Interactive Tutorials in Undergraduate Mathematics: What Are They Good For?

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In-person tutorials present a prime opportunity for students to work with others to engage their problem-solving and critical-thinking skills. We investigate the use of interactive tutorials in a large, second-year service mathematics course as part of a quasi-experiment whereby students could either attend in-person tutorials (for a participation mark) or complete the tutorials individually without attending the live sessions and submit solutions for credit. Our analyses of student data and self-efficacy measures suggest that consistent attendance at in-person tutorials may maintain and improve students' self-efficacy. Median changes to self-efficacy measures for students who attended in-person tutorials were higher than those who completed tutorials individually without attending the live sessions. The difference between the changes to the Emotional Regulation aspect of tutorial self-efficacy was statistically significant (p = .031)*, highlighting the role in-person tutorials play in supporting students' mathematical learning beyond academic outcomes.*

Keywords: self-efficacy, tutorials, in-person learning, online learning

The integration of online learning and technology into higher education continues to induce a paradigm shift in the way we view teaching and learning in mathematics. Recently, the Covid-19 pandemic has perturbed the norms of teaching and learning. Despite setbacks, it has been a chance for institutions to realize the potential and necessity for online delivery methods, not only as means to continue activities during a crisis but also to stay relevant in an increasingly competitive tertiary market. It is difficult to compete with the low-cost and flexible nature of online education. As a result, we can expect to see the number of online components within traditional courses continue to grow. The use of lecture capture technology and learning management systems have made it possible for lectures and resources to be readily accessible. However, finding an online substitute that can deliver the same level of engagement and retain the interactive components is an issue yet to be resolved. One component of undergraduate mathematics that cannot be easily replaced is the opportunity for collaborative face-to-face learning – in New Zealand, this usually happens during tutorials, which are weekly 1-hour classes scheduled in addition to lectures.

Tutorials, like those conducted within our course of interest, have not received as much attention from researchers, especially in comparison to lectures. Hence, we must gain a deeper understanding of the contribution of in-person tutorials to one's experience of learning mathematics. This study aims to quantify the effects of in-person undergraduate mathematics tutorials on self-efficacy and address the benefits that tutorials can provide that simply cannot be matched through online means.

Theoretical framework

Self-efficacy

Theoretical framework Self-efficacy is a psychological construct that allows researchers to understand how an individual's action can shape an outcome. Used extensively within educational psychology, Bandura (1997) defines perceived self-efficacy as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (p.3). Self-efficacy may have a potentially greater initial impact on performance than other related constructs, such as outcome expectations (Sexton & Tuckman, 1991).

Self-efficacy, first proposed by Bandura (1977), is influenced by four main sources: mastery experience, vicarious experience, social persuasion, and psychological states (1997). Mastery experience is considered the most significant source (Bandura, 1997; Usher & Pajares, 2008) as it provides the most realistic indication that students can succeed in a given task. All four sources have a significant contribution to self-efficacy beliefs.

Self-efficacy, the measure of one's belief in their ability to successfully perform a given task, has been well-established as a strong predictor of performance and intrinsic factors in mathematics. Early research into mathematics self-efficacy showed it had a much stronger direct effect on performance than variables such as prior experience, gender, or self-concept (Pajares & Miller, 1994). Similar positive relationships between self-efficacy and performance have been reported in schools (Pajares & Kranzler, 1995; Pantziara & Philippou, 2015) and at the undergraduate level (Pajares & Miller, 1994; Peters, 2013). As a significant predictor of achievement, analyzing measures of self-efficacy can help us to better understand their impact on students and inform the way they are implemented into higher education courses.

Motivation

Using a quasi-experimental design, we sought to examine the potential impacts of tutorials in two ways. First, we were interested to see if there was a significant difference in student performance (final exam grades and overall grades) between students that primarily attended the in-person tutorial sessions compared to those that submitted their work online. Previous studies in similar settings report the use of live components to be associated with higher achievement (Howard et al., 2018; Inglis et al., 2011). However, these studies focused on the difference between attending live lectures versus watching lecture recordings. Students often justify their use of asynchronous video resources by praising the control of pace it provides and the flexibility it affords (Howard et al., 2018). However, the negative association between achievement and higher use of lecture recordings has primarily been consistent across the undergraduate mathematics education literature reported in a recent systematic review (Lindsay & Evans, 2021). It is thought that lecture recordings promote surface-level approaches, thus degrading the quality of learning. However, considering the interactive nature of tutorials, we expect to see a similar relationship between in-person tutorial attendance and performance.

Second, we set out to investigate tutorials' impact on a significant intrinsic construct: self-efficacy. As a significant predictor of success, among other variables, understanding this impact would allow researchers and course designers to utilize this understudied aspect of undergraduate courses best, whether it be to justify policies in favor of more fully online mathematics education at undergraduate levels or as evidence to consolidate the use of in-person tutorials for the near future in a delicate time of change in education.

Study setting

This study investigated the tutorials within a large, second-year service mathematics course at the University of Auckland. The course, General Mathematics 2, is split into three main topics that cover the content required across many disciplines: calculus, linear algebra, and differential equations. Assessments in the course are divided into four sections: coursework (including engagement with tutorials) – 15%, mid-semester test – 20%, quizzes – 15%, and a final exam – 50%.

While the Covid-19 pandemic disrupted many on-campus activities throughout 2020 and led to a shift to remote delivery methods, the first semester of 2021 presented itself as a relatively unperturbed semester, with most university activities returning to campus. However, with the risk of Covid-19 still looming over the community and international students being located outside of the country, remote options to complete coursework were made available for students.

Tutorials

This format of interactive tutorials is standard at the undergraduate level at the University of Auckland and is often met with positive feedback from students that note the usefulness of learning from others in a supportive space (Oates et al., 2016). In the tutorials, students are given opportunities to collaborate with their peers while problem-solving. Each tutorial session is one hour long and occurs weekly. A tutor is available during the session to help address questions and monitor each group's progress. While attendance or completion of the tutorials in our course was not mandatory, it was highly encouraged for all students and had a small contribution to overall grades. Students could receive marks contributing to their coursework grade by attending an in-person session or completing the questions and uploading their work to a learning management system (Canvas).

The term 'tutorial' is often used in two contrasting ways in the literature. One refers to learning opportunities where attendance is optional and is directed at supporting students, often serving a remedial purpose. In many institutions, mathematics support centers subsume this role (Cronin & Meehan, 2021; Mullen et al., 2022). The other, which we utilize in this work, refers to a core component of undergraduate courses that, like lectures, aim to provide another medium to engage learners with the content. This shares many aspects of a lab session in chemistry courses, where students apply knowledge from lectures to engage their problem-solving and critical-thinking skills.

Data

Student Data

Student data was collected during the first semester of 2021 via Canvas. In total, there were 354 students enrolled in the course. Student data included tutorial attendance/completion and performance in the course, including final exams. Of the 354 students enrolled,186 students attended or completed all 9 tutorials. Due to Covid-19 health restrictions, the first scheduled tutorial session (in the second week of the semester) occurred online rather than in-person. To best capture the potential impact of consistent engagement of tutorials, we have not included the data of students that did not complete all the tutorials or were limited to one option in our analyses (e.g., offshore students that could not attend the on-campus sessions). Data from these 129 students (36% of the course) will be analyzed further to capture the impact of consistent tutorial engagement over the semester.

Self-efficacy Measures

Student self-efficacy was measured using the Measure of Assessment Self-Efficacy for Mathematics Tutorials (MASE-T) (Evans & Jeong, 2023; Riegel et al., 2022). The instrument measures assessment-related self-efficacy across two factors: *Comprehension and Execution* (CE), and *Emotional Regulation* (ER). The instrument has been validated and shown to be reliable at measuring student assessment self-efficacy across different contexts, including tutorials. Of the students enrolled in the course, 219 students provided measures of their self-efficacy at the start and the end of the semester. In total, data from 100 students who completed all tutorials and provided self-efficacy measures will be used for the analysis.

Attendance Groups

Students were classified into two groups by the number of tutorials they attended over the course. Table 1 shows the distributions of the 129 students by the number of in-person tutorials they attended. Students were grouped into two groups: those that attended less than half of the total in-person tutorials (i.e., 0-4 in-person tutorials attended, $n = 23$) and those that attended more than half of the total in-person tutorials (i.e., 5-9 in-person tutorials attended, $n = 106$). Herein, the two groups will be referred to as *online* and *in-person*, respectively.

Table 1. Number of in-person tutorials attended across the semester.

In-person tutorials attended	*n*	%
0	11	8.5
1	3	2.3
2	5	3.9
3	2	1.6
4	2	1.6
5	1	0.8
6	6	4.7
7	15	11.6
8	25	19.4
9	59	45.7

The attendance behavior of students throughout the semester suggests that students showed a strong preference for one of the learning environments over the other, as seen by the large proportion of students that attended either 0-2 or 7-9 in-person tutorials. The number of students opting for each method of tutorial completion (in-person/online) remained relatively consistent across the semester (Table 2). One possible explanation for the slight decrease in the number of in-person attendees for tutorials 4 and 5 could be that some students may have prioritized their time to prepare for the mid-semester test and completed the tutorials individually for those weeks.

Table 2. Tutorial attendance across the semester by attendance groups.

Tutorial	2	3	4	5	6	7	8	9	10
In-person	107	106	92	90	101	102	102	104	100
Online	22	23	37	39	28	27	27	25	29

Results

Performance

An independent-sample *t*-test was run to determine if there were differences in the mean final exam score and overall grade of online and in-person students. An initial assessment for outliers, normality (as assessed by Shapiro-Wilk's test ($p > .05$), and homogeneity of variances (Levene's test ($p = .405$, $p = .325$)) was conducted for both the final exam grade and overall grade data with no violations being detected in either set of data.

The mean final exam score was higher for online students ($M = 73.8$, $SD = 13.3$) than in-person students ($M = 61.3$, $SD = 16.8$), a statistically significant difference with medium effect size, $M = 12.5$, 95% CI [5.1, 19.9], $t(127) = 3.349$, $p = .001$, $d = .77$. The online group also had a higher mean overall grade ($M = 78.2$, $SD = 9.9$) than the in-person group ($M = 70.8$, $SD = 12.6$). This difference was also statistically significant with medium effect size , $M = 7.4$, 95% CI [1.8, 12.9], $t(127) = 2.637$, $p = .009$, $d = .61$.

Self-efficacy

Due to violations in the normality of the self-efficacy data, Mann-Whitney *U* tests were undertaken to determine whether there were any significant differences between groups. First, the median and mean ranks for all measures of initial self-efficacy were higher in the online group than in the in-person group. By the end of the semester, this was not the case. In particular, the median and mean rank for all tutorial self-efficacy measures were higher in the in-person group than in the online group. The online group still had a higher median and mean rank for all exam self-efficacy measures by the end of the semester. However, these results were not statistically significant ($p > .05$).

Second, the analysis of the changes in participant self-efficacy between the start and the end of the semester revealed the following. A significant difference was observed in the *Emotional Regulation* factor of tutorial self-efficacy, which was statistically significantly higher at the end of the semester for the in-person group (mean rank = 53.12) than for the online group (mean rank = 35.63), $U = 860.5$, $z = 2.153$, $p = .031$ (Figure 1).

Similarly, change in the *Comprehension and Execution* factor of tutorial self-efficacy ($U = 792$, $z = 1.491$, $p = .136$) and overall change in tutorial self-efficacy ($U = 835$, $z = 1.907$, $p = .057$) was higher for the in-person group with these differences almost reaching a level of statistical significance.

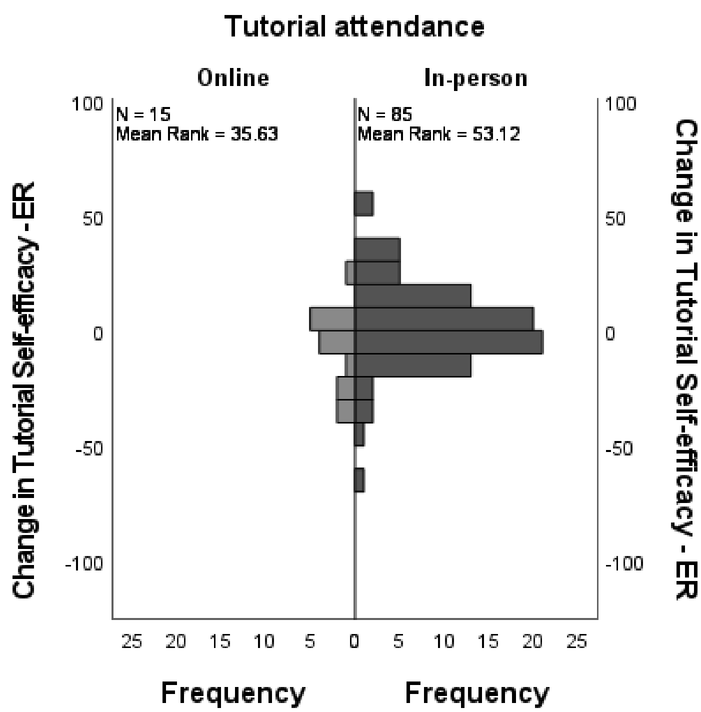

Figure 1: Histograms of the change in the Emotional Regulation (ER) factor of tutorial self-efficacy. The in-person group saw a greater increase than the online group, p = .031.

Discussion

Performance

Our findings showed a statistically significant between-group difference in performance in the final exam and overall grades in the course. A significant difference in performance between groups of students that utilize different study methods is not a unique finding. Inglis et al. (2011) reported that students that relied more on online recordings (lecture capture) were associated with lower grades in the course, while live lecture attendance was met with improved grades. Similar findings were reported by Howard et al. (2018).

While we report a correlation within our data pertaining to learning activities within a large undergraduate course, our study differs from the existing literature in two ways. The first is that our study investigated the use of tutorials, which, as an integral part of tertiary mathematics, has not been fully explored using quantitative analyses. This study analyses the value of undergraduate mathematics tutorials through the lens of self-efficacy. Secondly, our correlation found that using a live study component, that is, in-person tutorials, was associated with lower performance grades, unlike the studies mentioned previously. While we cannot say whether students with a higher aptitude for mathematics chose to study a particular way or that the use of tutorials may not foster mathematical learning, we speculate that there is more to this phenomenon that warrants further investigation. With both forms of tutorial engagement involving the same problem sets, it seems unlikely that this difference is due to differences in content coverage.

One possible cause for this difference could lie in prior knowledge. In a recent study, Zakariya et al. (2021) consider prior knowledge when examining students' approaches to learning and their performance. Their analysis suggests that low prior knowledge may be conducive to surface-level approaches to learning which can have a significant, negative effect on performance (Zakariya et al., 2021). Within our learning context, we can expect students enrolling into a service mathematics course to have a wide range of mathematical abilities that may have influenced how they choose to learn. Possibly, students with low prior knowledge perceived in-person tutorials as an easier option to score 100% by simply showing up, whereas the online option required a written submission for marking.

The presence of high- and low-achieving students in both groups could indicate that students are making more conscious decisions about how they choose to study. This may be driven by a heightened appreciation of the benefits of each study option. Research from the pandemic shows that many students desired opportunities for social interaction, immediate feedback, and wanted to return to campus, noting difficulties in staying focused and motivated at home (Mullen et al., 2022; Radmehr & Goodchild, 2022). However, the oft-praised flexibility provided by remote study options could very well be a priority for many individuals that prefer to study online (Thompson & McDowell, 2019). Thus, we cannot make any concrete claims about students' motivation behind their preferred study method without using qualitative data.

Self-efficacy

First, the median initial self-efficacy measures were higher for online students than the in-person students. While this difference was not significant, it is worth noting as a potential factor in student decision-making about how to study. This hypothesis is in line with the literature reporting that students find enrolling in online courses for subjects that are perceived to be easier for them to be more favorable (Jaggars, 2014).

When comparing the changes to self-efficacy, the in-person students saw no negative changes to the median exam and tutorial self-efficacy measures. For the online group, the change to median self-efficacy measures remained unchanged for the *Comprehension and Execution* factor of their exam self-efficacy, while it dropped for all others. The greatest median changes for online students were seen in their tutorial self-efficacy, with significant changes in the *Emotional Regulation* factor of tutorial self-efficacy. The localization of this significant change is consistent with the domain-specific nature of self-efficacy (Pajares & Miller, 1995). Additionally, it strongly suggests that the benefits of interactive tutorials at the undergraduate level can branch into affective factors. It may help to maintain positive beliefs within individuals and foster a greater sense of community between learners.

The in-person tutorials with a group-work component promote a high degree of social engagement between peers and experienced tutors, seen in the form of immediate feedback and words of encouragement and motivation. At the undergraduate level, these are conducive to active learning and position tutorials as positively contributing to achievement (Freeman et al., 2014). The negative correlation between achievement and in-person tutorial attendance, while significant, cannot be used to make a claim for or against one form of tutorial engagement. In order to do so, we need to control for factors that influence performance, such as prior knowledge. We can also reflect on the differences offered by each delivery mode.

One key difference between the two groups in our study is the learning environment where student active (cognitive) engagement occurs. In-person tutorials provide an opportunity for collaborative learning through the presence of peers and tutors. From the perspective of cognitive psychology, this could be beneficial, as evidenced by the *collective working memory effect* (Kirschner et al., 2011; Kirschner et al., 2018). This effect suggests that learning as a group is more effective than individual learning if the material is sufficiently complex, exceeding the limits of each individual student's working memory. "In this situation, the cognitive load of processing this complex material is shared among the members of a collaborative learning team enabling more effective processing and easier comprehension of the material." (Kirschner et al., 2018, p. 222). However, the researchers caution that bringing together a group of learners is no guarantee that the learning would happen efficiently as many other factors are involved.

Our findings show that, on average, the trajectory of students' *Emotional Regulation* component of tutorial self-efficacy is improved through their participation in in-person tutorials. Thus, shifting our perspective to what is uniquely offered by in-person tutorials could be worthwhile to better understand their importance in undergraduate mathematics learning.

Limitations

It would be ill-considered to generalize the finding to different courses or contexts or to completely refute the effects tutorials may have on other aspects of self-efficacy. Considering many of the differences were borderline statistically significant, it would be worth investigating different courses, including those specific to mathematics majors.

We recognize the importance of collecting more measures of learning, including qualitative data, such as students' perspectives on tutorials as a learning resource. This could improve our understanding of students' preferences, provide us with a different lens to analyze our findings, and allow us to explore the more nuanced differences between the delivery modes.

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