STUDENTS' CHOICE AND PERCEIVED IMPORTANCE OF RESOURCES IN FIRST-YEAR UNIVERSITY CALCULUS AND LINEAR ALGEBRA

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With a plethora of (digital) resources available to first year engineering students studying mathematics, it becomes increasingly important to understand which resources are preferably selected by students. In this study we investigated (1) which student clusters can be distinguished in the perceived importance of resources to study first year mathematics courses; and (2) how these clusters can be related to selected student characteristics and the perceived importance of resources at high school. We conducted a survey among Calculus and Linear Algebra students (N=403) at a Dutch university of technology. In terms of data analysis, we used "community analysis" based on a social network approach. Results showed that three clusters could be identified; these are portrayed and discussed. In one cluster interactive digital resources for formative assessment were considered of some importance, while students in the other clusters preferred traditional curriculum resources.

Keywords: student resources; university mathematics; community analysis; student cluster

INTRODUCTION

Undergraduate university students have a plethora of digital and traditional resources at their disposal to study mathematics. Several studies have addressed undergraduate university students' learning with and use of particular resources to study mathematics (Anastasakis, Robinson, & Lerman, 2017; Howard, Meehan, & Parnell, 2018). These studies focused on the use of resources provided by the university, such as textbooks, live lectures, online lecture videos and mathematics support centres. Anastasakis et al. (2017) noticed a lack of empirical studies on the full range of resources students use to learn mathematics (those provided by the university and those selected by the students themselves). They studied this range of resources, in relation to the students' goals, among second year undergraduate engineering students. In this paper, we report on a survey study on the selection and perceived importance of digital and traditional resources, conducted among first-year engineering students at a Dutch university of technology. We identified groups of students across different mathematics courses who held similar views on the resources they considered the most important. Moreover, we compared selected student characteristics in these groups (e.g. importance of high school resources).

We expected that different mathematics courses, in terms of student body and organizational context, may lead to a different selection and use of resources. Therefore, we studied the resources, and their importance, in first term Calculus (CS) courses, offered to all first-year students at three different levels (CS A, B and C), and a Linear Algebra (LA) course, offered only to mathematics and physics students, in a first-year Bachelor College programme. We also investigated, retrospectively, the selection of resources and their importance in high school, because high school experiences might have had an impact on first-year engineering students' approaches to learning (Cook & Leckey, 1999).

In this paper, we first outline the theoretical frame of "resources" (and their use), we review research literature related to "high school to university transition", and student selection of resources, as lenses to investigate the role of resources in students' mathematics learning. Second, we describe our methodology, data collection strategies, and methods of data analysis. In the third section we present our findings and discuss our results, followed by, fourth, the identification of potential implications for the practice of university mathematics learning and teaching.

THEORETICAL FRAMEWORK

The lens of resources

We assume that the ways university students study mathematics are influenced and shaped by their use of the various resources at their disposal. Gueudet and Pepin (2018) have defined 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" (used by teachers). This definition emphasizes that resources are not limited to material artefacts. Associated with the "resources approach to mathematics education" (Trouche, Gueudet, & Pepin 2019), Pepin and Gueudet (2018) have proposed a classification of (curriculum) resources in order to understand and discuss their selection and use. For this paper, we distinguish between (1) *curriculum resources*, which are proposed to students and are aligned with the course curriculum, (2) *general resources*, which students might find/access on the web, and (3) *social resources*. The traditional textbook belongs to the curriculum resources, and so do digital documents (e.g. lecture notes) and interactive digital resources (e.g. digital homework and practice systems). Interactivity allows digital curriculum resources to play a role in personalized formative assessment practices, helping students to understand their progress and take the next step in learning (Pepin & Gueudet, 2018). In terms of social resources, we refer to formal (e.g. tutor-student conversations) and casual human interactions (e.g. conversations with friends, or social media contacts). At times it is difficult to distinguish between curriculum and social resources: for example, live lectures and tutor group meetings are proposed to students and aligned with the curriculum, but they clearly also have a social component.

RELATED RESEARCH

Transition from secondary to tertiary education

In terms of mathematics learning, the transition from high school to university is challenging for many students (Pepin, 2014). High school mathematics prepares students to work on a precise and narrow set of tasks, for which they follow the teacher or use worked examples in textbooks for guidance. Hence, completing many exercises appears to lead to success in tests and examinations (Gueudet, 2008). However, in the transition to university, students experience an number of discontinuities (Artigue, 2016), and a change in the (implicit) rules and expectations related to studying and learning (Pepin, 2014). In particular (a) the mathematical content is introduced faster; (b) more autonomy is expected; (c) the levels of generalization and abstraction are higher; (d) the mathematical approach is more formal; and (e) the institutional cultures at high school and university are different (Artigue, 2016; Gueudet, 2008). Moreover, at university students have to autonomously manage the various resources to learn mathematics, but high school does not prepare them well for this task (Williams, Black, Davis, Pepin, & Wake, 2011).

Student selection of resources

Several studies have focused on student selection among a limited number of resources (e.g. the choice between live lectures and video recordings). Howard et al. (2018) studied first-year Business

Studies students' choices to attend live mathematics lectures, watch short online videos, or combine the two. They identified four usage patterns: students focusing on the videos, students focusing on the live lectures, dual users of videos and live lectures, and switchers. Students with a weaker mathematical background tended to belong to the group of dual-users. However, students may need guidance to combine the use of various resources into an effective study strategy (Inglis, Palipana, Trenholm, & Ward, 2011).

Regarding the selection among a wider range of resources, Anastasakis et al. (2017) made an inventory of the resources selected and used by students when studying mathematics modules, and related these to student learning goals. Participants in this study predominantly focused on success in examinations, and selected resources accordingly. The most widely used resources were those that the university provided, and students' own notes. The use of mathematics textbooks was specifically linked to the study of worked examples, which were said to help students to prepare for examinations.

In our earlier qualitative and quantitative studies (Kock & Pepin, 2018; Pepin & Kock, 2019) we identified the resources considered important by students (a) at the end of high school, (b) at university in three CS courses, and (c) at university in an LA course. At high school a limited range of mostly traditional resources was considered important by the students. These included first of all the textbook, followed by worked solutions, past exam papers, the graphical calculator and the teacher. From focus group interviews we identified a number of *actual student study paths* for resource use at university, that is, ways in which students arranged and orchestrated the resources to study mathematics. Students' perceived importance of resources at university had similarities with that at high school, although general web-based resources gained some importance (e.g. Kahn-academy videos). Moreover, we identified differences between the importance of resources in the four courses (3 CS, LA), which to some extent could be explained by the nature and organization of these courses. However, from these studies it did not become clear if there were clusters of students, characterized by similar views on the importance of resources.

Research questions

We propose the following research questions for this study:

1. What student clusters can be distinguished in the perceived importance of resources to study first-year mathematics (CS and LA) courses?

2. How can these clusters be related to selected student characteristics and the perceived importance of resources at high school?

METHOD

Context

The study took place at a university of technology in the Netherlands, with a student body of approximately 13,000 engineering students. The university offers 15 bachelor courses related to technology and engineering. We collected data on the importance of resources in two first-year first term courses: Calculus (CS); and Linear Algebra (LA). CS was offered to all first-year students (approximately 2000), and was differentiated at three levels of increasing perceived difficulty and formality of mathematics: CS A, CS B and CS C, selected according to students' majors and preferences. LA was only taken by mathematics and physics students (approximately 150). The university offered a Digital Learning Environment (DLE), digitally giving access to text resources (e.g. lecture notes), as well as access to videotaped lectures and, in the case of Calculus, access to an interactive homework/practice system for formative assessment.

Data collection strategies

A survey was designed and administered to all first-year engineering students of the university at the end of the first quartile of the 2017-2018 academic year. The survey was administered on paper to selected students in one of the final first term lectures and electronically to the remaining first-year students. We received 446 responses in total, of which 403 responses remained (after removing largely incomplete responses).

The survey contained items on the frequency, importance, and use of resources for studying mathematics (a) at high school, and (b) at university. In particular we asked students what they considered the five most important resources to study mathematics, from a list of relevant resources based on the course catalogue, interviews with lecturers and students, and the literature (e.g. Anastasakis et al., 2017). The list included traditional and digital curriculum resources, digital general resources and social resources. Additional information (age, gender, mathematics course, high school mathematics results, mathematics self-efficacy at university) was collected to relate the data on resources to student characteristics. The items were partly amended from surveys used in the Transmath study in the UK and Norway (e.g. Pampaka, Pepin, & Sikko, 2016).

Analysis

To investigate if any clusters were present in the perceived importance of resources across the university cases, we followed the community analysis procedure described by Brunetto (2017), based on a social network approach. We chose this method, because it is said to produce meaningful results in spite of the distribution of the survey responses, which did not allow for the classical forms of cluster analysis. To our knowledge, this application is relatively new in an educational context (Brunetto, 2017), although it is recognized as a powerful tool in other contexts, such as criminal networks (Calderoni, Brunetto, & Piccardi, 2017). The method consisted of three steps.

First, we created an undirected, weighted network between students based on their responses to the item concerning the five most importance resources. We emphasise that we did not consider this student network as a real network of social relations, but as a tool to analyse commonalities among students based on their survey responses. In the network, students were represented as nodes. We created a link between two nodes (i.e. two students), if they chose the same resource; the more important the resources were to the students, the stronger the link. To be precise, the weight of a link was calculated as follows: (a) the five most importance resources selected by a student were given a score between 5 (most important) and 1 (least important); (b) for the same resources selected by two students, the corresponding scores were multiplied; (c) the weight of the link between the two students was calculated by summing the multiplied scores. Responses to other items in the survey, such as the students' mathematics self-efficacy, represented further attributes of the nodes.

Second, we looked for possible clusters in the network, that is, groups of nodes characterised by comparatively large internal connectivity (Calderoni et al., 2017). In general terms, a cluster consists of nodes that tend to connect more with the other nodes of the same cluster than with the rest of the network. In our context, a cluster would include students with a similar pattern concerning the importance of resources. We adopted the Louvain method (see Calderoni et al., 2017) to identify clusters (or communities) of students according to their responses to the survey. The Louvain method partitions the set of nodes based on the optimization of a particular quantity, the network modularity Q. Given a partitioning of a network into clusters ($C_1,C_2,\dots,C_k$), the modularity Q is by approximation the (normalized) difference between the total weight of links internal to the clusters C_k, and the expected value of such a total weight in a randomized null network model suitably defined. We evaluated the quality of the clusters that were identified by the Louvain algorithm by calculating the persistence probability α_k, which measures the cohesiveness of the cluster C_k. The significance of α_k is identified by the standard z-score (Calderoni et al., 2017). In this way, we were able to identify clusters in the network, as well as their "goodness".

Third we compared the average perceived importance of resources and other student characteristics in the resulting clusters using Analysis of Variance (ANOVA). The statistically significant differences between variables made a qualitative characterization of the clusters possible.

RESULTS

Community analysis and identification

The community analysis, employed on this network, identified three clusters (or communities). These were non-trivial because of their persistence probability α_k around 0.4 and high z-score (see Table 1).

Table 1. Details of the community analysis

Cluster	Number of students	α_k	z-score
C1	93	0.38	29.26
C2	138	0.48	25.58
C3	172	0.49	12.52

Using ANOVA and Games-Howell post hoc tests, we compared the mean perceived importance of resources among the three clusters to characterize them, confirming their non-triviality. Table 2 shows only the significant differences resulting from this comparison. In particular, the last column informs about the statistically significant characterization of the three clusters.

Table 2. Comparison of mean perceived importance of resources among the three clusters

	Mean (SD); scale 0 – 5			
Resource	C1	C2	C3	Post Hoc test
Textbook	1,56 (1,7)	4,36[a] (0,87)	1,12 (1,3)	C2 > C1 & C3
Worked solutions	0,86[a] (1,3)	2,13 (1,6)	1,92 (1,8)	C1 < C2 & C3
Materials created by the teacher (e.g. lecture notes)	1,00 (1,6)	1,00 (1,5)	2,77[a] (2,2)	C3 > C1 & C2
DLE, homework and practice environment	0,55 (1,3)	0,67 (1,4)	1,35[a] (1,9)	C3 > C1 & C2
Past examinations	0,71[a] (1,3)	1,42 (1,7)	1,88 (1,9)	C1 < C2 & C3
General online videos[b]	0,35[b] (1,0)	0,76 (1,5)	0,70 (1,4)	C1 < C2 & C3
Teacher explanation of content	3,91[a] (1,4)	0,19 (0,5)	0,27 (0,7)	C1 > C2 & C3
Teacher explanation of problem solving	2,26[a] (1,9)	0,20 (0,7)	0,30 (0,8)	C1 > C2 & C3
Working together, outside class	0,19[a] (0,8)	0,40 (0,9)	0,60[a] (1,3)	C1 < C3

Notes: [a]: p<0,01 in post-hoc test, [b]: p<0,10

Cluster 1 (C1) students considered *teacher explanation of content* and *teacher explanations of problem solving* as the most important resources whilst *worked solutions*, *past examinations*, and to a lesser extent *general online videos* were less important, than in the other clusters. Students in cluster 2 (C2) considered the *textbook* as the most important resource. In cluster 3 (C3) *materials created by the teacher (lecture notes), worked solutions*, *past examinations* and the university's *DLE (homework and practice environment)* were perceived as the most important resources.

Further characterisation of the clusters

The network was created based on students' perceived importance of resources. In the subsequent analysis we exploited other characteristics of the cluster members to enhance the picture. We compared the different clusters in terms of the *different courses*, the *background variables* measured in the survey, and the *relative importance of resources at high school*, measured retrospectively.

The clusters consisted of students from all four mathematics courses (see Table 3), with the exception of C2 among LA students. This is understandable, as C2 consisted of students who considered the textbook as the most important resource, and in LA no textbook was used.

In the courses CS A and CS C, more students belonged to C2 (textbook oriented) than to C1 (lecturer oriented) and C3 (oriented to teacher created materials and DLE). In CS B, more students belonged to C3 than to the other clusters. LA students belonged to C1 and C3 in equal numbers. In general, C3 was the largest cluster, followed by C2 and C1.

Table 3. The three clusters and the mathematics courses

Course	C1	C2	C3	Total
CS A	19	50	18	87
CS B	44	77	126	247
CS C	7	10	5	22
LA	23	1	23	47
Total	93	138	172	403

The membership of male and female students to the different clusters was investigated per course because the distribution of male and female students across courses was not equal. We used SPSS Crosstabs and Chi-Square tests. No significant differences were found, except for the case of CS B, where 23% of male (more than expected), and 11% of female students (less than expected) belonged to C1, while 44% of male (less than expected) and 60% of female students (more than expected) belonged to C3 ($\chi^2(2)=8{,}27$, $p=0{,}016$). No significant differences were found between the clusters regarding mathematics self-efficacy or high school pedagogy.

The most important resource at high school for the students in all clusters was the textbook. Based on ANOVA, the students in C1 reported a significantly higher importance of teacher explanations at high school than the other clusters ($p<0{,}01$). They reported a significantly lower importance of past exam papers than the other clusters ($p<0{,}05$). No significant differences were found regarding the importance of other resources at high school. The students in C2 perceived less meaningful connections in the university learning environment than the other clusters ($p<0{,}01$). However, this was only due to the CS A members of this cluster.

CONCLUSION AND DISCUSSION

To answer the first research question, we found that three student clusters could be distinguished: a cluster of students who considered explanations by the lecturer the most important resource (C1, the smallest cluster), a cluster who considered the textbook the most importance resource (C2), and a cluster who considered other curriculum materials (teacher materials, worked solutions, past examinations, the DLE) the most important resources (C3, the largest cluster). Members of all clusters were present in the four courses, with the exception of C2 in LA (as in LA no textbook was used). However, different proportions of students belonged to the three clusters in the different subjects. Concerning the second research question, we found that concerning teacher explanations, members of C1 on average perceived these as more important in high school than members of the other clusters. Moreover, we found that relatively more female CS B students belonged to C3, and less to C1, while relatively more male CS B students belonged to C1 and less to C3. Digitally provided materials (e.g. lecture notes, past examinations) had some importance, in particular in C2 and C3. However, the DLE did not rank among the most important resources (though relatively more important in C3). In an earlier study, we found that for some students the formative assessment provided by the DLE was not sufficiently aligned with the final exam (Pepin & Kock, 2019).

The results provide quantitative support for the claim that students choose different study paths to study mathematics at the start of university (Pepin & Kock, 2019), that is, they put different resources at the centre of their approach. Selected students who relied on the textbook at high school, did so also at university. The university lecturer took an important role for those students who considered the teacher explanations as relatively important in high school. Apparently for these students their high school study practices remained the default position. Another group relied on new resources in the university environment: the teacher materials, and to some extent the DLE. However, membership of C2 or C3 could not be related to the selected student characteristics we included in our survey. Further research needs to clarify if other student characteristics are relevant, or if the selection of resources at the start of university is a process with little predictability, due to the new situation students encounter at university and the plethora of resources available.

The results provide quantitative support for the claim that curriculum resources and course organizations effect student study practices (Pepin & Kock, 2019), as the distribution of cluster membership varies per course. Further research among a larger group of students is needed to investigate differences within courses between different lecturers or student majors. Such differences might also explain the different cluster memberships of male and female students in CS B, for which we now have no further explanation.

The most important resources for members of C1 and C2 were traditional curriculum resources (Pepin & Gueudet, 2018), while members of C3 valued resources belonging to a more blended approach. In many cases the resources mix to study mathematics does not appear optimal (Inglis et al., 2011). It is relevant to monitor the changes over time in the selection and importance of resources, as digital resources receive more emphasis and course developers begin to guide students on resource selection.

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