Can I Eat Melted-Frozen-Melted Bread?: Use of Practical Assignments to Harmonize Mathematics and STEM Courses and as a Measure for Future Technology Studies*

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Abstract: In the domain of engineering education, the crucial role of mathematics, especially Calculus, cannot be overstated, as it lays the foundational groundwork for numerous sciences, technology, engineering and mathematics (STEM) courses. The integration of mathematics into STEM disciplines is achieved through the practical application of mathematical concepts in real-world scenarios or in conjunction with other STEM subjects, thereby enhancing the coherence of engineering studies and acting as a significant motivational catalyst for students. This paper presents an analytical narrative of a practical mathematics assignment, woven into the Calculus curriculum and other STEM courses from 2013 to 2018. It delves into the potential impacts of these practical assignments on student performance and attitudes by evaluating data sourced from final exam scores and anonymous course surveys, both before and after the intervention period. Through the analysis of an extensive dataset comprising 1526 final exam scores, this study endeavors to make a substantive contribution to Future Technology Studies (FTS), focusing on the strategic harmonization of mathematics and STEM courses to enrich the educational experience and foster a more cohesive and applied learning framework in these disciplines.

Keywords: Problem-based learning (PBL), Student active learning, Practical assignments, STEM education.

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Introduction

In the evolving field of sustainable engineering education, combining mathematics with science, technology, and engineering (STEM) courses is essential. The harmonization of these disciplines, especially through practical mathematics applications, not only speed up the learning process but is also crucial for deepening students' comprehension and engagement. While the significance of integrating practical mathematical applications within STEM courses is widely acknowledged, a precise gap exists in understanding the direct impacts of such integrations on student outcomes and attitudes towards STEM subjects.

This paper investigates the specific hypothesis that practical assignments (problem-based learning methods) in mathematics can significantly enhance student performance and motivation within STEM education. The research question guiding this study is: "How do practical mathematics assignments integrated into calculus courses influence student performance and perception in subsequent STEM courses? This question arises from significant gaps noted in existing literature and academic practice. While the impact of real-world mathematical applications on student learning has been explored over shorter durations, our research comprehensively examines this impact over an extended period, particularly focusing on STEM education objectives.

* This study is extended version of the abstract that was presented in MNT-23 conference 16.-17. March 2023 in Stavanger, Norway. The abstract called “Practical assignments to harmonize mathematics and STEM courses in engineering education” can be found here: https://www.uis.no/nb/det-teknisk-naturvitenskapelige-fakultet/mnt-konferansen-2023 on page 248-252.

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In 2022, the Norwegian University of Science and Technology (NTNU) embraced strategic guidelines from the Future Technology Studies (FTS) project (NTNU, 2022), aimed at cultivating integrated competencies among students. This paper leverages the FTS framework from the outset, using it as a lens to evaluate the effects of practical assignments introduced in calculus courses between 2013 and 2018. By aligning our study with the FTS objectives early in this introduction, we highlight the relevance and timeliness of our research within current educational strategies.

Through this investigation, we aim to contribute robust empirical data to the ongoing dialogue about the harmonization of mathematics and STEM courses, a discourse pivotal for the advancement of future technology studies and the preparation of students for a dynamically changing technological landscape.

**Literature Review**

Mathematics, due to its abstract nature and its role as a foundational language in sciences, often necessitates practical applications or real-life contexts to make its abstract notions more accessible and relatable for students. Problem-based learning methods or Project Based Learning methods are suggested to be used to bring practical and real-life tasks to education. Their definitions are as follows.

- “Problem-based learning (PBL), a student-centered approach in which students learn about a subject by working in groups to solve an open-ended problem. This problem is what drives the motivation and the learning” (Center for Teaching Innovation, n.d.).
- “Project Based Learning (PBL) is a teaching method in which students learn by actively engaging in real-world and personally meaningful projects” (PBL Works, n.d.)

In this paper, we consider interventions problem-based if the interventions or manipulations only consist of one topic such as integration, derivation, or differential equations. A project, in our understanding, would contain several topics, such as e.g. optimizing the cost and material used in construction engineering.

Both problem-based learning and project-based learning are commonly used in education, e.g., in medical education (Neville, 2008), agriculture (Sumarni & Kadarwati, 2020), as well as in mechanics or electronics in Physics (Pérez-Sánchez & López-Jiménez, 2020; Zhang et al., 2016), or laboratory work in Chemistry (Nainggolan et al., 2020).

The integration of problem-based and project-based learning in mathematics education has also been scrutinized. These methodologies aim to not just impart abstract mathematical concepts but to contextualize them within practical, real-life scenarios, thereby fostering a deeper and more meaningful learning experience (Dahl, 2018; Perrenet et al., 2000; Roh, 2003). Research has also demonstrated positive correlations between problem-based learning and students’ attitude towards mathematics as well as their own potential (Boaler et al., 2022), students’ self-efficacy in problem-solving (Samsudin et al., 2020), creativity (Roble et al., 2021), and motivation and knowledge transfer (Rezaei & Asghary, 2024).

Regarding Calculus, there exist several other studies that also focus on teaching the Calculus course and the difficulties that students have in understanding the mathematical concepts, see e.g., ref. (Andrá et al., 2019). The following examples of studies show how different problem-based learning methods in Calculus courses have affected performance.

In the paper (Awaludin et al., 2020), the effectiveness of the problem-based learning method, where the intervention was a hypermedia e-book, on Integral Calculus learning was examined. The results showed that their method improved learning outcomes.

Personalized homework conducted on an online platform in a large-scale setting in multivariate calculus class was focused on (Kushnarev et al., 2020). Their findings showed that students performed better in the exam regarding those topics they had achieved top-level proficiency on the online homework platform than students who had not practiced a lot with the homework platform.

In the article (Cano & Lomibao, 2023) the influence of phenomenon-based learning videos (PhBLVs) on students’ self-efficacy in mathematics, problem-solving and reasoning skills, and mathematic performance at Calculus class was studied. The results indicated that PhBLVs can increase students’ performance, self-efficacy, problem-solving and reasoning skills in mathematics.

However, often in these studies, e.g. the studies mentioned above, the effect of the intervention is measured during one single course and/or one single semester. Our paper contributes to the topic by evaluating the usage of practical assignments (problem-based learning) for six years. Also, the practical assignments cover several STEM topics, as the students by themselves have selected tasks that are most relevant to their future study path.

**Methodology**

In this study, we have used design-based research (Anderson & Shattuck, 2012), where intervention has been a practical assignment each year, and the iterations are the calculus courses in the years 2012-2019. We also implemented a control group, conducting the intervention exclusively within one subset of the various Calculus groups. Our data collection was comprehensive, including exam results, time spent on the course by the students, and course satisfaction levels indicated...
through anonymous questionnaires. Throughout the years, all Calculus classes conducted identical final exams, allowing for an equitable comparison of final grades across the classes. During the 2012-2018 period, the breadth of the curriculum and the difficulty level of the final exam remained consistent, ensuring valid year-on-year comparisons. While the year 2019 saw minor curriculum adjustments in the Calculus course, comparability across classes was maintained given the uniformity of the final exam.

Calculus and Class 1

Calculus serves as a foundational course for all engineering students, and due to its importance, the student body is typically large. To manage this effectively and ensure a quality learning environment, the cohort was divided into several parallel sections. In this discourse, the section that was part of the innovative practical assignment initiative spearheaded by the main author will be referred to as Class 1.

A significant portion of the students in Class 1 showcased their proficiency in foundational mathematics by passing the pre-calculus examination conducted by the university just before the start of the semester. This pre-calculus course is designed to be on par with advanced mathematics courses at the high school level, aiming to equip students with the necessary skills and knowledge for university-level calculus. Students in the control group completed advanced high school mathematics before entering the university. So theoretically, both Class 1 and the control group should share a similar baseline of knowledge before beginning their university-level Calculus course.

The instructor of Class 1 implemented various instructional strategies to enhance the overall learning outcomes of the course. Among these, a central focus was laid on not just solidifying mathematical concepts, but also on conveying the real-world relevance of calculus, particularly within engineering contexts. One strategy of notable importance was the incorporation of practical assignments. These assignments, which form the primary focus of this paper, were designed to increase the perceived relevance of mathematics and encourage active engagement in concept comprehension. Through these assignments, students were able to directly link theoretical learning from lectures to tangible, applicable scenarios, making mathematics feel not only more digestible but also highly pertinent. To facilitate student engagement, other strategies were simultaneously employed, such as promoting good attendance during lectures and exercise sessions, encouraging more dialogue and discussion-based learning approaches during the lecture, and emphasizing the intrinsic significance of understanding mathematical principles.

Practical assignments

To include practical problems in Calculus for engineering students has always been a part of the curriculum. The practical examples will usually be introduced and given in lectures after the mathematics part of the lecture is done; since the lecture time is very limited, students do not always have enough to both fully understand the practical problem and to solve the problem by their own understanding. Another challenge is that Calculus classes are mandatory for all engineering students, so there is a mix of students with different fields of study, which makes it difficult to find practical example that feels relevant for all the students. During the Calculus course in 2012, the instructors discussed and acknowledged this challenge, and the feedback from students confirmed this as well, that they felt a lack of relevance while learning mathematics. To make more connections between mathematics and the other STEM courses and to motivate students to learn mathematics, a non-mandatory practical assignment was implemented in Class 1 in 2013 by the main author. The requirement for the practical assignments was to find practical use of subjects such as derivation, integration, and differential equations in other STEM courses that the students are following or in real-life problems that relate to at least one of the mentioned mathematical subjects. The students had the opportunity to select a topic of their preference, encouraging a sense of autonomy and personal investment in the learning process. They could also consult with the instructor for guidance, ensuring their selection fit within the course objectives. Furthermore, collaboration with peers was encouraged, fostering a richer, shared learning environment.

Feedback from students and observations during exercise classes made it clear that these assignments positively contributed to student motivation. Due to the positive feedback, the practical assignment became mandatory for all Calculus classes from 2014. With consistently favorable responses, such tasks remained integral to the curriculum until substantial modifications to the Engineering study program necessitated changes in 2019.

The grading criteria for the practical assignment were binary: pass or fail - and did not contribute to the final grade tally. The 'pass' requirements remained consistent each year. A successful assignment as mentioned earlier had to demonstrate practical usage of mathematical areas that are the main topics in Calculus, such as derivation, integration, or differential equations, either within the context of other STEM courses that the students were enrolled in, or in real-world problems directly related to at least one of the highlighted mathematical themes. The assignment's structure should be as follows: first, present the problem clearly and thoroughly. Second, illustrate the solution in a step-by-step manner. Lastly, conclude by discussing and analyzing the results drawn from solving the problem. The students received information regarding the assignment at the beginning of the semester. This advanced notice not only facilitated their planning for the assignment but also engendered a thought process in them about potential practical applications of each topic as it was taught. This cognizance acted as a motivating force, prompting the students to strive for a deeper
understanding of the mathematical concepts. The assignment submission portal was made accessible approximately a month prior to the final scheduled lecture.

Fig. 1 shows an example of a task from the practical assignment. Here, the students are supposed to apply Newton's law of cooling to determine how long the bread can stay outside the freezer at room temperature before it defrosts and needs to be put back into the freezer.

Over the years, the format of these practical assignments evolved. The years 2014 and 2015 saw students submitting their assignments individually. Throughout this two-year period, exercise sessions were marked by a high level of engagement as students energetically deliberated and collaborated on the practical assignments. Feedback indicated that group work was more motivating and engaging for students. Moreover, it provided them with the opportunity to delve into more complex, practical problems that necessitated additional time and effort. Recognizing the potential for collaborative learning and the benefits of peer engagement, the format transitioned to group submissions from 2016 to 2018. This period also marked the introduction of group presentations in Class 1, offering students the opportunity to present their findings and methodologies in front of their peers and instructors.

This transition to group activities and presentations was carefully monitored and adjusted based on the class size and logistical feasibility. The year 2018, in particular, witnessed larger class sizes, necessitating the division of group presentations into three separate sessions spread across the semester. This modification was in response to the observation that while group presentations significantly boosted student motivation and engagement, they were more manageable and effective in smaller class settings. The logistical challenges associated with larger classes warranted a re-evaluation of this approach, leading to the decision not to extend group presentations to larger cohorts, despite their success in smaller, more intimate class settings.

Tests

In addition to the practical assignments, the study also considered the impact of high-stake tests on student performance. From 2012 to 2017, the calculus course included high-stake tests, comprising six minor tests throughout the semester. The aggregate score of these tests contributed to 40% of the final grade, with the remaining 60% derived from the final exam. However, in 2018, a significant shift occurred due to a course reform prompted by structural changes within the university. This reform led to the elimination of high-stakes tests from the curriculum. In their place, Class 1 adopted a low-stake testing approach while the control group did not have any tests during the semester. These low-stakes tests were characterized by their non-compulsory nature, meaning that student participation was optional, and their scores did not contribute to the final grade. This transition marked a move towards a less pressured and more flexible assessment structure, aiming to align the course's evaluation methods with the revised educational framework and objectives.

This comprehensive approach, encompassing both practical assignments and varied testing methodologies, provides a multifaceted perspective on the pedagogical strategies employed within the calculus course, underscoring the
commitment to not only enhance student understanding but also to foster a more engaging and interactive learning environment.

Collection of Data

The university conducts overall evaluation of all the courses at the end of each course. The questions under analysis in this article are part of that anonymous survey. The survey ordinarily comprises fewer than 10 questions, concluding with an open-ended question soliciting free comments. These surveys were designed to garner feedback on the course overall and specifically in areas earmarked for attention, to gain insight into students’ experiences. This feedback is instrumental in improving future courses. The survey remained largely unchanged each year, ensuring consistency in the data collected. The specific questions that form the basis of our analysis in this article were kept consistent throughout the years.

The questions that are related to this article are:

- Q1: How satisfied are you with the course in overall? On a scale from 1 to 10, where 1 is very unsatisfied, and 10 is very satisfied.
- Q2: Approximately, how many hours did you spend on the Calculus course each week, including both class time and studying on your own?

As the same questions regarding the satisfactory level and time spent on the course are asked each year, we considered both the validity and reliability of these results as good. The overall student performance in Calculus course is evaluated by examining achieved grades. Typically, students receive letter grades ranging from A-F as their final exam result. However, for a more precise analysis in this article, we use the final exam scores, expressed as a percentage from 0 to 100.

For each year we have computed mean, median, standard deviation, and standard error for two groups: Class 1 and the control group. In addition, we have drawn a box-plot figure of the final exam scores. We have used Excel for computations and drawings.

As the curriculum of the Calculus course has remained the same over the years, the difficulty and comprehensiveness of the exams have been consistent, thereby maintaining their reliability. The validity of the exams is ensured by the Calculus teachers, who collaboratively create the exam each year. This collaboration ensures that the difficulty level remains similar over time and guarantees that all exam tasks have been covered during the lectures.

Results

In the years 2012 – 2019, a total of 1255 samples with data in the form of percentage scores on the final exam in Calculus was collected in this research. When including exam results given in letter grades (A-F), which are translated into percentages by averaging the percentages associated with each letter grade, the total number of samples reaches 1526. Statistics from 2020 and 2021 are excluded, as various factors related to the COVID-19 pandemic influenced changes in the data.

Comparison of Exam Results Between Class 1 and the Control Group

In this section, we compare the final exam scores between Class 1 and the control group in Calculus. All the students were given the same final exam. The difficulty level of the final exam was on a similar level each year, so the exam scores should be comparable.

Exam Results of Class 1

The practical assignments were first introduced in one of the calculus classes in 2013, mainly as an experiment and were not mandatory. The experience was positive, and thus the assignments were introduced as a part of the Calculus course for all the students in 2014.

The yearly performance for the Calculus course, illustrated via final exam scores from Table 1, presents noteworthy patterns and trends. In Class 1, an emphatic increase in the mean score was observed from 2012 to 2013, increasing from 52% to 68%. This immediate upsurge in performance coincided with the implementation of practical assignments, hinting at their direct contribution to enhanced student learning and understanding.

Interestingly, this trend was sustained over the subsequent six years, with the mean scores hovering around 65%, even peaking at 70% in 2017. This sustained improvement signifies the potential of practical assignments in fostering consistent academic progress over time. However, the decline in the mean score from 67% in 2018 to 55% in 2019, concurrent with the discontinuation of practical assignments, reinforces the positive influence these assignments appear to have on student performance.
Table 1. Final Exam in Calculus for Class 1. Scores are given in percentage

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Standard error</th>
<th>N</th>
<th>Practical assignment</th>
<th>High stake tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>52</td>
<td>52</td>
<td>24.99</td>
<td>3.77</td>
<td>44</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2013</td>
<td>68</td>
<td>67</td>
<td>20.70</td>
<td>2.90</td>
<td>51</td>
<td>Yes*</td>
<td>Yes</td>
</tr>
<tr>
<td>2014</td>
<td>61</td>
<td>64</td>
<td>19.94</td>
<td>2.91</td>
<td>47</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2015</td>
<td>65</td>
<td>67</td>
<td>26.34</td>
<td>3.88</td>
<td>46</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2016</td>
<td>65</td>
<td>67</td>
<td>26.59</td>
<td>4.26</td>
<td>39</td>
<td>Yes**</td>
<td>Yes</td>
</tr>
<tr>
<td>2017</td>
<td>70</td>
<td>74</td>
<td>21.05</td>
<td>4.30</td>
<td>24</td>
<td>Yes**</td>
<td>Yes</td>
</tr>
<tr>
<td>2018</td>
<td>67</td>
<td>69</td>
<td>20.42</td>
<td>3.08</td>
<td>44</td>
<td>Yes**</td>
<td>Yes***</td>
</tr>
<tr>
<td>2019</td>
<td>55</td>
<td>55</td>
<td>18.75</td>
<td>2.89</td>
<td>42</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

* Not mandatory, but most of the students in Class 1 participated. ** Practical assignment with group presentation  *** Low stake tests

Exam Results of the Control Group

In stark contrast, the control group from Table 2, not initially exposed to the same level of focused practical assignments, shows a less prominent shift in performance. Although a slight increase in mean scores was observed post-2014 following broader implementation of practical assignments - the overall trend was relatively flat compared to Class 1. This discrepancy could be attributed to variations in implementation quality, student engagement, or other classroom-specific factors.

Table 2. Final Exam Scores in Calculus for Control Group (Scores are Given in Percentage)

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Standard error</th>
<th>N</th>
<th>Practical assignment</th>
<th>High stake tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>50</td>
<td>52</td>
<td>24.22</td>
<td>2.39</td>
<td>103</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2013</td>
<td>44</td>
<td>40</td>
<td>26.58</td>
<td>2.43</td>
<td>120</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2014</td>
<td>46</td>
<td>46</td>
<td>27.87</td>
<td>2.36</td>
<td>140</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2015</td>
<td>60</td>
<td>67</td>
<td>24.29</td>
<td>1.79</td>
<td>185</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2016</td>
<td>54</td>
<td>53</td>
<td>26.94</td>
<td>1.87</td>
<td>207</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2017</td>
<td>60</td>
<td>62</td>
<td>27.38</td>
<td>2.13</td>
<td>166</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2018</td>
<td>48</td>
<td>50</td>
<td>28.51</td>
<td>2.48</td>
<td>132</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2019</td>
<td>56</td>
<td>58</td>
<td>21.35</td>
<td>1.83</td>
<td>136</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

The data from both Class 1 and the control group (see Table 1 and Table 2) offer an essential perspective on score distribution and variability across the years. Class 1, benefiting from introducing practical assignments, typically demonstrated improved outcomes and fewer score fluctuations than the control group. The reduced variance in scores suggests that practical assignments may level the playing field for students, by offering structured, practicable learning opportunities. This could potentially enable a more universally high standard of learning, regardless of individual learning strengths and weaknesses.

Comparison of Exam Results

Figure 2 shows a box-plot comparison between Class 1 and the control group. Notably, the median scores and interquartile ranges depicted further substantiate the differential performance between Class 1 and the control group, especially in 2013, the inaugural year of the practical assignment implementation in Class 1. The box-plot analysis clearly shows that the assignment has benefited students to pass the course, as the percentage of students passing the course is higher than in the control group. This year marks a significant deviation, with Class 1 outperforming the control group, suggesting that the introduction of practical assignments may have been a catalytic factor in enhancing student engagement and comprehension in Class 1.
Moreover, the comparative standard deviation and standard error metrics across the years indicate a degree of variability in student performance within both Class 1 and the control group. This variability might reflect inherent differences in student cohorts, the distinct pedagogical approaches of individual instructors, or the varied classroom environments. The consistently higher median scores in Class 1 compared to the control group, particularly in the years when practical assignments were a focal teaching strategy, suggest that these assignments could be a significant factor in fostering a deeper understanding and appreciation of the course material.

**Analysis of Course Evaluation Survey Data**

Data for time spent and satisfaction were collected via anonymous surveys. The questions about the time spent included time spent on lectures and exercises classes as well as time spent outside the classes doing math related work. No data on time spent was collected in the control group.

Survey participation is a key variable to consider, as the high participation rates significantly influence the reported time spent on coursework and satisfaction levels. The percentage of students \( \frac{N}{N_{\text{tot}}} \) taking part in the survey each year, displayed in the last column of Table 3, offers an overview of the survey participation rates, showing a strong turnout each year. The survey is usually given to Class 1 at the end of a lecture towards the end of the semester.

As shown in Table 3, the satisfaction level increased from an average score of 8.6 in 2012 to 9.38 in 2013, when the practical assignments were introduced. We can also see the average time spent increased when practical assignments were introduced in 2014, and it dropped when the high-stake tests were replaced by low-stake tests in 2018. It dropped even more when the practical assignments were discontinued in 2019. The original plan was to make further observations in the following years to see more effects of the practical assignments in Calculus, but the drastic changes in teaching during the COVID epidemic made it hard to have more accurate measures.

**Table 3. Overview of Student Satisfaction, Time Spent, and Mean Exam Scores per Year in Class 1 in Calculus in the Period 2012-2019**

<table>
<thead>
<tr>
<th>Year</th>
<th>Satisfaction (1 - 10)</th>
<th>Time spent (per week)</th>
<th>Mean score final exam (%)</th>
<th>Practical assignment</th>
<th>High-stake tests</th>
<th>N</th>
<th>( \frac{N}{N_{\text{tot}}} ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>8.6</td>
<td>21.53</td>
<td>52</td>
<td>No</td>
<td>Yes</td>
<td>40</td>
<td>91</td>
</tr>
<tr>
<td>2013</td>
<td>9.38</td>
<td>18.62</td>
<td>68</td>
<td>Yes*</td>
<td>Yes</td>
<td>42</td>
<td>82</td>
</tr>
<tr>
<td>2014</td>
<td>9.74</td>
<td>25.24</td>
<td>61</td>
<td>Yes</td>
<td>Yes</td>
<td>46</td>
<td>98</td>
</tr>
<tr>
<td>2015</td>
<td>9.65</td>
<td>22.06</td>
<td>65</td>
<td>Yes</td>
<td>Yes</td>
<td>31</td>
<td>67</td>
</tr>
<tr>
<td>2016</td>
<td>9.63</td>
<td>21.37</td>
<td>65</td>
<td>Yes**</td>
<td>Yes</td>
<td>26</td>
<td>67</td>
</tr>
<tr>
<td>2017</td>
<td>9.78</td>
<td>31.78</td>
<td>70</td>
<td>Yes**</td>
<td>Yes</td>
<td>18</td>
<td>75</td>
</tr>
<tr>
<td>2018</td>
<td>9.36</td>
<td>19.45</td>
<td>67</td>
<td>Yes**</td>
<td>Yes***</td>
<td>33</td>
<td>75</td>
</tr>
<tr>
<td>2019</td>
<td>9.05</td>
<td>15.08</td>
<td>55</td>
<td>No</td>
<td>No</td>
<td>38</td>
<td>90</td>
</tr>
</tbody>
</table>

N is the number of participants in the survey. \( N_{\text{tot}} \) is the total number of students who took the final exam.

* Not mandatory, but most of the students in Class 1 participated. ** Practical assignment with group presentation. *** Low-stake tests

**Figure 2. Median Scores (\( - \)), Mean Scores (\( \bar{x} \)), and Interquartile Range Compared Between Class 1 and the Control Group**
The introduction of practical assignments in 2013 marked a significant turning point in both the satisfaction levels and the time students devoted to the course. Notably, there was a marked increase in student satisfaction from an average score of 8.6 in 2012 to 9.38 in 2013, indicating a positive reception of the practical assignments among the students. This upward trend in satisfaction continued, peaking in 2017 with a score of 9.78, which coincided with the implementation of group presentations as a component of the practical assignments.

Concurrently, the average time students spent on the course per week exhibited fluctuations that are noteworthy. The introduction of practical assignments in 2014 corresponded with an increase in the average weekly time spent on the course, reaching its maximum in 2017 at 31.78 hours. This suggests that the practical assignments, particularly in their group format, were not only well-received but also prompted students to invest more time in the course. However, it is important to note the drop-in time spent in 2018 and 2019, aligning with the replacement of high-stake tests with low-stake tests and the discontinuation of practical assignments, respectively. The drop in time investment in 2019 to 15.08 hours per week, coupled with a decrease in satisfaction to 9.05, underscores the potential influence of practical assignments in sustaining student engagement and commitment to the course.

**Other Factors Affecting Findings**

While quantitative data highlights a distinct positive correlation between practical assignments and student outcomes, we must account for potential confounding variables. The impact of varying instructor effectiveness on outcomes can be significant, given that each teacher has a unique teaching style that can influence student understanding, performance, and willingness to invest time in the course. Similarly, variances in student motivation can greatly affect performance, as motivation is complex and individualistic, shaped by factors spanning beyond the course, like personal goals or types of motivation (intrinsic or extrinsic). Notably, it’s not a single variable but a complex aggregation of these factors that can explain the diverse fluctuations in student performance. Hence, our data, while pointing to a correlation between practical assignments and enhanced student performance, is embedded in a larger, nuanced academic context. Still, our quantitative observations are echoed in qualitative data and anecdotal evidence, further attesting to the significant role of practical assignments in fostering comprehension and course material engagement.

**Discussion**

The integration of practical assignments into the calculus curriculum, as evidenced by our data, has elucidated several key insights into the dynamics of STEM education, particularly concerning student performance and engagement.

**Correlation Between Practical Assignments and Student Performance**

The introduction of practical assignments in Class 1 led to a notable increase in student performance, with mean scores rising from 52% in 2012 to 68% in 2013. This improvement underscores the potential of practical, real-life applications to make academic content more accessible and engaging for students. However, the subsequent fluctuations in mean scores from 2014 to 2019 necessitate a nuanced understanding. These variations imply that while practical assignments have the potential to enhance learning, their effectiveness is not isolated but interwoven with various instructional and contextual factors. During the assignment years, the mean scores and lower interquartile of Class 1 was higher than for the control group. In addition, the decline in performance in 2019, after the withdrawal of practical assignments, subtly points to the positive role these assignments might play in the educational process.

**The Complexity of Educational Interventions**

Our analysis reveals that the efficacy of practical assignments is not universal but varies across different classroom settings and instructional methodologies. This variation is reflective of the complex nature of educational interventions, where multiple factors interplay to influence learning outcomes. The differential impact of practical assignments across Class 1 and the control group underscores the need for a tailored approach to educational strategies, one that considers the unique dynamics of each learning environment. Our findings support earlier studies showing positive effect of problem-based learning in Calculus course, see e.g. (Andrá et al., 2019; Awaludin et al., 2020).

**Student Satisfaction**

Parallel to improvements in academic performance, the introduction of practical assignments was also associated with an increase in student satisfaction. This correlation between hands-on, practical learning and student contentment emphasizes the value of engaging instructional methods. It highlights the importance of not just teaching the academic content but doing so in a manner that resonates with the students, fostering a learning environment where practical application and theoretical knowledge complement each other.

**Balancing Time, Resources, and Learning Outcomes**

While the practical assignments did not significantly alter the overall time students allocated to the course, the highest levels of engagement and performance coincided with periods where these assignments were a central component of the
This observation points to the qualitative impact of learning activities; it’s not just the quantity of time spent, but how that time is utilized that influences learning outcomes. Implementing such assignments, however, requires thoughtful consideration of the resources, time, and logistical support needed, particularly in larger classes where the complexity of coordination is amplified.

Reflecting on the Findings

As we interpret these findings, it’s crucial to maintain a critical perspective. The observed correlations between practical assignments and learning outcomes, while suggestive, do not definitively establish causality. Educational environments are inherently complex, and thus, these findings should be considered as part of a broader pedagogical context. They underscore the importance of continued research and reflective practice to fully comprehend and harness the potential of practical assignments in enhancing STEM education.

Conclusions

This longitudinal study, (2012-2019) with 1526 samples, highlights the significant role of practical assignments in enhancing the understanding and performance of calculus students within STEM education as it answers to our research question: "How do practical mathematics assignments integrated into calculus courses influence student performance and perception in subsequent STEM courses?"

The incorporation of these assignments, in tandem with strategic high-stake testing, appears to correlate with notable improvements in academic performance, demonstrating the effectiveness of connecting mathematical theory with practical, real-world applications. Additionally, the increase in satisfaction underscores the value of experiential learning in making educational content more relevant and stimulating.

As Calculus course is mandatory for several different STEM-studies, and student, with different interests, participate the same course, the course is often given as a “generalized” version. The assignments used in our Calculus 1 course were student-generated, meaning that the students had the possibility to select tasks that were relevant to their own STEM-study path, closing the gap between Calculus and the other STEM courses.

However, the successful implementation of practical assignments requires careful consideration of curriculum design, resource allocation, and instructional methodologies. Future research should aim to explore the long-term impacts of these assignments, considering various student demographics and educational contexts.

In conclusion, the findings of this study advocate for the strategic integration of practical assignments in STEM education, emphasizing their potential to enrich the learning experience and foster a more engaging and contextually rich educational environment.

Recommendations

To maximize the potential of practical assignments in enhancing STEM education, it is recommended to ensure the contextual relevance of these assignments, aligning them closely with real-world scenarios to render the learning experience more engaging. Appropriate resource allocation is crucial, particularly in larger classes where logistical complexities can undermine the efficacy of practical assignments. Instructor training is paramount; educators should be equipped with the necessary skills and strategies to integrate, manage, and assess these assignments effectively. This includes creating meaningful assignments, evaluating them appropriately, and offering constructive feedback. A system for continuous assessment is also vital, enabling the monitoring of student progress and the evaluation of the assignments’ effectiveness in real time. Finally, fostering a collaborative learning environment can significantly enhance the value of practical assignments, encouraging teamwork, communication, and the development of problem-solving skills among students.

Limitations

However, this study is not without its limitations. The findings are drawn from a specific academic context, potentially limiting their applicability to other settings or disciplines within STEM education. The impact of instructor variability, such as differences in teaching styles and the integration of assignments into the curriculum, can influence the outcomes and consistency of the study. Furthermore, the possibility of student self-selection bias should be considered; students who are more inclined to engage with practical assignments might inherently possess greater motivation or interest in the subject. The study’s timeframe also imposes constraints, particularly concerning the exploration of the long-term impacts of practical assignments on student learning trajectories. Lastly, the study’s emphasis on quantitative analysis, while robust, could be complementarily enhanced by incorporating qualitative data to capture a fuller spectrum of student and instructor experiences and perceptions.

In acknowledging these limitations, the study not only provides a nuanced understanding of the current landscape but also paves the way for future research. It encourages further exploration into the role of practical assignments across various educational settings and disciplines within STEM education, advocating for a balanced approach that combines both quantitative and qualitative methodologies. By doing so, it aims to foster a more comprehensive and profound

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understanding of the dynamic interplay between teaching methodologies, student engagement, and educational outcomes in the realm of STEM education.

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Authorship Contribution Statement

Jin: Concept and design, data acquisition, data analysis and interpretation, drafting manuscript, critical revision of manuscript, final approval. Helkala: Analysis and interpretation, drafting manuscript, critical revision of manuscript, final approval.

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