

First-year engineering students' attitudes and learning goals in calculus: A ten-year follow-up study

Thea Bjørnland^{a *}, Aslak Bakke Buan^a and Vidar Gynnild^b

^aDepartment of Mathematical Sciences, Faculty of Information Technology and Electrical Engineering, Norwegian University of Science and Technology, Trondheim, Norway.

^bDepartment of Education and Lifelong Learning, Faculty of Social and Educational Sciences, Norwegian University of Science and Technology, Trondheim, Norway.

Abstract A study of learning goals and attitudes in a first-year mandatory calculus course was conducted among first-year engineering students at the Norwegian University of Science and Technology in 2007. Over the course of one semester, “educationally unwelcome” trends were observed. The current follow-up study (2017) was motivated by comprehensive course revisions from 2013 through 2015, including the use of digital learning resources, improved tutoring sessions and the introduction of active learning methods. Contrary to expectations, this follow-up study brings no evidence of positive impacts of the course revisions at the mean level. Some students had stable attitudes and goal orientations, while others switched to undesired territories throughout the semester in the same way as observed ten years earlier. Better integration between foundational and applied courses, and consideration of the entire teaching and learning environment, may yield more of desired attitudes and goal orientations in the first year of study.

Keywords Attitudes towards mathematics; engineering students; achievement goals; undergraduate calculus; STEM

*Email: thea.bjornland@ntnu.no

1 Introduction

Calculus is a portal to engineering education, and for many students unfortunately also a major obstacle to succeed in their studies. The research literature features a long history of educational interventions, partially motivated by disappointing results such as high failure and drop-out rates. The engineering education at the Norwegian University of Science and Technology (NTNU) may serve as a typical example. The first-semester calculus course (henceforth referred to as Calculus 1) is mandatory for all students in the 5-year integrated Master of Technology programs at NTNU. The course is delivered by the Department of Mathematical Sciences and has an annual enrolment of approximately 1700 students.

Teaching and learning methods in Calculus 1 were substantially reformed as part of a comprehensive educational development project during the years 2013-15. The project was inspired by current trends in tertiary education, such as active learning methods and formative assessment, improved student support, and extended use of digital learning resources. Given the scope of the educational intervention, the department hoped that students' goals and attitudes in Calculus 1, including motivation and self-confidence, would move in positive directions. Changes in learning goals over the first semester of university studies were examined among engineering students at NTNU already in 2007 by way of two validated research instruments (Sundre et al., 2012). The study concluded that students' goals and attitudes towards Calculus 1 changed over time, but "... unfortunately opposite to the instructors' aspirations" (Sundre et al., 2012). On average, engineering students in 2007 started out with a clear goal of mastering the course content and a willingness to learn. However, by the end of the term a significant decline in mastery goals was observed and instrumental approaches were more prevalent. Students tended to be more motivated by a fear of forgetting, and less motivated by the prospect of achieving a good grade. Furthermore, self-confidence and enjoyment in mathematics, as well as the perceived value of Calculus 1, declined over the course of the semester.

With the current follow-up project, we aimed to explore potential effects of educational interventions. Hypothesizing that students in more mathematics-oriented programs may differ from the average engineering student, a comparative study is also included. Our research questions are then as follows:

1. Following up on the 2007 study, are there observable differences in course-specific achievement goals and attitudes towards mathematics one decade later, and if so, may these be associated with course revisions?
2. Are changes in achievement goals and attitudes consistent across study programs, and may goal orientation profiles and change patterns be identified?

The short answer to the first research question is disappointingly "no", and a detailed statistical analysis is included to substantiate this finding. Given the central role of Calculus 1 in engineering education, we strongly believe educational designers and practitioners alike will find the current analysis to be of interest. In the next sections, we will outline the nature and scope of educational interventions from 2013-2015, followed by a comparative analysis of students' goals and attitudes.

2 Educational interventions

The educational project KTDiM (“Quality, Accessibility and Differentiation in the basic teaching of Mathematics”) at NTNU (Goodchild and Rønning, 2015) was motivated by international research literature as well as evidence collected in Calculus 1. Although most engineering students may not primarily be interested in mathematics as such (Kümmerer, 2001), the application of mathematics is a central part of an engineering degree. The literature tells us that engineering students’ ability to cope with academic and other demands in the first year of study vary widely. Transitional issues are well documented (Brandell et al., 2008; Geisler and Rolka, 2021; Hourigan and O’Donoghue, 2007; Luk, 2005), and several studies report gaps between applications of mathematical procedures in high school and the conceptual understanding required at the university (Clark and Lovric, 2009; Nortvedt and Siqveland, 2019). A study conducted in Nordic countries concluded that engineering students enrol with good levels of motivation and self-efficacy; however, in their studies tend to “. . . focus on solving problems and discovering regularities more than on other aspects of mathematics” (Tossavainen et al., 2020).

With such general issues in mind and triggered by disappointing results in Calculus 1 at NTNU, the KTDiM-project was initiated and implemented by mathematics instructors. The key vision of the project was that the students should acquire a deeper understanding of mathematical concepts and processes, which in turn would strengthen their ability to apply mathematics to solve problems. Based on this vision, and influenced by current pedagogical trends, a series of interventions were implemented from 2013 through 2015. These are outlined below, along with their respective purposes. A brief outline of contextual aspects that were *not* directly addressed by these interventions, but which we believe to be central for the discussion of our findings, are stated as non-changes.

Change 1: Introduction of interactive lectures

Lectures in large classes (300-500 students) dominated by one-way communication were replaced by a mix of (i) overview lectures based on a traditional lecture style, but focused on fundamental concepts and less on examples/computations, and (ii) interactive lectures and group work for solving exercises with support from instructors who would give hints and/or solutions in plenary. This design was motivated by the flipped classroom paradigm with an emphasis on student activity and communication between all involved parties. Overview lectures were also accessible online offering students an opportunity to prepare in due time for interactive lectures and exercises.

Change 2: Improved feedback to students

Weekly hand-written and mandatory hand-ins, checked by TAs (TA = Teaching Assistant) but with little feedback, were replaced by (i) weekly mandatory digital exercises, with immediate digital feedback on routine exercises and (ii) monthly hand-ins which were (if requested by the student) given written, and ideally extensive, feedback by TAs. This intervention can be seen as a move towards formative assessment, spending more resources on feedback and less on control.

Change 3: Accessibility and quality of support

Before 2013, groups of 30 students would have access to one TA for 2 hours per week, mainly to assist with the hand-ins. This was replaced by a “mathematical laboratory”, open 28 hours per week, operated by several TAs and PhD-students. The use of PhD-candidates represented an increased use of resources for the department. This was motivated by the emergence of mathematics support centres (Matthews et al., 2013) aimed to increase the accessibility of qualified instruction, and to facilitate student co-operation in designated areas.

Change 4: Varied assessment methods

Before 2013, there would only be a final exam and a mid-term counting 20% towards the final grade. This assessment form was replaced by weekly credits for digital exercises and hand-ins, so as to encourage continuous work with exercises throughout the semester.

Change 5: Extended use of digital resources

A wide range of digital resources were developed, including short thematic videos, recorded lectures and wiki-like thematic pages, all aimed to meet the needs of a heterogeneous student population characterized by diverse preferences and approaches to learning.

Non-change 1: Learning outcomes and progression

Content and learning outcomes of Calculus 1 have not been substantially altered for decades. Also, the structure and progression has sustained, starting out with relatively abstract definitions of limits and continuity, proceeding to differentiation and integration, ending up with discussions of sequences and series, including Taylor expansions of functions.

Non-change 2: Program structure and culture

The first year in all the five-year integrated master programs in technology at NTNU are dominated by foundational courses. In the first semester, all study programs typically include four courses of equal credit: Calculus 1, introduction to computer science, a course of relevance to the study program, and either a generic course in science/technology e. g. mechanics, electronics or chemistry or an introductory philosophy course. There has been modest dialogue and cooperation between departments offering these foundational courses, neither in terms of content and learning outcomes, nor in terms of structural and pedagogical aspects of teaching and assessment methods.

Non-change 3: Student recruitment

The five-year integrated master programs at NTNU are very popular, and only students with top grades in the most advanced mathematics courses from high school are admitted. The grade 4 (out of 6) is a minimum requirement; however, the vast majority of admitted students have 5 or even 6. The national average for this course in the period 2007-2017 was 3.9 (according to The Norwegian Directorate for Education and Training, www.udir.no). By Norwegian standards, this can be considered an elite education. Anecdotal evidence

suggests that a quite competitive culture is widespread among students, typically stressing the importance of top grades to achieve successful future careers.

Non-change 4: Teaching culture

The Department of Mathematical Sciences has, and have had, the responsibility for Calculus 1 and other foundational courses in mathematics/statistics. All courses are designed and implemented by research mathematicians with no or very little background in engineering and technology. Most of them have no or minimal formal pedagogical education and training, except a brief course in university pedagogy.

3 Achievement goals and motivations to learn

In this article we aim to explore motivational aspects and attitudes of Calculus 1 students, and to compare observations prior to and succeeding the educational interventions outlined above. Albeit the KTDiM-project was not designed to target students' motivation and attitudes directly, we were in the belief that educational measures aimed to support learning would also impact students' goals and attitudes. The instruments and methods used by Sundre et al in 2007 were therefore replicated in 2017. Two sets of surveys were given to Calculus 1 students at the beginning and end of their first semester of university studies.

The first questionnaire was the Achievement Goal Questionnaire by Elliot and McGregor (2001) supplemented by additional items that assessed work avoidance. As noted by Sundre et al. (2012), the five-factor structure of this instrument has been previously documented by e.g. Pieper (2003). The achievement goal approach to motivation originated in the early 1980s with the work of Dweck (1986) and Nicholls (1984). In the 2x2 framework of Elliot and McGregor, mastery approach goals reflect an intrinsic motivation to learn, while performance approach goals are related to external factors such as test scores. Avoidance goals capture the worry of not mastering a subject, or of performing poorly compared to others. A fifth goal orientation, work avoidance, refers to putting in as little effort as possible (Nicholls, 1989). Achievement goals have been linked to both short-term and long-term consequences for motivation and performance (Harackiewicz et al., 1997), and current research suggests that students' attitudes towards mathematics correlate with academic achievements (Gynnild and Tyssedal, 2020).

The second questionnaire was a Norwegian translation of the Attitudes Toward Mathematics Instrument (Tapia, 1996; Tapia and Marsh, 2002) featuring four dimensions; enjoyment, motivation, self-confidence, and value. The enjoyment items reflect the attainment value and intrinsic value of mathematics (e. g. "I get a great deal of satisfaction out of solving a mathematics problem"), but also the environment of mathematics instruction (e. g. "I am happier in a mathematics class than in any other class"). The self-confidence scale taps into efficacy and outcome expectancies such as "I believe I am good at solving mathematics problems" and "I expect to do fairly well in any mathematics class I take". The value items concern the instrumental value of mathematics outside university, future studies, and careers.

Using these two instruments, sample-level declines in learning goals and attitudes were observed among first-year engineering students at NTNU in 2007 (Sundre et al., 2012). These negative trends were linked to educational aspects of the Calculus 1 course, but also the challenges that first-year students are confronted with. University studies require

adaptability both in terms of learning environments and scientific content (Bengmark et al., 2017), and the transition from school to university is often associated with declines in academic self-concept (Marsh, 1987). Motivation, expectations to succeed, enjoyment and ability beliefs have all been reported to contribute positively during this transition (Bengmark et al., 2017; Liston and O’Donoghue, 2009), while a low sense of self-efficacy may induce surface approaches to learning (Zakariya et al., 2020). In accordance with the observations of Sundre et al. (2012), others have observed sample-level declines in achievement goals in transitional phases of education (Fryer and Elliot, 2007; Midgley et al., 1998; Symonds et al., 2010). A previous study conducted at NTNU reported on the use of formative assessment as a tool to stabilize achievement goals in preparatory engineering courses (Hansen and Ringdal, 2018), but much is still unknown of what mediates goal changes, and intervention studies designed to target achievement goals have yielded only modest results (Urdu and Kaplan, 2020).

4 Methods

4.1 Questionnaires

The Achievement Goal Questionnaire (AGQ) consisted of 16 items and responses were given on a discrete 7-point scale ranging from “not at all true of me” to “completely true of me”. After scanning all responses, each participant’s item scores were summarized into five subscales: mastery approach (MAP, 3 items), mastery avoidance (MAV, 3 items), performance approach (PAP, 3 items), performance avoidance (PAV, 3 items) and work avoidance (WAV, 4 items). The Attitudes Towards Mathematics Instrument (ATMI) contained 40 items to which responses were given on a discrete 5-point scale ranging from “strongly disagree” to “strongly agree”. Each participant’s item scores were summarized (with reverse scoring of negatively worded items) into four subscales: enjoyment (EN, 10 items), motivation (MO, 5 items), self-confidence (SE, 15 items), and value (VA, 10 items).

4.2 Participants

All first-year students enrolled in Calculus 1 were invited to respond to the two questionnaires at the beginning of the fall semester (August 2017, time T1). While all the programs considered here have an engineering profile, one of the programs offers a specialization in Applied Physics and Mathematics enrolling approximately 150 students annually. These students are referred to as MSc PhyMa students, while the entire group of engineering students are referred to as MSc students - highlighting that these students are enrolled in five-year integrated master programs. NTNU also offers 3-year bachelor programs in mathematics and physics, and for comparison, these BSc PhyMa students were also invited to take part in the study. The number of respondents at time T1 was: 1146 MSc students, including 131 MSc PhyMa students; and 88 BSc PhyMa students.

By the end of the term (December 2017, time T2), students were again invited to respond to the same questionnaires. The number of students responding on both occasions, T1 and T2, was: 524 MSc students, including 55 MSc PhyMa students; and 47 BSc PhyMa students. The questionnaires were administered during lectures at both time points, replicating the design from 2007 (Sundre et al., 2012). Those students responding at times T1 and T2 are referred to as “completers” and those responding only at time T1

as survey drop-outs. A short on-line survey was distributed to MSc students in February 2018 (time T3) asking for their final grades and study habits in Calculus. A total of 318 completers and 292 survey drop-outs responded digitally. Survey completers had somewhat higher grades, attended more lectures, and spent more time working with the course material (see Supplementary Table 1). These results correspond with observations made by Bengmark et al. (2017) who followed Swedish engineering students over the entire first year of university studies.

4.3 Statistical analysis

Our main analysis was to compare score changes over the course of the semester (T1 to T2) in 2017 to the 2007-results published by Sundre et al. (2012). For this analysis we considered mean-level subscale score changes among the first-year MSc students (completers only). Assuming that the change in score between two time points (score at T2 - score at T1) was approximately normal, we performed a two-sample t -test (unequal sample sizes, unequal variance) to test whether the mean score changes observed in 2017 were significantly different from the 2007 survey. For completeness of the follow-up, we also reproduced summary statistics of the two questionnaires (AGQ and ATMI) for the 2017-data, and performed paired sample t -tests of $H_0 : \mu = 0$ against $H_1 : \mu \neq 0$ for each AGQ and ATMI subscale, where μ represents the mean score change between T1 and T2. A non-parametric paired sample Wilcoxon test was carried out as a quality control of the normal assumption. At an overall significance level of 5%, and using a Bonferonni correction for 18 tests, we defined a statistically significant test result as having a p -value less than $0.05/18 = 2.8 \cdot 10^{-3}$. Statistical analysis was performed in R (R Core Team, 2019), and plots were generated using the ggplot2 package (Wickham, 2016).

The main analysis concerned mean-level trends. As a supplement, we studied individual-level uncertainty in subscale score changes in the 2017-material by estimating 95% prediction intervals based on the assumption of normality. We also analysed simultaneous change patterns among the MSc engineering students by hierarchical clustering (function `hclust` in R with the complete linkage method). We determined the number of clusters using the silhouette method (Rousseeuw, 1987) as implemented in the R package `factoextra` (Kassambara and Mundt, 2019).

Finally, we included the sample of first-year BSc PhyMa students (completers only) in order to compare mean-level changes in mathematically oriented study programs (55 MSc PhyMa students and 47 BSc PhyMa students) to the mean-level changes among other MSc engineering students ($n = 469$). We repeatedly sub-sampled 50 MSc engineering students from the larger sample and visualized the distribution of mean subscale score changes in these smaller samples.

5 Results

5.1 Main analysis: 2017 versus 2007

5.1.1 AGQ

Figure 1 features mean scores from the AGQ at times T1 and T2 in 2007 and 2017. The average goal orientation profile at T1 (the first week of university studies) was quite similar in 2017 and 2007. An almost identical decline in mastery approach goals was

observed in both years, and the same was true for the increase in mastery avoidance and work avoidance goals. Slight, but not statistically significant, differences were observed for performance approach goals (a lesser decline in 2017 compared to 2007, $p = 9.5 \cdot 10^{-3}$) and performance avoidance goals (in 2007, the average PAV score changed minimally between time T1 and T2, while in 2017 the score increased to a somewhat greater extent, $p = 6.9 \cdot 10^{-3}$). In summary, differences between 2007 and 2017 are minor, and due to the substantial number of survey drop-outs both in 2007 and 2017 (approximately 50%), we refrain from interpreting such minor differences in light of the course developments that took place between these years.

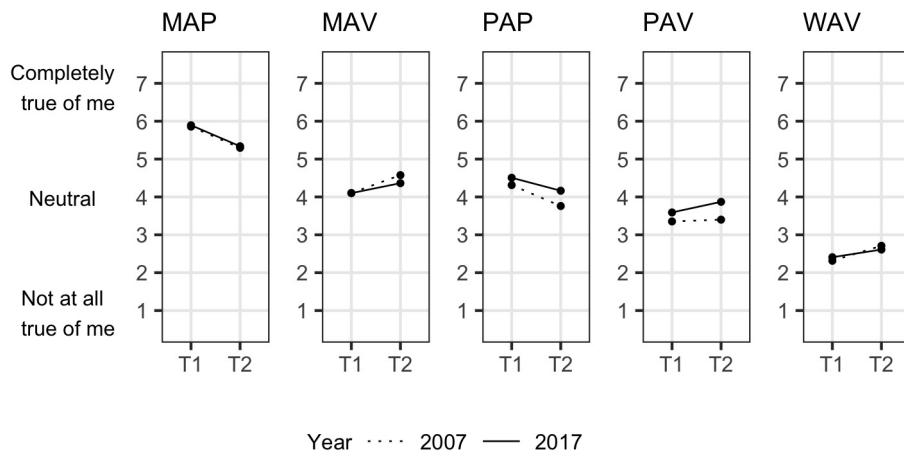


Figure 1: 2017 vs 2007 (AGQ). Mean scores at two time points. T1: beginning of university studies, and T2: end of the first semester.

Statistically significant mean-level changes over the course of the 2017 fall semester were observed for all AGQ subscales (Table 1). The same results were found using a non-parametric Wilcoxon test (not shown). In contrast, a statistically significant increase in PAV was not found in 2007 (Sundre et al., 2012). Although the MSc students held mastery approach goals at both time points T1 and T2 (Figure 1), the greatest decline was observed for this subscale. In light of the skewness in mastery approach items at time T1 (Supplementary Table 2), we note that the *median* decrease was -0.33 per mastery approach item in 2017. This number is comparable to observed changes in other goal orientations, and somewhat less pronounced than the average decrease of -0.56 per item.

Table 1: Descriptive statistics and test results for changes in AGQ subscales (2017)

| <i>Subscale</i> | MAP | MAV | PAP | PAV | WAV |
|-----------------|-----------------------|----------------------|----------------------|----------------------|----------------------|
| Mean difference | -0.56 | 0.26 | -0.34 | 0.28 | 0.20 |
| SD | 0.83 | 1.44 | 1.28 | 1.24 | 0.88 |
| <i>t</i> | -14.60 | 4.01 | -5.85 | 4.94 | 5.02 |
| <i>p</i> | $3.41 \cdot 10^{-40}$ | $7.10 \cdot 10^{-5}$ | $9.09 \cdot 10^{-9}$ | $1.10 \cdot 10^{-6}$ | $7.28 \cdot 10^{-7}$ |

Further descriptive statistics for the Achievement Goal Questionnaire (AGQ) in the 2017 survey are presented in Supplementary Table 2. The correlations between times T1 and T2 (Supplementary Table 2) were similar to other studies on the transition to upper secondary school (Tuominen-Soini et al., 2008) and to university (Dresel and Grassinger,

2013), and indicated a certain degree of rank-order consistency over the course of the academic semester. We note a numerical ceiling effect for the mastery approach items at the first time point. In particular, item 7 (“I want to learn as much as possible in this course”) seemed to drive this ceiling effect (mean = 6.37, SD = 0.79). A slight floor effect for work avoidance was also observed at both time points.

5.1.2 ATMI

Figure 2 features the average ATMI subscale scores from 2007 and 2017, at time points T1 and T2. We observed slightly higher per-item mean scores for enjoyment, motivation and value in 2017. However, the changes over the course of the semester were very similar. Regarding our first research question, we found no discernible differences in attitude changes that could be linked with recent course developments. A statistically significant mean-level decrease was observed for all subscales over the course of the 2017 fall semester (Table 2). The same results were found using a non-parametric Wilcoxon test (not shown). The greatest from T1 to T2 decrease was observed for self-confidence, while the decrease in value was to all intents and purposes negligible (and in 2007, not statistically significant, see Sundre et al. (2012)). Supplementary Table 3 features further descriptive statistics for the Attitudes Towards Mathematics Instrument based on the 2017 survey. We observed ceiling effects for some items, e.g: “I have usually enjoyed studying mathematics in school” (enjoyment, mean = 4.4 out of maximum 5), “I would like to avoid using mathematics in university” (motivation (reverse-scored), mean = 4.5), “It makes me nervous to even think about having to do a mathematics problem” (self confidence (reverse-scored), mean = 4.4) and “A strong mathematics background could help me in my professional life” (value, mean = 4.5).

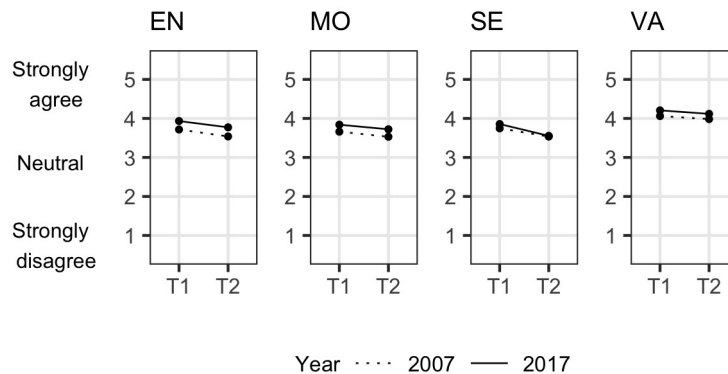


Figure 2: 2017 vs 2007 (ATMI). Mean scores at two time points. T1: beginning of university studies, and T2: end of the first semester.

5.2 Individual-level change patterns

As noted by Fryer and Elliot (2007), the stability and changes of subscale scores observed at the sample level may to some extent mask important individual-level differences. For example: in the 2017-data we observe that some students increased their performance approach goals by 3 points per item while others decreased with as much as 5 points per item. Prediction intervals for the goal changes of a future, or unobserved, MSc engineering student (excluding MSc PhyMa) may reflect such person-level variation. The 95%

Table 2: Descriptive statistics and test results for changes in ATMI subscales (2017)

| <i>Subscale</i> | EN | MO | SE | VA |
|-----------------|-----------------------|----------------------|-----------------------|----------------------|
| Mean difference | -0.16 | -0.12 | -0.30 | -0.09 |
| SD | 0.38 | 0.51 | 0.47 | 0.36 |
| <i>t</i> | -8.67 | -4.69 | -13.20 | -5.09 |
| <i>p</i> | $1.03 \cdot 10^{-16}$ | $3.69 \cdot 10^{-6}$ | $1.96 \cdot 10^{-33}$ | $5.51 \cdot 10^{-7}$ |

prediction intervals for AGQ score changes, each goal orientation considered individually, were: $[-2.24, 1.10]$ for MAP items; $[-2.46, 3.01]$ for MAV items; $[-2.83, 2.12]$ for PAP items; $[-2.19, 2.79]$ for PAV items; and $[-1.56, 1.96]$ for WAV items. The 95% prediction intervals for ATMI score changes 95% prediction intervals for score changes in enjoyment, motivation, self-confidence and value were $[-0.91, 0.60]$, $[-1.11, 0.89]$, $[-1.21, 0.61]$ and $[-0.80, 0.62]$, respectively. In other words, even though point estimates for score changes are in “unwanted” directions, the substantial variability in our sample points toward a wide range of individual score changes in both wanted and unwanted directions.

To assess *simultaneous* change patterns across all goal orientations, we performed a hierarchical cluster analysis on the individual-level changes. For AGQ, we identified two clusters consisting of 325 and 106 students. The main differences between these two clusters were the changes in mastery avoidance and performance avoidance goals over the course of the semester (see Supplementary Table 4). The larger cluster of students were *neutral and stable* with respect to the mastery avoidance and performance avoidance subscales. In contrast, the students in the second cluster disagreed to mastery avoidance and performance avoidance statements at time T1, but then *developed mastery and performance avoidance goals* over the course of the semester. Based on the ATMI-results, we identified two clusters consisting of 172 and 203 students. In the first cluster, attitudes were *stable or even improving* over the course of the semester (Supplementary Table 5). The second cluster consisted of engineering students that decreased on all subscales. Furthermore, there was little evidence of goal switching in either of the clusters; students had positive attitudes (score > 3.5 , neutral) at both time points, except for the self-confidence subscale in the second cluster. These results should be taken into account when interpreting the over-all mean-level changes in attitudes.

5.3 Comparison of study programs

Finally, we also studied differences between study programs. By repeatedly sub-sampling $n = 50$ students from the sample of MSc engineering students (excluding MSc PhyMa) and calculating mean score changes, we visualized the range of possible observations of mean scores ($n = 50$) within this group (see violin plots in Figures 3 and 4). Thus we could compare the smaller samples of MSc PhyMa and BSc PhyMa students with these students. From this analysis, it is not evident that the MSc applied physics and mathematics students differ substantially from other MSc engineering students. In contrast, bachelor students in physics and mathematics seem more stable than the engineering students when it comes to mean score changes for mastery performance approach items (Figure 3), as well as for all ATMI sub-scales (Figure 4).

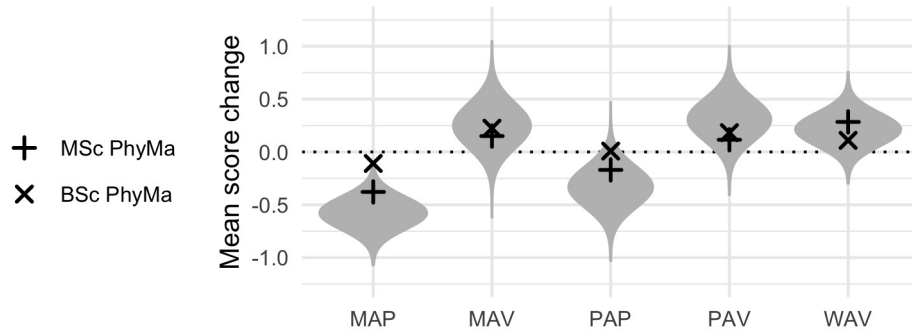


Figure 3: Program specific changes (AGQ, 2017). Mean changes in two mathematically oriented study programs as compared to the empirical distribution of similar sized sub-samples from the MSc engineering students (violins).

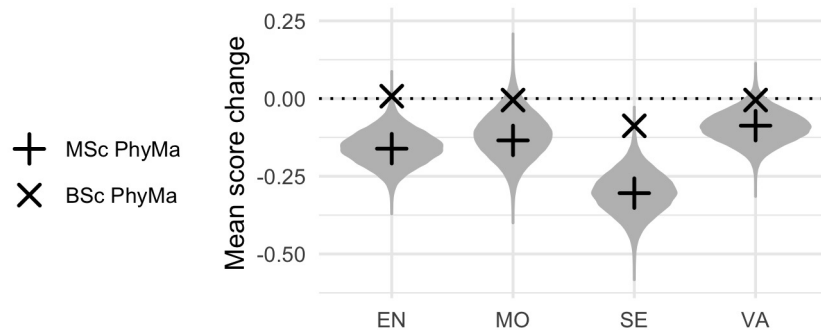


Figure 4: Program specific changes (ATMI, 2017). Mean changes in two mathematically oriented study programs as compared to the empirical distribution of similar sized sub-samples from the MSc engineering students (violins).

6 Discussion

Essentially the same pattern of goal changes over the course of the semester was observed in 2017 as in 2007. High initial mastery approach goals decreased, while low initial work avoidance goals increased. On both occasions declines in enjoyment, motivation, self-confidence, and value were observed. Since the aim of the current study was to follow-up on the study by Sundre et al. (2012), identical research instruments were used in 2017 as in 2007 for replication purposes. However, we find it appropriate to comment on some possible limitations of these instruments. A confirmatory factor analysis for the AGQ instrument using data from the current study found the five-factor to be appropriate (Skaue, 2020), yet we have some comments on individual items. When responding to the Achievement Goal Questionnaire, most students considered the statement “I want to learn as much as possible in this course” to be “completely true of me” at time point T1. In fact, their scores on mastery approach items at the beginning of the semester were at such a high level (statistical ceiling effect) that the survey would have failed to sufficiently capture positive changes at the individual level (registered as no change), leaving those with negative changes to weight down average scores. There is also evidence of a similar, albeit less pronounced, limitation of work avoidance items. The Attitudes Towards Mathematics Instrument was developed for High School students of all mathematics levels, and concerns

regarding the factor structure of the ATMI instrument were raised already by Sundre et al. (2012). Our students only made partial use of the scale, and items such as “I would like to avoid using mathematics in university” do not make sense in our context. A shortened version of the ATMI, such as that proposed by Lim and Chapman (2013), might be considered for future research. Also, Opstad and Årethun (2019) proposed a shorter questionnaire regarding attitudes towards mathematics in a Norwegian business school context. In particular, the concept of “motivation” was dropped, and an ongoing bachelor thesis regarding the 2017 ATMI data also suggests a three-factor rather than a four-factor structure (i.e. by excluding motivation items). The failure of the current study to find notable differences between 2007 and 2017 may of course be partially due to the limitations of the instruments used. With respect to these instruments, we should also note that these instruments were selected by Sundre et al. (2012) to measure attitudes towards learning and not content-based results. Although we observe no substantial improvements after KTDiM based on these instruments, we draw no conclusions regarding actual learning. Notably, Deslauriers et al. (2019) found that students in active classrooms in an introductory physics course learnt more than those attending in traditional passive lectures, but that the students in the active classroom felt that they learnt less.

Drop-out rates were substantial on both occasions; $\approx 50\%$ in 2007, and $\approx 55\%$ in 2017. Notably, these numbers reflect the attendance rates of students in (voluntary) lectures and we observe a similar reduction in attendance in both years. As noted by Sundre et al. (2012), most NTNU students attend lectures in the beginning of the semester but attendance rates typically drop after a few weeks to be replaced by more independent and group-based study activities. Survey respondents may therefore not be representative of the entire student population. In support of this, completers had somewhat higher grades, attended more lectures, and spent more time on course material.

Classroom interventions targeted to increase value and foster positive outcomes expectancies have been suggested as a remedial measure (Ambrose et al., 2010). As there is evidence that engineering students have difficulty seeing the relevance of mathematics to their future studies (Flegg et al., 2012), perceived value may be enhanced by showing relevance to students’ academic as well as to their future professional lives. We assumed that greater self-confidence and positive outcome expectancies may be built by constructive alignment of course content, assessment, and instruction; exercises at the appropriate level; ensuring that students experience success and mastery early in the course; and providing students with the flexibility to make choices among different learning activities. Although many of these measures were implemented in Calculus 1, no positive impact on goals and attitudes were observed. Changing these goal structures appeared to be more challenging than expected, a finding also reported elsewhere (Urdu and Kaplan, 2020).

This reminds us that higher education is embedded within larger systems, sometimes interacting in complex and unpredictable ways. The ways in which students respond to any teaching strategy will be impacted by numerous individual and contextual factors. This study addressed one single course; however, it is not at all evident that goals and attitudes are formed exclusively within these bounds. Becoming a student represents a process of enculturation, including codes and cues of teaching and learning cultures (Snyder, 1970). Fast progression, a fragmented and non-coherent organization of the foundational courses, and a competitive student-culture may contribute, as may the culture and attitudes among the teaching staff. In this study, a group-level decline in achievement motivation was observed among engineering students, although less pronounced among those specializing in physics and mathematics. Changes in attitudes among the bache-

lor students in physics and mathematics were less unwanted or even positive compared to applied physics and mathematics students, and other engineering students. Bachelor students enjoy less time pressures and are often taught in smaller classes, and may also adopt a theoretical rather than an applied focus. We also found evidence that albeit declines were observed at the mean level, many students had stable goals and attitudes throughout the semester, while others moved towards undesired territories.

7 Conclusion and implications

For future efforts, we recommend the consideration of the broader educational context with the aim of improved integration of all first-year courses. A close collaboration between mathematics and engineering departments in designing mathematics curricula and problem-solving tasks is also supported by the research literature. On the other hand, a recent study of first-year engineering students found “a toolbox view of mathematics” to be a negative predictor of performance, and so mathematics courses for engineers should still emphasize fundamental reasoning strategies and theoretical foundations (Tossavainen et al., 2020). Designing “mutually supportive” courses is a key component of the CDIO approach to engineering education (Crawley et al., 2014), and such efforts are currently being undertaken at NTNU. However, this does not offer any guarantee of desired outcomes. Engineering students do not normally pursue careers in mathematics, and the application of “survival strategies” in the first year has a long history. Declines of variables related to academic success remain a basic challenge for future interventions.

From an educational point of view, efforts may include increased emphasis on demonstrating the relevance of Calculus 1 in engineering, paralleled by improved interaction between foundational courses, and integration of these courses within study programs. Still, what the literature tells us is that there is no quick fix to achieve desired outcomes:

“What changes even more slowly than curricula is the behaviour of the majority of educators in a field. It is going to take course changes, content changes, pedagogical changes, organizational changes, structural changes, and cultural changes to realize systems to educate the engineers of 2020.” (Watson, 2009).

Efforts aimed at educational change need to attend to all those variables to build a valid understanding of how the entire system operates, and how it may be improved.

Acknowledgements

We would like to thank Kyrre Svarva and Marianne Øvervatn Dalfest for printing and scanning the questionnaires; Marius Thaule and Øyvind Solberg for administering the questionnaires during their lectures; and Fredrik Hildrum for posting the online survey. Finally, we thank the reviewers for valuable comments.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

- Ambrose, S. A., M. W. Bridges, M. DiPietro, M. C. Lovett, and M. K. Norman (2010). *How learning works: Seven research-based principles for smart teaching*. John Wiley & Sons.
- Bengmark, S., H. Thunberg, and T. M. Winberg (2017). Success-factors in transition to university mathematics. *International journal of mathematical education in science and technology* 48(7), 988–1001.
- Brandell, G., K. Hemmi, and H. Thunberg (2008). The widening gap -A Swedish perspective. *Mathematics Education Research Journal* 20(2), 38–56.
- Clark, M. and M. Lovric (2009). Understanding secondary - tertiary transition in mathematics. *International journal of mathematical education in science and technology* 40(6), 755–776.
- Crawley, E., J. Malmqvist, S. Ostlund, D. Brodeur, and K. Edstrom (2014). *Rethinking engineering education - The CDIO approach* (2 ed.). Springer International Publishing.
- Deslauriers, L., L. S. McCarty, K. Miller, K. Callaghan, and G. Kestin (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences* 116(39), 19251–19257.
- Dresel, M. and R. Grassinger (2013). Changes in achievement motivation among university freshmen. *Journal of Education and Training Studies* 1(2), 159–173.
- Dweck, C. S. (1986). Motivational processes affecting learning. *American Psychologist* 41(91), 1040–1048.
- Elliot, A. J. and H. A. McGregor (2001). A 2×2 achievement goal framework. *Journal of Personality and Social Psychology* 80(3), 501.
- Flegg, J., D. Mallet, and M. Lupton (2012). Students’ perceptions of the relevance of mathematics in engineering. *International Journal of Mathematical Education in Science and Technology* 43(6), 717–732.
- Fryer, J. and A. Elliot (2007). Stability and change in achievement goals. *Journal of Educational Psychology* 99, 700–714.
- Geisler, S. and K. Rolka (2021). “That wasn’t the math i wanted to do!”—students’ beliefs during the transition from school to university mathematics. *International Journal of Science and Mathematics Education* 19(3), 599–618.
- Goodchild, S. and F. Rønning (2015). Innovation in mathematics teaching and learning in engineering courses in Norway. Paper presented at the The 8th IMA Conference on Mathematical Education of Engineers.
- Gynnild, V. and J. S. Tyssedal (2020). Can students’ attitudes and behaviors be changed by educational interventions? A comparative case study. *Dansk Universitetspædagogisk Tidsskrift (DUT)* 16(29), 14–33.

- Hansen, G. and R. Ringdal (2018). Formative assessment as a future step in maintaining the mastery-approach and performance-avoidance goal stability. *Studies in Educational Evaluation* 56, 59–70.
- Harackiewicz, J. M., K. E. Barron, S. M. Carter, A. T. Lehto, and A. J. Elliot (1997). Predictors and consequences of achievement goals in the college classroom: Maintaining interest and making the grade. *Journal of Personality and Social Psychology* 73(6), 1284.
- Hourigan, M. and J. O’Donoghue (2007). Mathematical under-preparedness: The influence of the pre-tertiary mathematics experience on students’ ability to make a successful transition to tertiary level mathematics courses in Ireland. *International Journal of Mathematical Education in Science and Technology* 38(4), 461–476.
- Kassambara, A. and F. Mundt (2019). *factoextra: Extract and Visualize the Results of Multivariate Data Analyses*. R package version 1.0.6.
- Kümmerer, B. (2001). Trying the impossible. In *The teaching and learning of mathematics at university level*, pp. 321–334. Springer.
- Lim, S. Y. and E. Chapman (2013). Development of a short form of the attitudes toward mathematics inventory. *Educational Studies in Mathematics* 82(1), 145–164.
- Liston, M. and J. O’Donoghue (2009). Factors influencing the transition to university service mathematics: Part 1 a quantitative study. *Teaching Mathematics and its Applications: An International Journal of the IMA* 28(2), 77–87.
- Luk, H. S. (2005). The gap between secondary school and university mathematics. *International Journal of Mathematical Education in Science and Technology* 36(2-3), 161–174.
- Marsh, H. (1987). The-big-fish-little-pond effect on academic self-concept. *Journal of Educational Psychology* 79(3), 280–295.
- Matthews, J., T. Croft, D. Lawson, and D. Waller (2013). Evaluation of mathematics support centres: A literature review. *Teaching Mathematics and Its Applications: International Journal of the IMA* 32(4), 173–190.
- Midgley, C., A. Kaplan, M. Middleton, M. L. Maehr, T. Urdan, L. H. Anderman, E. Anderman, and R. Roeser (1998). The development and validation of scales assessing students’ achievement goal orientations. *Contemporary Educational Psychology* 23(2), 113–131.
- Nicholls, J. G. (1984). Achievement motivation: Conceptions of ability, subjective experience, task choice, and performance. *Psychological Review* 3(91), 328–346.
- Nicholls, J. G. (1989). *The competitive ethos and democratic education*. Harvard University Press.
- Nortvedt, G. A. and A. Siqveland (2019). Are beginning calculus and engineering students adequately prepared for higher education? An assessment of students’ basic mathematical knowledge. *International Journal of Mathematical Education in Science and Technology* 50(3), 325–343.

- Opstad, L. T. and T. Årethun (2019). Choice of courses in mathematics at upper-secondary school and attitudes towards mathematics among business students. The case of Norway. *International Journal of Learning, Teaching and Educational Research* 18, 228–244.
- Pieper, S. (2003). *Refining and extending the 2 x 2 achievement goal framework: Another look at work-avoidance*. Ph. D. thesis, James Madison University.
- R Core Team (2019). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.
- Rousseeuw, P. J. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. *Journal of computational and applied mathematics* 20, 53–65.
- Skaue, N. (2020). Confirmatory factor analysis of the achievement goal questionnaire.
- Snyder, B. R. (1970). The hidden curriculum.
- Sundre, D., C. Barry, V. Gynnild, and E. T. Ostgard (2012). Motivation for achievement and attitudes toward mathematics instruction in a required calculus course at the norwegian university of science and technology. *Numeracy* 5(1), 4.
- Symonds, R., D. Lawson, and C. Robinson (2010, 08). An investigation of physics undergraduates’ attitudes towards mathematics. *Teaching Mathematics and Its Applications* 29, 140–154.
- Tapia, M. (1996). The Attitudes Toward Mathematics Instrument. Paper presented at the Mid-South Educational Research Association, November.
- Tapia, M. and G. Marsh (2002). Confirmatory factor analysis of the Attitudes Toward Mathematics inventory. Paper presented at the Mid-South Educational Research Association, November.
- Tossavainen, T., R. J. Rensaa, P. Haukkanen, M. Mattila, and M. Johansson (2020). First-year engineering students’ mathematics task performance and its relation to their motivational values and views about mathematics. *European Journal of Engineering Education*, 1–14.
- Tuominen-Soini, H., K. Salmela-Aro, and M. Niemivirta (2008). Achievement goal orientations and subjective well-being: A person-centred analysis. *Learning and instruction* 18(3), 251–266.
- Urduan, T. and A. Kaplan (2020). The origins, evolution, and future directions of achievement goal theory. *Contemporary Educational Psychology* 61, 101862.
- Watson, K. (2009). Change in engineering education: Where does research fit? *Journal of Engineering Education* 98(1), 3.
- Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York.
- Zakariya, Y. F., H. K. Nilsen, S. Goodchild, and K. Bjørkestøl (2020). Self-efficacy and approaches to learning mathematics among engineering students: empirical evidence for potential causal relations. *International Journal of Mathematical Education in Science and Technology*, 1–15.