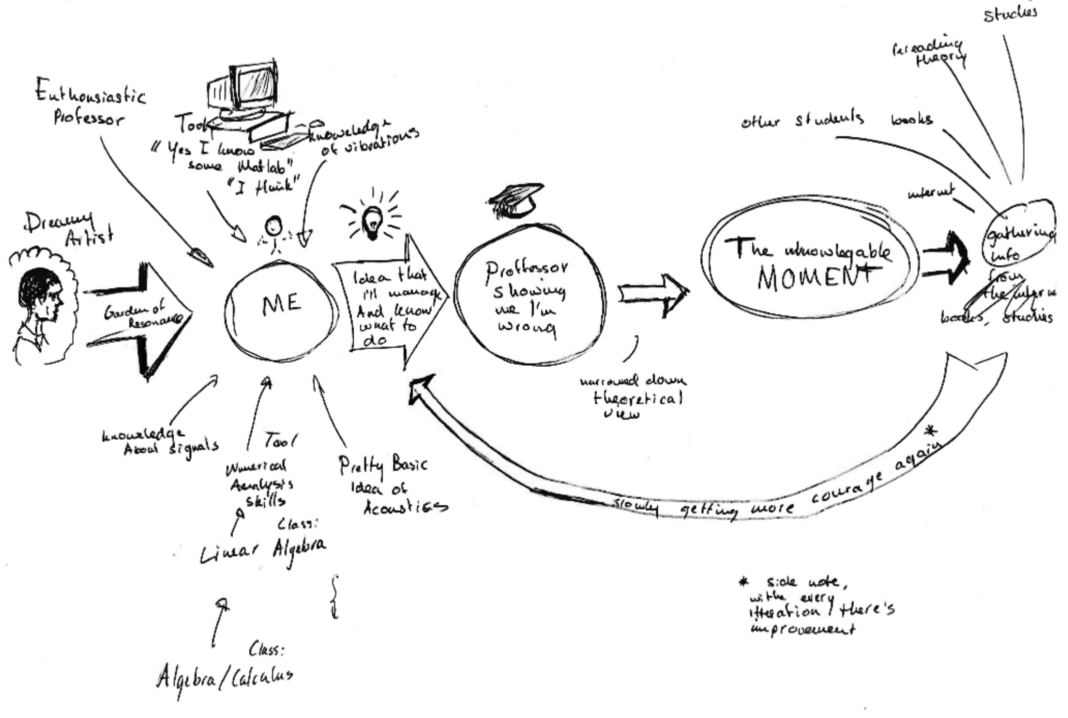

Figure 2. Student H SRRS

Compared to the first year CS and LA courses (Pepin & Kock 2019), the CBL projects had no pre-determined structure or study path. In the CBL projects the multi-disciplinary student group had to find their own ways of defining and solving the problem. Whilst the suggested resources for the CS and the LA course/s were pre-selected, and partly well-defined and aligned, there were no pre-defined resources for the CBL projects, apart from the supervisors and the peer support.

CONCLUSIONS

The findings show that in their CBL projects the students used resources other than the curriculum resources offered to them in traditional courses. These included cognitive resources, digitally accessed scientific papers, digital software tools, peers, and experts in the field. The ASSPs were either (a) iterative/cyclical and feedback based, or (b) focused on the common project goal, or (c) on the supervisor providing advice, with a combination of approaches being quite common. This was in contrast to the more sequential ASSPs, described in our earlier study, which students had used to individually master mathematical content for examination purposes. Indeed, some students mentioned the importance of the basic mathematics courses as cognitive resources. In these, the ASSP appears to have its benefits in terms of students developing confidence with particular mathematical concepts. However, the CBL ASSPs show that students need to develop confidence when dealing with uncertainties in a multidisciplinary group. For example, students experienced uncertainty when they looked for conceptual mathematics resources and digital modelling resources, to address the CBL problem. They acquired confidence with the help of the social resources at their disposal, in particular with their supervisor. An implication is that students have to be supported with CBL trained supervisors, in addition to suitable curricular, technological, and social resources. This will help them develop as self-determined, open-minded, and mathematically-knowledgeable engineers, willing and able to solve engineering challenges.

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