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Towards a better understanding of engineering students' use and orchestration of resources: Actual Student Study Paths

Birgit Pepin and Zeger-Jan Kock

Eindhoven University of Technology, Eindhoven School of Education, The Netherlands;

b.e.u.pepin@tue.nl, z.d.q.p.kock@tue.nl

In this study we explore (1) which kinds of 'resources' engineering students use in selected first year university mathematics courses (Calculus, Linear Algebra); and (2) how they use/orchestrate them for their study of mathematics. Using a case study and mixed methods approach, we found that in the large Calculus course students followed various study paths. Moreover, it appeared that in such courses students used/included human and social resources extensively. In the smaller Linear Algebra course students could follow the study path established by the lecturer/course designer, with all resources provided for students to pass their examinations. At the theoretical level, we coined the term Actual Student Study Path to describe their self-reported ways of how they identified and orchestrated their chosen resources for their study of the mathematics.

Keywords: Student use of resources, university mathematics education, actual student study path/s.

Introduction

In most western (engineering) universities students now have access to a plethora of resources, both digital/online resources and 'traditional' curriculum resources, such as textbooks, readers (course textbook/set of materials prepared by the lecturer), worksheets, provided by the university and by lecturers. In particular in large first year courses (e.g., Calculus), students are typically expected to use and blend the available resources according to their individual needs, to support their learning. The rationale for our study is that, in times where students have access to almost limitless learning resources online, it becomes increasingly important to understand which resources are preferably (and beneficially) used by students from the ones on offer, and how they orchestrate them for their study of mathematics. This, in turn, is likely to inform the designers and teachers/lecturers of mathematics courses in their efforts to enhance their courses.

The use of particular curriculum resources by teachers and students in higher education mathematics has been subject of current research. In a recent review study (Biza, Giraldo, Hochmuth, Khakbaz, & Rasmussen, 2016), the opportunities afforded by introductory university mathematics textbooks and the actual use made of these curriculum materials by students are described. Anastasakis, Robinson, and Lerman (2017) investigated the different types of tools ('external' to the university, and 'internally' provided resources) that a cohort of second year engineering undergraduates used. Their results showed that although to some extent students used resources external to their university, their practices were dominated by tools that their institution provided. The students in their sample chose certain tools mainly because these enabled them to pursue their examination-driven goals. Specifically, the use of visual resources (e.g. online lectures) has been studied by Inglis, Palipana, and Ward (2011). Using the Documentational Approach to Didactics, Gueudet (2017) investigated mathematics teachers' interactions with resources at university, and Gueudet and Pepin (2018) explored how Brousseau's (1986) Didactic Contract can

be seen through the lens of the use of curriculum resources. Whilst the learning of Calculus (CS) has been studied extensively (e.g. Bressoud, Mesa, & Rassmussen 2015), Linear Algebra (LA) learning has had less attention (e.g. Grenier-Boley 2014).

However, we note here that relatively little research is available on the broad range of resources available to first year university students to learn the mathematics, and moreover how students actually orchestrate the resources in order to study mathematics. Typically, studies include the curriculum resources made available or recommended as part of mathematics courses (e.g., textbooks), but there are also *social resources* (e.g. lecturers, tutors, peers) that students tap into, and digital and other resources mobilized by students themselves. Inglis et al. (2011) suggest that students might need explicit guidance on how to combine the use of various resources into an effective learning strategy. Before this guidance can be given, more in-depth information on students' actual use of resources is needed. Hence, we ask the following research question:

How do first year engineering students identify and use the available resources for their study of Calculus and Linear Algebra in their first year at university, and what kinds of paths do students describe?

Theoretical frames/literature review

The lens of resources

Leaning on the Documentational Approach to Didactics (e.g. Trouche, Gueudet, & Pepin, 2018), in this study we use the notion of *re-source/s* that students have access to and interact with in and for their learning. We assume that the ways university students learn the mathematics is influenced/shaped by their use of the various resources at their disposal. By *use of resources* we denote, for example, which resources students choose (amongst the many on offer) and for what purpose (e.g. revision); the ways they align and orchestrate them (e.g. first lecture then checking the textbook); which ones seem central to achieve particular learning goals (e.g. for weekly course work, for examinations, for their engineering topic area). However, we do not address the specific learning of CS and LA, that is how students interact with particular (e.g. cognitive) resources to learn particular topic areas in CS and/or in LA.

Gueudet and Pepin (2018) have coined student resources as anything likely to re-source (“to source again or differently”) students' mathematical practice, leaning on Adler's (2000) definition of mathematics re-sources, in Adler's case used by teachers. In this study, following Pepin and Gueudet (2018), we distinguish between (1) material/traditional text/curriculum resource (including digital resources); and (2) human/social resources. As to (1) material/traditional text/curriculum resources: a further distinction has been made between (a) curriculum resources (those resources proposed to students and aligned with the course curriculum), and (b) general resources (which students might find/access randomly on the web). Curriculum resources are developed, proposed by teachers and used by students for the learning of the course mathematics, inside and outside the classroom. They may include text resources, such as textbooks, readers, websites and computer software, to name but a few. General resources are the non-curricular material resources mobilized by students, such as general websites (e.g. Wikipedia, YouTube). (2) In terms of social resources,

we refer to formal or casual human interactions, such as conversations with friends, peers or tutors/lecturers.

Actual student study paths

The research literature in mathematics and science education shows many different terms and concepts linking to student study paths, often associated with instructional theory and curriculum design, such as Hypothetical Learning Trajectory (HLT) (Simon, 1995); Learning Trajectories/Progressions (Lobato & Walters, 2017); or, Learning Trajectories in mathematics education (Weber, Walkington, & Mc Galiard, 2015). Whereas some of the approaches focus primarily on learners (e.g. Lobator & Walters, 2017), Simon's (1995) HLT approach includes instructional supports for learning and was originally conceived as part of a model of teachers' decision making. Simon and Tzur (2004) later highlighted the importance of and principles for selecting tasks that promote students' development of more sophisticated mathematical concepts. Building on this work, Clements and Sarama (2004) define learning trajectories as

descriptions of children's thinking and learning in a specific mathematical domain and a related, conjectured route through a set of instructional tasks designed to engender those mental processes or actions hypothesized to move children through a developmental progression of levels of thinking, created with the intent of supporting children's achievement of specific goals in that mathematical domain. (p. 83)

Whilst recognizing this important work, it is clear that we have to define what we mean by student study paths for our purpose: first, when using the lens of resources to investigate students' study paths, we look at the alignment and orchestration of resources, and not at the actual tasks or activities and how students develop understandings of mathematical concepts; second, we view this from the students' perspective, how they actually orchestrate and align the resources for their own learning, and how they give meaning to these self-reported paths. We call these *Actual Student Study Paths*.

The study

Using a case study approach, we explored two first year mathematics courses in a Dutch engineering university: Calculus (CS) and Linear Algebra (LA), as our cases.

LA was taught to one group of approximately 130 students, mainly mathematics and physics students. The LA course was organized with four hours of lectures per week, and four hours of tutorials (in groups of approximately 30 students). The learning aims were described as the acquisition of mathematical skills, and to help students develop the skills and appreciate the importance of correct mathematical communication, including writing formal proofs. Completing a mathematical writing assignment was part of the course requirements to reach this aim. According to lecturers, the purpose of LA was to prepare students for higher mathematics (used in the mathematics and physics courses).

CS was taught as an obligatory subject to approximately 2000 students, in 6-7 groups of 300 students each (all types of engineering). The CS course was organized with six hours of lectures and one hour of tutorials (in small groups of approximately eight students). It was also differentiated at

three levels (A, B, and C), according to perceived level of difficulty and with varying level of emphasis on formal aspects of mathematics (e.g. proof). The aim of the CS course (according to lecturers) was to provide students with a basic set of mathematical/computational tools they could subsequently use in their engineering studies and in their future work as engineers.

In terms of participants, in total 24 students participated in the study; all of them 'opted in' after a general mail to all CS and LA students: 18 CS students, involved in nine different engineering programs and all taking the B level CS course; 1 CS student who dropped out of university; 5 LA students, all studying for the applied mathematics engineering course. In terms of background, of the interviewed CS students 15 came from secondary schools in the Netherlands, three came from other educational systems.

For this paper we used data from the following data collection strategies:

- Individual and focus group interviews with students (24): 19 CS + 5 LA. The CS students were interviewed in four focus groups, and one individual interview. The LA students were interviewed in two groups of two, and one individual interview.
- CS students' drawings (see example Figure 1): students were asked to draw Schematic Representation of Resource System (SRRS - see Pepin, Xu, Trouche, & Wang, 2017) during the interviews, 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 were a methodological tool, to help the researchers better understand student use of resources.
- Interviews with course designers/lecturers and tutors (of the CS and LA courses): 3CS + 2LA.
- Selected observations of CS and LA lectures and tutorials, and examination of documents/curriculum materials provided by the university for the students, such as syllabi, textbook/s, reader/s, and lecture videos (mainly to understand the context in which students were working).

In terms of analysis, the interviews were first transcribed and interview quotes were coded using ATLAS-ti software. The codes were based on our knowledge from the literature (e.g. concerning the different curriculum resources and their use) and on our knowledge about student approaches to learning mathematics. Second, student drawings were compared with their explanations (within case comparison): how they explained their identification of (for them) suitable resources and the orchestration of these resources; this resulted in self-reported study paths. Third, these self-reported study paths were compared (across case comparison), and this resulted in particular types of study paths. In another step, the findings from CS and LA were compared, also taking into account our knowledge of the context and course organization.

Results

Overall, students used different/additional resources in the two courses, and they used the available resources differently for LA than for CS: (1) Basically, all LA curriculum resources offered/provided were used, and students worked with them according to the lecturer's guidance. (2) The CS resources seemed to be a large bag of 'tools', a 'pile of bricks', that the students could

pick from (according to their needs) and use for their learning. However, how students could orchestrate and align the resources for the learning of CS was not clear. These differences appeared to be related to (a) the size and student audience of the courses (130 students in LA; 2000 in calculus), and this, in turn, was connected to different organizations of the courses (4 hours lecture and 3 hours tutorials in LA; 6 hours lecture and 1 hour of tutorial in calculus); and (b) the organization and alignment of the resources with the assessment/tests. For example, there was a clear intended (by the lecturer) learning trajectory in LA, with exercises aligned with the examinations. Students mentioned that if they worked according to/with the reader and did “all exercises in the reader”, and the obligatory weekly assignments, they could expect to pass the examination. In the CS course, many support tools were proposed (e.g. on the web, in print), with many exercises and tasks that, according to the students, were not always clearly aligned with the examinations. Students said that it was not possible to do all exercises, read all materials provided, and they often had considerable difficulties choosing from the immensity of resources provided.

From the interviews based on students’ drawings of their resource system, we could identify several study paths, which were the paths students perceived/drew when we asked them which resources they used, the importance of those resources (their role with respect to their perceived study paths), and how they orchestrated them for their learning. The study path of the LA course appeared to be relatively traditional and most students followed it: students could identify core resources (e.g. the lecture, the reader, past examinations, weekly tests), and a particular blending of the different resources was recommended by the lecturer. This would help students to understand the weekly coursework and to pass the final examinations. In addition, students had time to work together (in tutorials), and they also used human resources (e.g. peers, tutor/s, lecturer) during that time. In this course the number of tutorials was balanced as compared to the number of lectures (4 + 4).

In contrast, the students on the CS course outlined several study paths, based on their individual preferences and experiences, and for each path different resources came into play, and different core resources were described. For example, in the interviews based on their drawings, only two students put the lecture as a center point for their learning. For others, it appeared that the lecture was for information only of what students had to learn: “If I hear them talk about it, it’s easier for me to revise/practice when I’ve already seen it, heard about it” (see Joanna’s¹ drawing in Figure 1).

¹ All names are pseudonyms

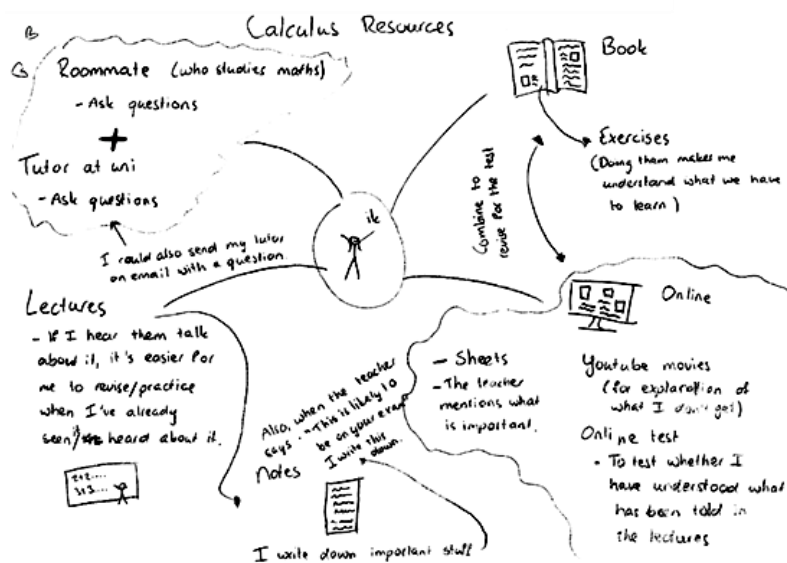


Figure 1: Joanna's drawing of her resource system

At the same time, either the lecture or lecture notes were mentioned by all students as a supporting resource for their learning of CS. Interestingly, a large number of students pointed to human resources, in particular their friends and peers, and the tutor, as resources they often used. As perhaps expected, books and tests/quizzes/exercises were mentioned as a huge help, and the digital resources (e.g. YouTube; Khan Academy) seemed to gain importance compared to high school. Altogether, the CS study paths showed a complex picture of students using a mixture and ever-increasing number of external resources, in particular of human and digital nature. Due to the interviews based on the SRRSs, we could identify a small number of (for students) 'productive' study paths that students self-reported upon. What made a study path 'productive' was that it allowed the students to orchestrate the different resources around a particular focus, in such a way that the students felt the demands of the course could be met.

The study paths we present here had different foci: (1) tests and examinations, weekly homework; (2) lecture; (3) friends and social media; and (4) understanding.

- (1) For most students the *weekly homework, tests and examinations* were the focal point, hence they described the resources that helped them to solve the associated tasks (e.g. "last resort professor"). Some students described a real trajectory of how they prepared for solving particular tasks or homework, and for passing tests and examinations.

- (2) Selected students chose the *lecture* as focus:

Dirk's path: from lecture → tests → tutor hour & old exams → YouTube/Khan academy → homework ("reading text" & "do it")

Naomi's path: from lecture (every week) → tutor time → homework every week → on-course extra questions & weekly quiz → discussion with friends → "my own comments" /writings to prepare for exam.

- (3) Example of *human resources and social media* as focus:

Rebecca's path: from "human resources" (at center) - first friends & summary chapters (book)/exercises & weekly homework → lecture "for orientation & overview, not in depth" (video lecture "only if I missed an essential") → Matlab "own curiosity & personal interest" → Tutor hour (falling asleep).

Jop's path: social media at the center

- (4) Example of students who differentiated between resources used for different kinds of learning: Melissa's path: she made a distinction between (a) procedural understanding: solving exercises/passing exams (resource/s: e.g. tutor, weekly quiz, online practice test), and (b) conceptual understanding: "if you do not understand underlying thought/concept" (resource: YouTube).

Conclusions

From our findings, it can be seen that students' use and orchestration of resources were largely shaped by the course organizations. In one case (LA), the lecturer/course designer provided a 'home-made' reader (no other textbook was needed) which provided all necessary and important information in terms of the mathematics (e.g. concept explanation) and the most relevant exercises. All other curriculum resources were aligned with the reader, and in line with the learning objectives/course aims (as described in the course guide booklet). In addition, the lecture and tutor hours afforded opportunities to discuss problems and ask for help from the lecturer/tutors, or indeed from peers. In the case of CS (at the B level), a commercially produced textbook was used, and several lecturers and tutors were involved. Moreover, in terms of opportunities for learning, the lectures were foregrounded (6 hours), with only one hour of tutor support. In addition, several resources had been prepared and were provided within the course web environment, as a support for students. However, it appeared that in this environment students looked for their own ways to use the affordances of the resources on offer (e.g. opportunities offered by textbooks and other resources, see Biza et al., 2016). They sometimes had difficulties navigating their ways around the different resources, benefitting from the quality of the resources on offer, with little (time and) guidance from the tutors. There were many (and new) resources to choose from, and the "didactic contract" (Gueudet & Pepin, 2018) was not clear to them; hence, students created their own actual study paths.

Based on our results we claim that it is not sufficient to provide a plethora of curriculum resources, may they be digital, traditional text or human resources, but that serious consideration should be given to how students might work with these resources, and orchestrate them into productive *Actual Student Study Paths*. In addition, it is advisable to help, perhaps even to train students how to develop such study paths, and these might be different from one subject to another (even from one mathematics course to another). This, we claim, is the responsibility of the lecturer/teacher/course designer. Such course design would involve purposeful design, including the development of particular (intended) study paths, and the design of particular resources supporting such paths. Simply providing access to curriculum resources does not seem to help students to orchestrate the resources on offer, neither to develop their individual study or learning strategies, but may rather confuse and overwhelm them (due to the immensity of resources on offer), and drive them towards

“learning for the test”. As Anastasakis et al. (2017) claim, under such conditions “students use the most popular resources [and] they aim mostly for exam-related goals” and use “certain tools because these enable them to pursue their exam-driven goals” (p. 67).

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