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Riikka Kangaslampi
Tampere University, Finland

Johanna Rämö
University of Eastern Finland, Finland

Petri Nokelainen
Tampere University, Finland

Jani Hirvonen
Tampere University, Finland

Elina Viro
Tampere University, Finland

Simo Ali-Löytty
Tampere University, Finland

Vikke Vuorenpää
Tampere University, Finland

Terhi Kaarakka
Tampere University, Finland

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Riikka Kangaslampi, Johanna Rämö, Petri Nokelainen, Jani Hirvonen, Elina Viro, Simo Ali-Löytty, Vikke Vuorenpää, Terhi Kaarakka

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Abstract

This study investigates the relationship between first-year higher education students' (N = 405) approaches to learning and academic performance on engineering mathematics courses. In addition, we study what combinations of approaches to learning students apply, how these combinations change over time, and whether they are linked to the pedagogical design. The students were divided into an intervention group taught with an instructional model based on flipped learning, and a control group taught with a modern lecture-based model. The students' approaches to learning were measured five times during one academic year. Multiple linear regression, dominance analysis and cluster analysis were used in analyzing the data. We found that a high level of organized studying and a low level of surface approach to learning were positively linked to exam performance, but a deep approach to learning was not linked to performance. In the last three measurements, the students in the intervention group were overrepresented in the cluster with the most desirable profile in terms of approaches to learning. In the long term, flipped learning seemed to foster deep approach learning and organized studying better than the lecture-based model.

Introduction

Mathematics is a key ingredient in engineering, and engineering students should build a solid mathematical background during their first years at university (Alpers, 2020). The teachers of engineering subjects expect their students to obtain the mathematical competence to understand and use mathematics in the contexts of physics and engineering, preferably before attending engineering courses (Alpers, 2020; Faulkner et al., 2019). Therefore, in many countries, the beginning of engineering studies focuses rather heavily on mathematics to achieve this competence, even though mathematics is not the subject the students have chosen to study and might feel unmotivating and irrelevant to them (Faulkner et al., 2019).

Since mathematics has such a prominent role in engineering education and students' motivation to study it might be low, it is important to consider the quality of learning that basic mathematics courses provide for engineering students. One widely used viewpoint to quality in learning is students' approaches to learning (Marton & Säljö, 1976; Parpala & Lindblom-Ylänne, 2012). They are the lens through which we view students' learning in this study. Students' approaches to learning describe the intentions that students have when approaching a learning situation and are typically divided into the deep approach to learning and the surface approach to learning alongside organized studying. Approaches to learning are linked to academic achievement. In many studies, the deep approach and organized studying have been shown to be favorable for high-quality learning outcomes, whereas the surface approach, in general, is not desirable (e.g., Asikainen et al., 2014; Öhrstedt & Lindfors; 2019; Rytkönen et al., 2012).

Learning environments have been found to be linked to students' approaches to learning. Student-centered instruction has been shown to support the deep approach to learning (e.g., Dolmans et al., 2016; Lahdenperä et al., 2019; Wilson & Fowler, 2005), but in some studies, it has been noticed that it can also encourage students to apply the surface approach to learning (e.g., Baeten et al., 2013; Leung et al., 2008). In this study, we investigate how engineering students' approaches to learning are linked to their performance in their first-year mathematics studies. In addition, we analyze how students' approaches to learning change in two different instructional models during one study year. Instead of studying only the whole-group level, we delve into subgroups of students with different combinations of approaches to learning.

Theoretical Framework

Approaches to Learning

Approaches to learning are a widely used framework for studying the quality of learning in higher education. Its origins lie in the work of Marton and Säljö (1976), who studied how university students read and process academic texts. Marton and Säljö distinguished between two different dimensions of students' actions: deep processing and surface processing. Later, these concepts were developed further to include students' intentions related to their studying and learning processes, and they were renamed the *deep approach to learning* and the *surface approach to learning* (e.g., Entwistle & Ramsden, 1983; Entwistle et al., 2006). Students who apply a deep approach to learning aim to understand the topic profoundly, make links between concepts, and analyze information critically. Students who apply the surface approach to learning use unreflective strategies, such as rote learning and memorization. Later, a third approach to learning, *organized studying*, was identified (Biggs, 1993; Entwistle & McCune, 2004; Entwistle & Ramsden, 1983). It comprises managing time and effort and planning one's studies. Organized studying has also been called the strategic approach and achieving approach.

Approaches to learning have been linked to students' academic performance. In many studies, the deep approach to learning has been found to correlate positively with study success (e.g., Marton & Säljö, 1976; Minbashian et al., 2004; Liebendörfer et al., 2022) and the surface approach negatively (e.g., Diseth, 2007; Liebendörfer et al., 2022; Marton & Säljö, 1976; Minbashian et al., 2004; Öhrstedt & Lindfors, 2019). In addition, organized studying has been found to be linked positively with study success (Asikainen et al., 2014; Öhrstedt and Lindfors, 2019; Rytkönen et al., 2012). A particularly favorable combination of approaches to learning seems to be a deep approach to learning alongside organized studying (Haarala-Muhonen et al., 2016).

Several studies have investigated how students' approaches to learning develop during their studies, and the results are somewhat mixed. (For an extensive review, see Asikainen and Gijbels [2017]). In some studies, it has been noted that students' deep approaches to learning increase during the study program (e.g., Asikainen et al., 2014; Mørk et al., 2022). In other studies, no change (e.g., Lietz & Matthews, 2010) or a decrease (e.g., Wilding & Andrews, 2006) in the deep approach has been found. Students' surface approach to learning has been shown to decrease (e.g., Mørk et al., 2022; Rodriguez & Cano, 2007) and increase (e.g., Ballantine et al., 2008) as students make progress in their studies. Asikainen and Gijbels (2017) commented that studies investigating the development of students' approaches to learning at a person-oriented level give more consistent results than those investigating the whole-group level. It seems that in different subgroups of students, approaches to learning can develop in a different way. Likewise, Lindblom-Ylänne et al. (2013) pointed out that at the individual level, the changes in students' approaches to learning are richer than at the group level. Another explanation Asikainen and Gijbels (2017) offered for the mixed results is the contextuality of approaches to learning. If the context (e.g., the learning environment) changes during studies, it may result in changes in approaches to learning.

Learning Environments and Students' Approaches to Learning

Although students have a general tendency to assume a certain approach to learning (Entwistle & Ramsden, 1983), their approaches can be affected by the learning environment. Several characteristics of learning environments have been linked to students' approaches to learning. Student-centered learning environments have been found to foster a deep approach to learning (e.g., Dolmans et al., 2016; Lahdenperä et al., 2019; Wilson & Fowler, 2005), but they can also make students use a surface approach to learning (e.g., Baeten et al., 2013; Gijbels & Dochy, 2006; Struyven et al., 2006). In the context of engineering students, Leung et al. (2008) found that teacher-centered learning environments were linked to the surface approach to learning in Hong Kong, but in mainland China, teacher-centered teaching was linked to the deep approach to learning. Support from peers seems to increase the deep approach to learning (Coertjens et al., 2016). In the case of engineering students, team projects have been found to promote a deep approach to learning (Du et al., 2019). Stress (Öhrstedt & Lindfors, 2018) and low autonomous motivation combined with heavy workload (Kyndt et al., 2011) can result in a surface approach. At the same time, a lack of challenges can lead to the same result (Coertjens et al., 2016).

Some studies have compared the development of students' approaches to learning in different learning environments. Wilson and Fowler (2005) investigated one group of students who took a traditionally taught course and an action learning-based course containing a project and group work. They found that the students' approaches to learning developed differently in different learning environments and that the development was linked to the students' initial approach to learning. Students who reported using a typically deep approach to learning had no difference in the approaches they used in the different learning environments. On the other hand, students who reported themselves typically using a surface approach to learning were prone to adopting a deep approach to learning in the action learning environment. Muis and Duffy (2013) compared the effects of traditional and constructivist teaching practices on students' learning strategies. With five measurement points over a semester, they found that in the constructivist learning group, students' learning strategies improved after a couple of months, whereas students in the traditional learning group were consistent with their learning strategies.

The Aim of this Study

In this study, we compare the development of students' approaches to learning in two different instructional models over a period of eight months. One instructional model functions within the framework of lecture-based teaching but contains several student-centered elements. The other instructional model disrupts the traditional constructs of teaching and is built on the idea of flipped learning (Talbert, 2017).

We take a longitudinal approach by analyzing the development of students' approaches to learning in five measurements over a period of eight months. This time period covers four consecutive courses, allowing us to gain detailed information on the development of students' approaches to learning in two different instructional models. In our previous study (Rämö et al., 2023), we investigated how approaches to learning developed in the same population of students. Compared to our earlier study, the new viewpoint in this study is analyzing the relationship between approaches to learning and academic performance and studying the development of combinations of approaches to learning, as opposed to the development of a single approach to learning.

Changes in students' approaches to learning (Asikainen & Gijbels, 2017), as well as the relationship between the learning environment and students' approaches to learning (Baeten et al., 2010), have been studied widely. The novel viewpoint in this study is analyzing the change not only at the whole-group level but also in subgroups of students and combining this analysis with the comparison of two different learning environments.

Our research questions (RQs) can be summarized as follows:

RQ 1: Is there a difference between the two instructional models in how students' approaches to learning relate to academic performance?

RQ 2: How do students cluster by their approaches to learning? What are the characteristics of the clusters that emerge (center, average exam points, number of students)?

RQ 3: Do students' cluster memberships change over time, and is there a relation to pedagogical design?

Methods

Context

The context of this study is a sequence of four engineering mathematics courses in a research-intensive Finnish university. The courses were taught in the 2019–2020 academic year. Each course was worth five credit units (European Credit Transfer and Accumulation System [ECTS]). They lasted for eight weeks. The topics of the courses were differential and integral calculus, linear algebra, and probability and statistics. The courses were compulsory for the students. Next, we describe the instructional models that were used in teaching the control and intervention groups. More detailed descriptions of the teaching methods can be found in Rämö et al. (2023).

The control and intervention groups were taught with two different teaching methods throughout the series of four courses. In the control group, new topics were introduced to the students in the lectures, whereas the intervention group's instructional model was based on flipped learning (Flipped Learning, 2014; Talbert, 2017). Course materials, educational videos, the mathematics support center, and basic skills support sessions were common to both groups.

In the control group, new topics were introduced in the lectures, in which the lecturer motivated the topics, explained the mathematics behind them, and gave examples. In addition, the students were given small problems to solve with their peers. If the students were not able to attend the lectures or needed revision, they could watch educational videos. After the lectures, the students were given tasks to complete at home and during the exercise sessions. The exercise sessions were classes of approximately 25 students led by a teaching assistant. They took place twice a week. In the exercise sessions, the students worked on problems in small groups and discussed solutions to the take-home exercises. The students could receive support in completing the take-home tasks in a mathematics support center where teaching assistants scaffolded their work. The students who did not master the necessary prerequisites were offered basic skills support sessions. The students' grades were based on tasks completed during the course and on a final exam.

In the intervention group, the students' first contact with new concepts took place in their individual learning spaces, following the principles of flipped learning (Flipped Learning, 2014). The students studied new topics by reading written course material, watching educational videos, and working on a weekly problem set prepared by the teacher. The problem set consisted of tasks similar to the control group, but the intervention group's problem sets also included tasks aimed at developing the students' conceptual understanding. As for the control group, the intervention group's students could receive help from the mathematics support center and basic skills support sessions. For the intervention group, the group learning space comprised exercise sessions and so-called prime-time sessions (Koskinen et al., 2018).

In both sessions, the students worked in dedicated small groups. In the exercise sessions, the solutions to the weekly tasks were discussed. In the prime-time sessions, each small group met with a teacher and discussed mathematical topics that were left unclear to them after self-studying. The intervention group's assessment included self- and peer-assessments in different forms. Some of the weekly tasks were peer- and self-assessed. In addition, the students regularly self-assessed their competencies against the courses' learning objectives. The students' grades were based on tasks completed during the course and on a final examination.

During the fourth course in the sequence of our focus courses, the COVID-19 pandemic closed universities in Finland. This forced all teaching into an online format. In the control group, lectures were canceled, and the students in both groups watched the same educational videos. In the intervention group, prime-time sessions were held with video conferencing in Microsoft Teams. In both groups, exercise sessions were canceled and replaced with self- and peer-assessments. The mathematics support center and basic skills support session took a virtual form in Microsoft Teams. Table 1, modified from Rämö et al. (2023), presents a summary of the teaching arrangements before and during the pandemic.

During the sequence of four courses, the control group was taught by two different teachers, and the intervention group was taught by four different teachers. All teachers were experienced and had a pedagogical qualification

(60 ECTS). The teaching resources allocated to the two groups did not differ considerably.

Table 1. Teaching Arrangements for two Student Groups: Control and Intervention

	Before the pandemic	
	Control	**Intervention**
Contact teaching	lectures and exercise groups	Prime-time meetings and exercise groups
Support	mathematics support center and basic skills support sessions	mathematics support center, and basic skills support sessions
Materials	course materials, videos, and weekly tasks	course materials, videos, computerized tasks, and weekly tasks
Collaboration	working with peers in the exercise groups and lectures	working with a fixed small group in prime-time meetings and exercise groups, and completing group assignments
Assessment	weekly tasks and exam	weekly tasks, exam, self-and peer assessment of tasks, and self-assessment of competencies
	During the pandemic	
	Control	**Intervention**
Contact teaching		Prime-time meetings
Support	mathematics support center and basic skills support sessions	mathematics support center and basic skills support sessions
Materials	course materials, videos, and weekly tasks	course materials, videos, and weekly tasks
Collaboration		working with a fixed small group in prime-time meetings, and completing group assignments
Assessment	weekly tasks, exam, self-assessment, and peer-assessment of tasks	weekly tasks, exam, self- and peer assessment of tasks, and self-assessment of competencies

Participants

The participants in this study were 405 bachelor’s students in engineering programs at a research-oriented university in Finland. They participated in four compulsory first-year mathematics courses during the 2019–2020 academic year. About one-half of the students studied the four consecutive courses with a lecture-based instructional model (control group), and another half studied with a student-centered instructional model based on group work, self-assessments, and flipped learning ideology (intervention group). The average age of the students was 21.9 years (*SD* = 2.346).

Procedure

The students were assigned to the control group (n = 216, 53.3%; 77 females, 35.8%) and the intervention group (n = 189, 46.7%; 59 females, 31.2%) based on their disciplines. The students in the control group majored in electrical engineering, bioengineering, and information technology, whereas the students in the intervention group studied automation engineering, mechanical engineering, materials science, and environmental and energy engineering. The students gave their consent to participate in this study, and they were informed that they had the right to cancel their participation at any point.

The students in both groups answered the survey five times during the study: at the beginning of the first course (August 2019), the second course (October 2019), the third course (January 2020), the fourth course (March 2020), and at the end of the fourth course (April 2020). At the end of each course, all the students participated in an examination measuring their mathematics skills in course-specific areas. Due to the COVID-19 pandemic, on March 18th, 2020, the Finnish government announced regulations that forbid face-to-face learning at the universities. Thus, five of the seven weeks of the fourth course were implemented via distance learning. The first three courses took place before the emergence of COVID-19 in Finland and were implemented as face-to-face learning.

The study sample of 405 students included 165 students who participated in all four engineering mathematics courses, including the final examinations, during the 2019–2020 semester and responded to all five surveys. A total of 89 of these 165 students (53.9%) belonged to the intervention group, and 76 belonged to the control group. This subsample of 165 students was used for RQ3 in analyzing the students' changes in their approaches to learning during the academic year.

Instrument

During this study, the participants completed a survey measuring approaches to learning five times. The statements on approaches to learning were from the HowULearn questionnaire (Parpala & Lindblom-Ylänne 2012). The HowULearn questionnaire measures university students' approaches to learning at a state/event (course specific) level with 12 self-response items. The responses to the items on the deep approach (4 items), surface approach (4 items), and organized studying (4 items) were given on a five-point Likert scale, which was transformed into a numerical scale for analysis, ranging from 1 (totally disagree) to 5 (totally agree). The HowULearn questionnaire is widely used and validated in Finnish and international higher education contexts (e.g., Herrmann et al., 2017). For the 165 students with complete data, the observed Cronbach's alphas for three different approaches to learning in the five surveys were 0.819 (deep approach), 0.890 (organized studying), and 0.836 (surface approach).

Statistical Analyses

Values for the three different approaches to learning for students in the control group and in the intervention group were calculated separately for each of the five surveys. The number of responses varied to some extent: Surveys 1–5 had 280, 278, 323, 316, and 319 responses, respectively. No imputation was applied to the data, as the attribution across the five measurements was non-significant. The analyses were conducted only for the students who had responded to the surveys related to the courses in which they had actually participated.

The methods used did not require scaling or centering the data. For each survey, a value representing each of the three approaches to learning was calculated by adding the numerical values of the answers to the four questions measuring that approach. The means and standard deviations of the data are shown in Table 2.

Table 2: Descriptive Statistics of the Students' Approaches to Learning

	N	Mean	St. Dev.	Min	Max
Deep (Survey 1)	280	15.989	2.186	6	20
Deep (Survey 2)	278	16.040	1.825	7	20
Deep (Survey 3)	323	16.006	2.084	9	20
Deep (Survey 4)	316	15.946	2.070	8	20
Deep (Survey 5)	319	15.470	2.254	4	20
Surface (Survey 1)	280	14.893	2.865	5	20
Surface (Survey 2)	278	14.367	2.889	5	20
Surface (Survey 3)	323	14.495	3.077	6	20
Surface (Survey 4)	316	14.532	3.125	4	20
Surface (Survey 5)	319	13.972	3.390	4	20
Organized (Survey 1)	280	10.368	2.598	4	19
Organized (Survey 2)	278	10.928	2.721	5	19
Organized (Survey 3)	323	11.288	2.832	4	19
Organized (Survey 4)	316	11.171	2.543	4	19
Organized (Survey 5)	319	12.053	2.718	4	19

Figure 1 shows the mean values for deep and surface approach and organized studying in the five measurements separately for the intervention group (IG) and the control group (CG). Figures 2 and 3 show the histograms of the values of the three approaches to learning separately for the intervention group and the control group in the five surveys. Mean values are shown in Figures 2 and 3 with dashed lines. Figures 1 to 3 are produced with RStudio (RStudio Team 2021) using package *ggplot2* (Wickham, 2016).

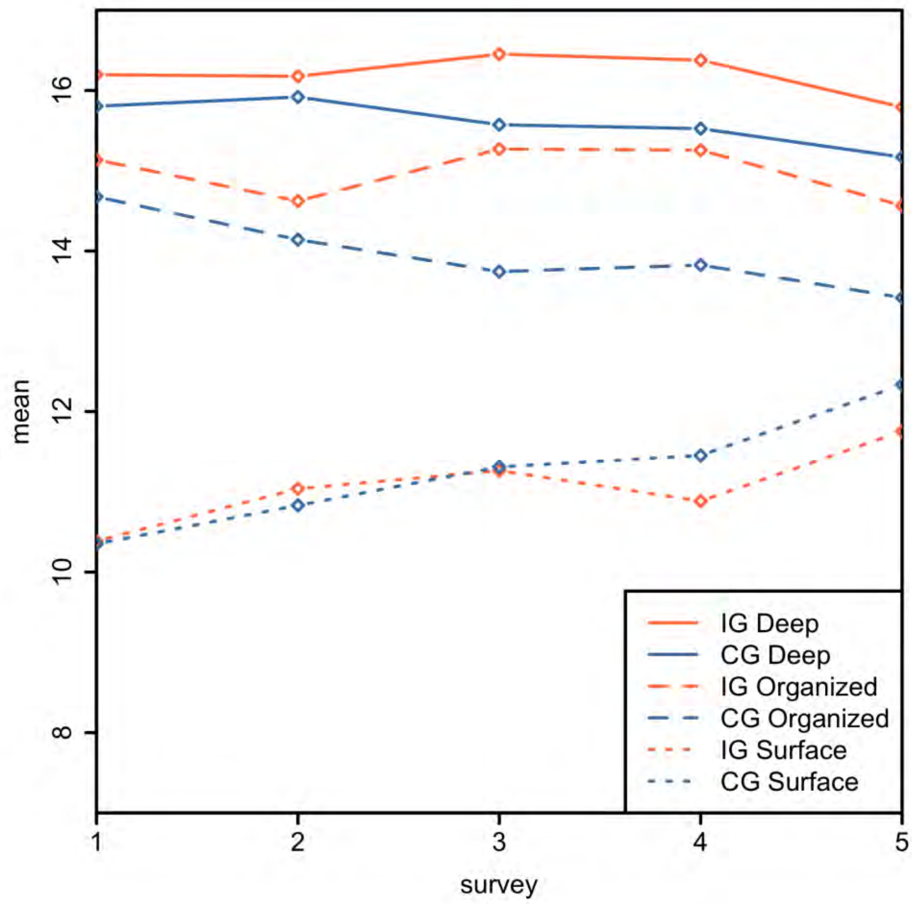

Figure 1. Mean Values for Approaches to Learning

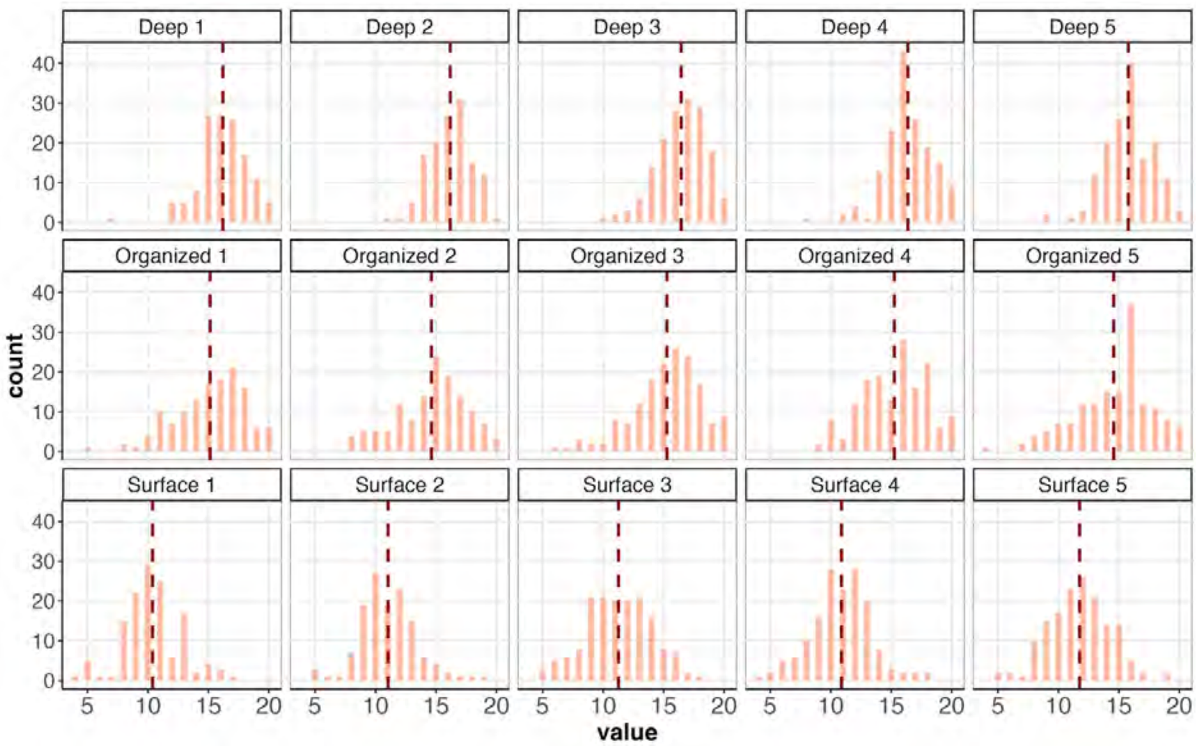

Figure 2. Approaches to Learning in the Intervention Group

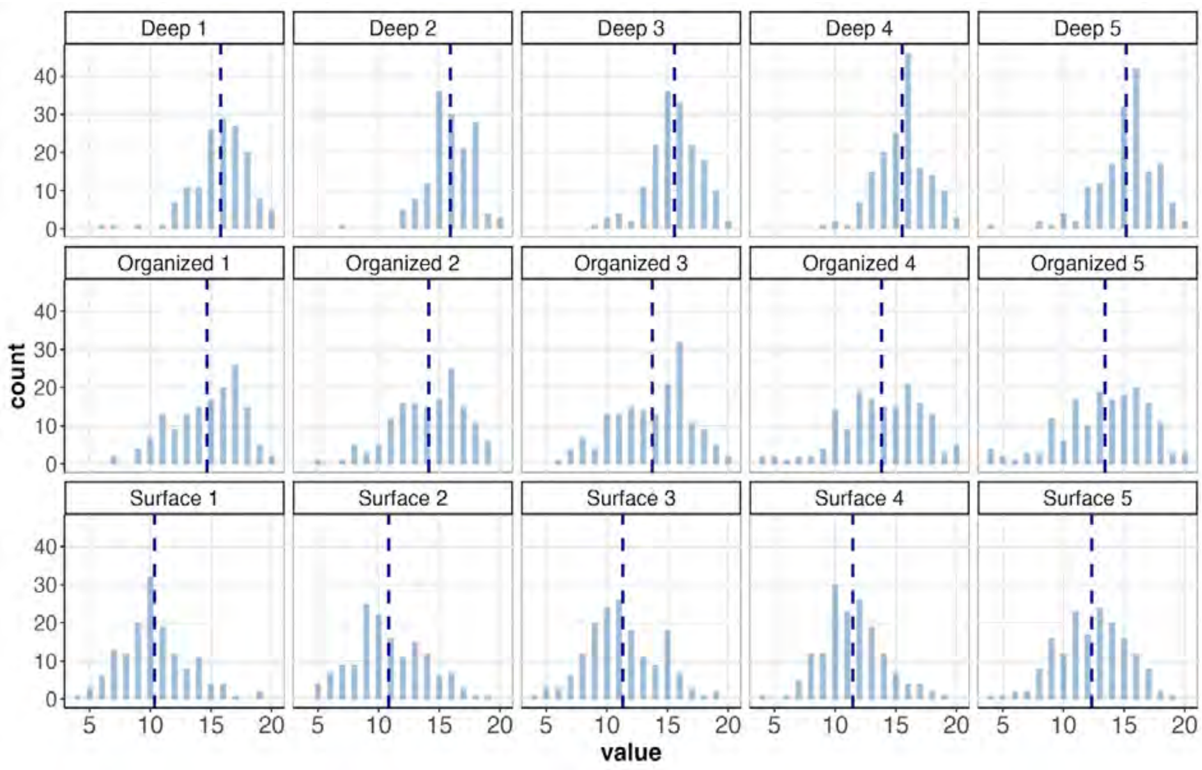

Figure 3. Approaches to Learning in the Control Group

Due to the investigation of the statistical assumptions related to linear regression analysis and k-means clustering, the normality of the data was investigated with Mahalanobis distances, calculated for the three values (deep, surface, and organized) in all five surveys. To determine if any of the distances were statistically significant, we calculated their *p*-values that corresponded to the chi-square statistic of the Mahalanobis distance with *k*-1 degrees of freedom, where *k* is the number of variables. Therefore, in this case, $k = 3$. Typically, a *p*-value of less than 0.001 is considered an outlier. Using this threshold, we found 3, 1, 0, 2, and 1 outliers in Surveys 1–5, respectively. The number of outliers with respect to the responses for each survey was so small that we decided not to remove any outliers and to keep all data.

The students participated in a preliminary mathematical skills test at the beginning of the first course and a final examination at the end of each of the four courses. They had three joint problems in each final examination. The average scores for these three problems are presented in Table 3; the maximum score was 18 points. The examination scores were not normally distributed, so a two-sided Mann–Whitney U test was performed to evaluate whether the scores differed by group. The difference in the scores between the control group and the intervention group was significant in the preliminary test ($W = 7759$, $p < 0.001$) and the second examination ($W = 9626$, $p = 0.013$), in which the intervention group scored higher. The scores in the other examinations did not differ significantly (Exam 1: $W = 11866$, $p = 0.126$; Exam 3: $W = 14610$, $p = 0.739$; Exam 4: $W = 12967$, $p = 0.687$).

The first RQ was examined with linear regression analysis and dominance analysis where the examination score was the dependent variable (DV) and the independent variables (IVs) were the levels of the deep and surface approach and organized studying. The second RQ was examined using k-means cluster analysis. For the third RQ, the results of the k-means clustering for the subsample of 165 students with complete data were analyzed further. The analysis was performed using R software (R Core Team, 2021).

Table 3. Preliminary Mathematics Skills Test and Course Examinations

	Pre-test	Exam 1	Exam 2	Exam 3	Exam 4
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Control group	10.62 (2.94)	11.28 (4.65)	8.98 (4.47)	8.36 (5.27)	9.31 (3.38)
Intervention group	11.90 (2.74)	10.33 (5.07)	10.22 (4.21)	8.06 (5.37)	9.50 (3.21)

Results

We analyzed the relationship between approaches to learning and learning outcomes using linear regression analysis and dominance analysis. A multiple linear regression was calculated to predict the examination points based on the values of deep and surface approaches and organized studying measured at the beginning of the course. A significant regression equation was found for all four courses, but only the values of organized studying and surface approach were statistically significant in the regression equation.

1. With points from Exam 1 as the DV and the values of the deep and surface approach and organized studying in Survey 1 as IVs, a significant regression was found ($F(3,275) = 4.612$, $p = 0.004$) with *R^2* of 0.048. Predicted exam points were equal to 14.4343 - 0.1099 * deep + 0.1342 * organized - 0.3701 * surface. Only the value of the surface approach was a significant predictor of the examination points ($p = 0.001$).
2. With points from Exam 2 as the DV and the values of deep and surface approach and organized studying in Survey 2 as IVs, a significant regression was found ($F(3,269) = 11.3$, $p < 0.001$) with *R^2* of 0.112. Predicted exam points were equal to 8.0042 + 0.0073 * deep + 0.3506 * organized - 0.3126 * surface. The values of the organized studying ($p < 0.001$) and the surface approach ($p = 0.001$) were significant predictors of the examination points.
3. With points from Exam 3 as the DV and the values of deep and surface approach and organized studying in Survey 3 as IVs, a significant regression was found ($F(3,308) = 10.01$, $p < 0.001$) with *R^2* of 0.089. Predicted exam points were equal to 12.3587 - 0.1871 * deep + 0.2886 * organized - 0.4519 * surface. The values of the organized studying ($p = 0.006$) and the surface approach ($p < 0.001$) were significant predictors of the examination points.
4. With points from Exam 4 as the DV and the values of deep and surface approach and organized studying in Survey 4 as IVs, a significant regression was found ($F(3,285) = 14.47$, $p < 0.001$) with *R^2* of 0.132. Predicted exam points were equal to 8.7695 + 0.0351 * deep + 0.2488 * organized - 0.3158 * surface. The values of the organized studying ($p < 0.001$) and the surface approach ($p < 0.001$) were significant predictors of the examination points.

When the values of the approaches measured after each course were chosen as IVs for the exam points of the course that had just ended, the results were similar: a significant regression was found for each course, with the values of organized studying and surface approach as significant predictors. In addition, when multiple linear regression analysis was used for the control group and the intervention group separately, organized studying and surface approach acted as significant predictors for the exam points.

We also used dominance analysis to compare the importance of the approaches as predictors of exam scores. The intervention group and the control group were studied separately, using the package *dominanceanalysis* (Bustos & Soares, 2019) in RStudio. The average contributions of each of the three approaches measured at the end of the course to the exam score as well as of the pair organized studying + surface approach and all three approaches together are presented in Table 4 (D = deep approach, O = organized studying, S = surface approach, O + S = organized studying and surface approach together and D + O + S = all three approaches together). It can be seen from the table that the surface approach and organized studying contribute more to the exam score than the deep approach. The model D + O + S, in which all three approaches are used as predictors, is in most cases as good as the model O + S, which omits the deep approach.

Table 4. Average Contributions of Approaches to Learning to Examination Scores

Group, course	D	O	S	O + S	D + O + S
Control group, 1	0.005	0.008	0.121	0.134	0.134
Control group, 2	0.015	0.094	0.120	0.229	0.229
Control group, 3	0.005	0.070	0.131	0.203	0.206
Control group, 4	0.010	0.081	0.036	0.128	0.128
Intervention group, 1	0.007	0.040	0.121	0.167	0.167
Intervention group, 2	0.004	0.048	0.023	0.075	0.075
Intervention group, 3	0.055	0.073	0.043	0.150	0.170
Intervention group, 4	0.003	0.043	0.066	0.110	0.110

The second research question was analyzed using k-means clustering for the five surveys separately. The students were clustered according to the values for their approaches to learning using the function *kmeans* and the package *cluster* (Maechler et al., 2022) in RStudio. Using the elbow method, the most reasonable number of clusters varied between 2 and 6 in the five surveys.

The gap method, which encourages a smaller number of clusters, suggests only two clusters. Five clusters seemed the most appropriate for this study because a very small number of clusters did not display the variety of the students' survey responses well, and four and six clusters resulted in uneven numbers of students in the clusters. K-means clustering was then performed on the data with k = 5.

The initial centers for the clusters with values for the deep approach, organized studying, and surface approach were chosen to be (18,17,8), (17,14,9), (16,16,13), (14,13,13), and (12,9,14) because running *kmeans* with random starting points several hundred times resulted in clusters with centers approximately at these points. Choosing the same initial centers for each survey ensured that the obtained clusters appeared in the same order. Thus, we used k-means with five clusters, the initial centers as above, and 500 iterations. The number of students in the control and intervention groups, as well as the average exam points, were calculated for each cluster. We performed Pearson's chi-squared test to study the cluster memberships of the control group and the intervention group.

Table 5. Clusters in the Surveys 1–5

	Deep	Organized	Surface	*N* (CG)	*N* (IG)	Exam 1	Exam 2	Exam 3	Exam 4
Survey 1									
Cluster 1	17.64	17.21	8.37	47	40	11.82	10.67	8.71	9.45
Cluster 2	15.81	12.64	9.36	40	35	11.27	9.49	8.99	9.91
Cluster 3	16.16	16.41	12.45	26	38	9.01	8.84	7.38	9.10
Cluster 4	11.84	15.20	10.96	16	9	12.50	10.29	9.52	9.63
Cluster 5	14.69	10.17	13.86	19	10	9.38	8.71	8.64	8.59
Survey 2									
Cluster 1	16.97	17.15	8.26	32	30	13.29	11.65	11.05	10.71
Cluster 2	16.11	13.18	9.38	43	30	12.19	9.83	8.93	10.05
Cluster 3	16.11	16.35	12.46	34	38	10.27	9.71	7.36	8.97
Cluster 4	15.73	12.47	14.47	25	20	8.45	8.70	7.39	8.45
Cluster 5	13.96	8.88	11.27	14	12	9.50	6.90	6.60	7.63
Survey 3									
Cluster 1	17.30	17.29	8.66	37	49	12.23	11.17	9.89	10.30
Cluster 2	16.33	12.59	9.36	38	26	11.68	10.24	8.89	10.17
Cluster 3	15.97	16.20	12.60	37	51	10.04	10.27	8.42	9.44
Cluster 4	15.29	12.73	14.51	31	24	9.79	8.13	7.12	7.67
Cluster 5	13.03	8.77	13.17	21	9	9.50	5.80	5.93	7.80
Survey 4									
Cluster 1	17.43	17.54	8.85	32	48	12.49	12.22	11.27	11.01
Cluster 2	16.51	13.17	9.59	31	32	11.07	10.05	9.30	9.64
Cluster 3	16.34	16.53	13.34	32	41	9.62	9.27	7.42	9.05
Cluster 4	14.40	13.02	12.87	36	24	10.00	8.57	6.76	8.76
Cluster 5	13.74	9.21	11.82	28	11	9.46	6.45	5.73	7.46
Survey 5									
Cluster 1	17.31	17.28	9.75	27	44	11.56	11.52	10.64	10.72
Cluster 2	15.48	13.08	9.54	34	27	12.51	10.85	9.92	9.98
Cluster 3	15.16	15.91	13.85	48	48	10.17	9.73	8.30	9.42
Cluster 4	15.40	10.85	13.99	41	27	10.72	8.94	7.33	8.49
Cluster 5	11.30	7.26	12.61	15	8	9.00	7.58	7.50	8.19

Cluster analysis was performed with the function *kmeans* in RStudio. The values of the deep approach, organized studying, and surface approach at the cluster centers are presented in Table 5, together with the number of students from the control group, N(CG), and intervention group, N(IG), belonging to this cluster and the average exam points of all four exams for the students in these clusters.

The five clusters appear in each survey with the same qualitative properties, regardless of the centers varying slightly. The levels of the deep and surface approach and organized studying in the five clusters from Survey 3 are presented in Figure 4 to visualize the cluster profiles. In all surveys, Cluster 1 had high values for both deep approach and organized studying and a low value for surface approach. Thus, Cluster 1 was labeled "Organized deep approach." The students in this cluster in Surveys 2–5 had the highest scores in all examinations. Cluster 2 differed from Cluster 1 by having a lower value for organized studying; the value of the deep approach was still high. Cluster 2 was labeled "Deep approach." The students in this cluster had the second highest examination scores. Cluster 3 differed from Cluster 1 by having a higher value for the surface approach. Thus, the students in Cluster 3 used all approaches to an average level, and accordingly, this cluster was labeled "All approaches." Cluster 4 had the highest value for the surface approach and intermediate values for the deep approach and organized studying; thus, it was labeled "Surface approach."

Finally, in all surveys, Cluster 5 had the lowest values of deep approach and organized studying and a high value for the surface approach. Therefore, Cluster 5 was labeled "Unorganized surface approach." Students in Cluster 5 had the lowest examination scores. The observed cluster characteristics agree with our findings using linear regression analysis and dominance analysis: high values for organized studying affect the average examination score positively and high values for surface approach affect the score negatively.

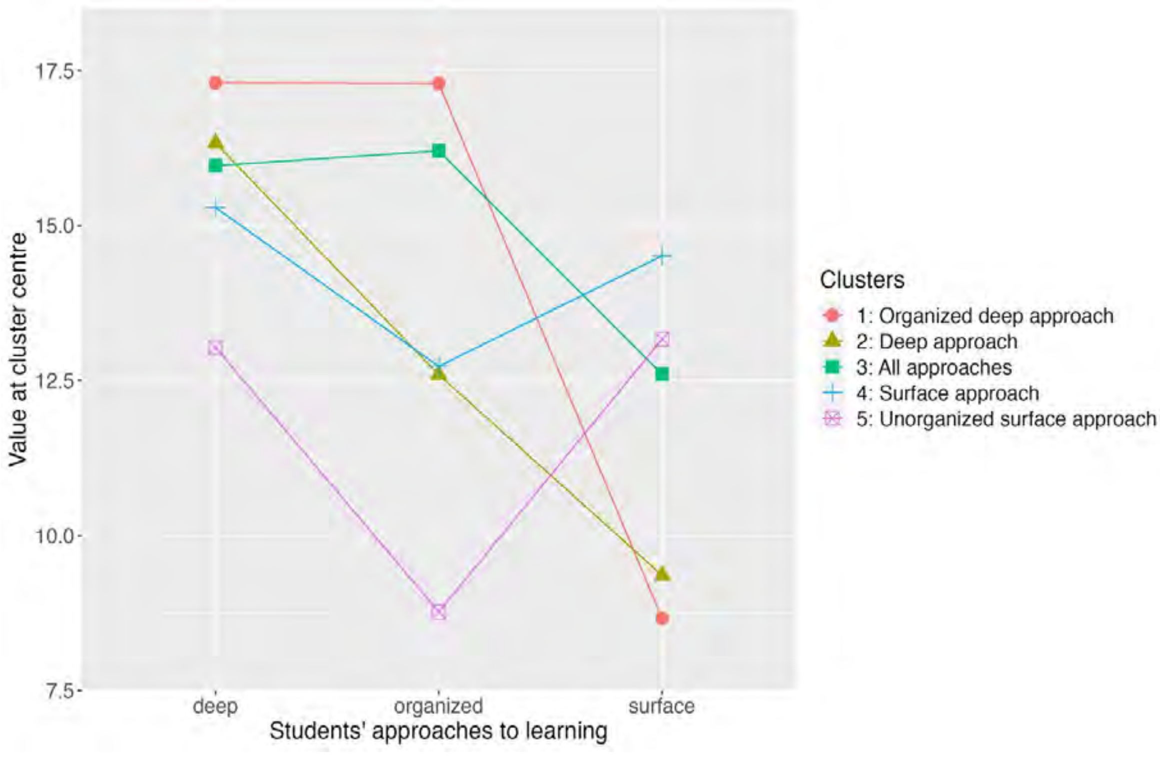

Figure 4. Cluster Profiles in Survey 3

We performed Pearson's chi-squared test to study the cluster memberships of the intervention group and the control group. According to the chi-squared test, the cluster memberships between the intervention group and the control group differed statistically significantly in Surveys 3, 4, and 5. The numbers of students in each cluster can be seen in Table 5, and the p-values for the chi-squared test in Surveys 1–5 were 0.1355, 0.7073, 0.0192, 0.0070, and 0.0494, respectively.

To answer RQ3, we used data from 165 students (76 from the control group and 89 from the intervention group) for whom complete data were available (i.e., those who responded to all five surveys and participated in the course exam in all four courses). Each student thus belonged to one of the five clusters at each measurement. We studied their movements over the five clusters during the academic year with alluvial plots of the cluster memberships of the students in the control group and the intervention group. We present the movement over the clusters for the members of the intervention group and the control group in Figures 5 and 6.

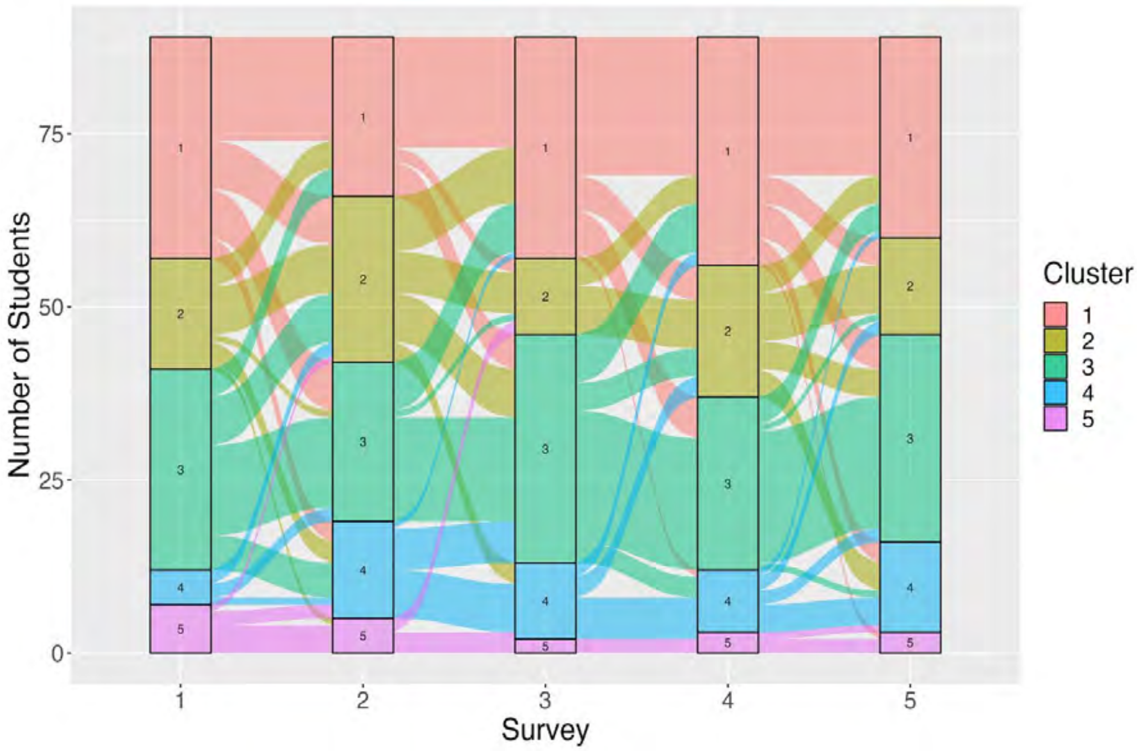

Figure 5. Movement between the Clusters in the Intervention Group

We also calculated the amount of change in cluster numbers and studied the possible difference between the control group and the intervention group using Pearson's chi-squared test. All analyses were conducted with RStudio (RStudio Team, 2021). We calculated the average changes in cluster numbers between any two consecutive surveys.

The value representing the change is negative if the number of the cluster that the student belongs to in the previous survey is higher than the number in the following survey. We also calculated the averages of the absolute changes. The values of the changes are presented in Table 6 (IG = intervention group, CG = control group).

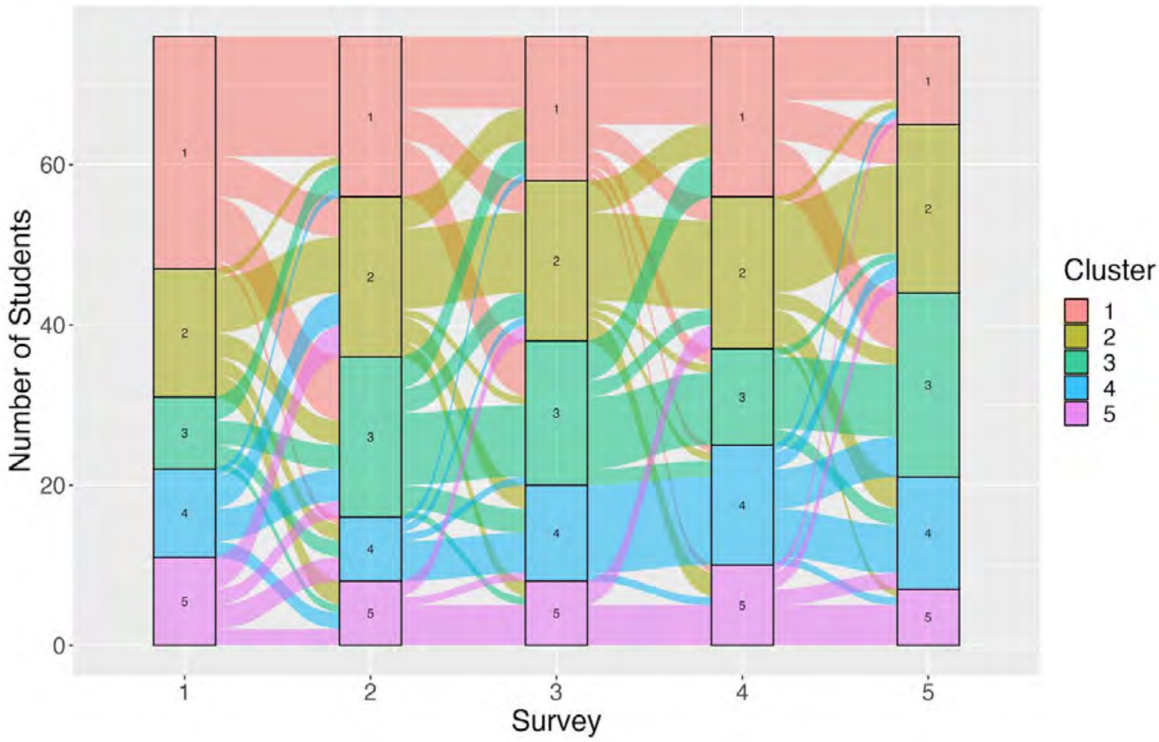

Figure 6. Movement between the Clusters in the Control Group

Table 6. Average Changes in Student's Cluster Numbers

	Surveys 1 and 2	Surveys 2 and 3	Surveys 3 and 4	Surveys 4 and 5
IG, change	0.18	-0.17	-0.09	0.16
IG, abs. change	0.83	0.73	0.67	0.67
CG, change	0.05	0.11	0.03	0.16
CG, abs. change	1.16	0.83	0.68	0.84
All, change	0.12	-0.04	-0.04	0.16
All, abs. change	0.98	0.78	0.68	0.75

Finally, we investigated how the students in the intervention group and in the control group moved between the clusters from measurement 2 to measurement 4 separately, that is, during the second and third mathematics courses. Table 7 presents the frequency of the students in the intervention group and in the control group having their cluster numbers changed by a certain amount between Surveys 2 and 4.

Table 7. Frequency Table of the Changes in Cluster Numbers

	Change in cluster number								
	-4	-3	-2	-1	0	1	2	3	4
Control group	0	3	4	6	43	10	6	4	0
Intervention group	2	2	8	13	52	6	4	2	0

The change is positive if the student is in Survey 4 in a cluster with a larger number than in Survey 2 and negative if the student has moved to a cluster with a smaller number. According to the chi-squared test, there was no statistically significant difference in the frequency tables for the intervention group and the control group (p = 0.328).

Discussion and Conclusion

In this study, we analyzed two groups of first year engineering students who were exposed to different instructional models. One instructional model functioned within the framework of lecture-based teaching, and the other functioned within the framework of flipped learning. We studied students' approaches to learning and academic performance during four consecutive courses.

We found that the effect of the surface approach to learning on students' exam performance was negative in both instructional models. This is in line with several previous studies (e.g., Marton & Säljö, 1976; Minbashian et al., 2004; Öhrstedt & Lindfors, 2019). The effect of organized studying, on the other hand, was positive, which supports earlier results (e.g., Asikainen et al., 2014; Öhrstedt & Lindfors, 2019; Rytkönen et al., 2012). The deep approach did not affect the students' exam performance in either of the two instructional models. This is different from many prior studies in which a deep approach to learning has been linked to study success (e.g., Marton & Säljö, 1976; Minbashian et al., 2004). This could be because the students' deep approach to learning was at a high level in this study, and there was less variation in the deep approach to learning than in the other approaches. Another explanation is that performing well in the exam did not require a deep approach to learning (Campbell & Cabrera, 2014; Öhrstedt & Lindfors, 2019). Indeed, in our focus courses, the exam questions were mostly calculations that did not require skills characteristic of a deep approach to learning (e.g., a profound understanding of the topic, linking different concepts, and analyzing information critically).

The students were classified into five clusters based on their approaches to learning. The smaller the number of clusters, the more favorable the students' approaches to learning. The students in the first cluster (organized deep approach) had the most favorable approaches to learning. They applied a deep approach, organized their studying, and did not apply a surface approach. The students in the second cluster (deep approach) resembled the students in the first cluster but used less organized studying. The students in the third cluster (all approaches) applied all approaches to learning to an average amount. The students in the fourth cluster (surface approach) resembled the third cluster but had a lower deep approach to learning and organized studying. The students in the fifth cluster (unorganized surface approach) had a low level of deep approach to learning and organized studying and a high level of surface approach to learning.

We examined how the students in the intervention and control groups were represented in the different clusters. At the first two measurement points, there was no significant difference in cluster memberships between the two groups. At measurement points 3–5, differences were detected in favor of the intervention group. There were more students from the intervention group in the organized deep approach cluster, which is the most favorable cluster, and fewer students from the intervention group in the unorganized surface approach cluster, which is the least favorable cluster. In other words, the intervention group's instructional model seemed to foster deep approach learning and organized studying better than the control group's instructional model. This is in line with previous studies in which student-centered teaching methods have been found to have a positive impact on students' approaches to learning (e.g., Dolmans et al., 2016; Lahdenperä et al., 2019; Wilson & Fowler, 2005). In addition, among the students who applied the deep approach to learning (clusters 1–2), the intervention group's students applied organized studying to a higher level than the control group's students. This suggests that for these students, the intervention model supported organized studying better than the control model.

Next, we investigated how the students' memberships in the clusters changed over time. The biggest changes occurred between the first and second surveys, and at this point, the average change was toward less favorable clusters for both the intervention group and the control group. This means that the surface approach to learning increased, and organized studying decreased. This can be due to the transition from high school to university, as stress has been linked to an increase in the surface approach to learning (Öhrstedt & Lindfors, 2018). Particularly among our participants, the motivation for studying mathematics is probably not very high, and low motivation accompanied by a heavy workload can result in applying the surface approach to learning (Kyndt et al., 2011). Between Surveys 2 and 4, the average change in the intervention group was toward more favorable clusters, and in the control group, it was toward less favorable clusters. This resulted in different distributions of students into clusters in Surveys 3–5 in the intervention group and the control group, as discussed above. The results imply that there is a delay in the impact of the instructional model. Our findings are in line with Muis and Duffy (2013), who noticed that in a student-centered learning environment, students' approaches to learning improved. In addition, Muis and Duffy (2013) reported that this change did not happen immediately but after a couple of months.

The global COVID-19 pandemic closed Finnish society and universities between measurement points 4 and 5. The students had been exposed to distance learning for five weeks before Survey 5. Between the two measurements, the students moved toward less favorable clusters. The effect of the pandemic on the control group was more negative than the intervention group: the most favorable organized deep approach cluster was reduced more in the control group than in the intervention group. This means that the intervention group was more resilient to changes caused by the pandemic. The same result was reported in our earlier study on the whole-group level (Rämö et al., 2023), and we now see the same phenomenon on the subgroup level.

Recommendations

We found that a high level of organized studying and a low level of surface approach to learning were positively linked to exam performance. However, the deep approach to learning was not linked to how well the students performed in the exam. In our focus university, as well as in many other institutions, the basic engineering mathematics courses are very calculation-driven and do not emphasize deep understanding, which may partly explain our results. However, since engineering faculties expect mathematics courses to provide their students with the competence to model and apply mathematics in engineering (Faulkner et al., 2019), fostering a deep approach to learning would help students achieve this goal. We suggest that educators should critically consider the content, teaching practices, and assessment of mathematics courses so that teaching fosters a deep approach to learning.

Our results confirm earlier results (e.g., Muis & Duffy, 2013; Wilson & Fowler, 2005) regarding the relationship of learning environments and students' approaches to learning: student-centered instruction such as flipped learning can foster favorable changes in students' approaches to learning. However, this change does not happen right away. In our study, a positive change in approaches to learning was detected only in the third survey—after the second course. This implies that instructional interventions need to be long enough. One short course might not be enough for a change to happen in students' approaches to learning.

Limitations of the Study and Future Research

The students were divided into an intervention group and a control group according to their study programs. Both groups had students from several engineering programs, so the cultures of the study programs and other courses the students took in their first year might have an effect on the time and energy they put into mathematics learning and their motivation to learn mathematics. The control group had two responsible teachers, and the intervention group had four teachers during the four courses. All teachers were pedagogically qualified and had extensive teaching experience, but their individual approaches to teaching might still affect their students' approaches to learning (Baeten et al., 2010).

Complete data were obtained from only 165 of the 405 students in total, and these 165 were a selected group in the sense that they continued their studies the whole year, responded to all surveys, and took all exams. This means that the students who forgot to answer even one of the surveys or interrupted their studies in mathematics due to failing one of the courses, attending military service, or having other personal reasons were not included. This might have caused a bias in the available data.

The results from the first survey did not provide a clear basis point for analyzing the changes in cluster memberships during the academic year, as in the first survey, the centers of the five clusters had slightly different values for deep approach, organized studying, and surface approach than in the later surveys. In particular, Cluster 4 appeared with the center approximately at (15,12,14) in Surveys 2–5 but at (12,15,11) in Survey 1; thus, the profile of the students in Cluster 4 in the first survey was different than in the later surveys. This difference in the cluster centers may arise from the fact that the first survey took place at the very beginning of the first university-level mathematics course and thus likely illustrated the students' approaches to learning mathematics in high school. After taking their first mathematics course at the university, the students were more able to reflect on their learning at the university level.

The data analyzed in this research were collected during the first year when the flipped model was used in engineering mathematics at the focus university. Therefore, the teaching practices were not in their final form but were developed later. In addition, the emergence of COVID-19 disrupted teaching in an exceptional way at the end of the study period. For these reasons, it would be of interest to study the student profiles and their relation to learning outcomes in more detail in a more stable situation to gain more insight into the possible benefits of flipped learning. Furthermore, since the deep approach to learning was not found to affect the learning outcomes, it would be interesting to find out whether this is due to how the learning outcomes were assessed, the content of engineering mathematics courses, the role of mathematics in engineering studies, or some other factor.

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Author Information

Riikka Kangaslampi
https://orcid.org/0000-0002-9059-8047
Tampere University
Finland
Contact e-mail: *riikka.kangaslampi@tuni.fi*

Johanna Rämö
https://orcid.org/0000-0002-9836-1896
University of Eastern Finland
Finland

Petri Nokelainen
https://orcid.org/0000-0002-8195-7001
Tampere University
Finland

Jani Hirvonen
https://orcid.org/0000-0003-1667-2760
Tampere University
Finland

Elina Viro
https://orcid.org/0000-0001-6644-4251
Tampere University
Finland

Simo Ali-Löytty
https://orcid.org/0000-0002-6720-7722
Tampere University
Finland

Vikke Vuorenpää
https://orcid.org/0009-0008-2926-3679
Tampere University
Finland

Terhi Kaarakka
https://orcid.org/0000-0002-3824-8939
Tampere University
Finland