Blending online homework and large class tutorials to provide learning support for introductory organic chemistry.

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Abstract
The logistics and cost of running large class tutorials to improve learning for students in high enrolment courses raise questions about whether the associated effort and cost are worthwhile. The option to replace these class activities with online homework with its promise of built-in feedback is attractive. Using an activity theory lens and an experimental design, we compared the impact of class tutorials and online homework to support learning offered in face-to-face lectures on student performance. We found that there were no topics in the introductory organic chemistry syllabus in which students who had completed online homework instead of large class tutorials performed better. By contrast, for all topics except "Curved arrows in mechanisms", the mean performance of students who attended a large class tutorial was statistically significantly better than for those who completed online homework instead. This large quantitative study with a sample of 667 students demonstrated the advantage conferred by face-to-face tutorials with peer learning and personal feedback even in a large class setting with only three sessions per student. Our recommendation is that an online homework system in blended courses should not replace face-to-face tutorials for topics reliant on personalized instruction and feedback. We motivate for investing resources and effort to provide face-to-face problem-solving sessions in high enrolment introductory organic chemistry courses to improve performance.

Keywords
First-year undergraduate, cooperative learning, hybrid learning, activity theory

Introduction

Increasing access to higher education has led to large classes which make effective class tutorials difficult and expensive to run, especially when the numbers can only be accommodated in large stadium venues. Educators have turned to blended learning which combines traditional face-to-face (F2F) learning with online (OL) learning to harness the advantages of both modalities and overcome their constraints. Online homework may bridge the gap between the students and the instructor in large enrolment courses by providing students with a supportive mechanism for regulated learning of content (Richards-Babb, 2015). Online learning does not suffer from venue limitations and offers flexible, convenient learning environments where students take responsibility for their learning (Chandra and Fisher 2009). Furthermore, online homework can potentially address student passivity and poor engagement with content by requiring time on task (Means et al., 2010). The use of online homework has been shown to improve student success in a large first-year statistics course when combined with a flipped class instructional design (Reyneke et al., 2018), and in organic chemistry (Malik et al. 2014; Parker & Loudon, 2013; Richards-Babb et al., 2018).

Despite these potential benefits of online homework, online learning is known to require students to take a greater responsibility for their learning than is the case during equivalent face-to-face sessions (Anthonysamy, et al., 2020). This raises the concern that the use of online homework may widen the performance gap between poorly performing students and successful students. Additional concerns are that students may guess or obtain answers from peers, resulting in artificially inflated grades in online work without translating to improved final performance (Richards-Babb et al., 2015; Smithrud & Pinhas, 2015), and that students may miss out on the peer learning associated with face-to-face settings and which has been shown to improve student motivation (Liu et al., 2018). Furthermore, some skills may be difficult to develop without explicit guidance from a knowledgeable other. For example, in organic chemistry, hand-held models have been used in face-to-face teaching of organic chemistry to develop a three-dimensional conceptual understanding of two-dimensional representations (Mohamed-Salah & Alain, 2016), but it is not known if this is likely to occur effectively in online settings.

In optimizing blended instruction, it is important to know when F2F interaction is essential or preferred for learning to occur and when online technologies are well suited to the topic (Graham, 2006). There has been no comparison of the impact of online homework and large class face-to-face tutorials on student performance in organic chemistry. Furthermore, such impact has not been investigated for specific topics in the introductory organic chemistry syllabus. This knowledge is particularly important as we return to contact teaching after the Covid-19 pandemic and respond to calls to reform our instructional design to include more online learning. We aimed to explore the association between tutorial modality and student performance for key topics in introductory organic chemistry.

The following research questions guided the project:

- What is the impact of the modality of tutorial support on student performance?
- Which tutorial modality (face-to-face versus online) is more successful for each topic in the organic chemistry syllabus?

Theoretical Framework

Activity theory (AT), first formulated by Engeström (1987) was used as the guiding theoretical framework for this study. Learning is complex and contextualized and AT provides a lens with which to examine different aspects of the learning system (Lee et al., 2021). AT arose from Vygotsky's (1978) social constructivist view that individuals co-construct learning in a social context through active processes. AT requires that an activity system be identified to explore how a subject (such as a group of students) moves towards an object (such as to learn chemistry) to achieve the outcome (such as successful completion of a course). AT recognizes that this process is dependent on the community in which the activity takes place mediated by the associated tools, rules and division of labour. Activities are not isolated. Rather, other components of the system and external influences can change the outcome of an activity system (Bottino et al., 1999). AT uses the term "contradictions"' to indicate a misfit within elements, between them, between different activities, or between different developmental phases of a single activity (Kuutti, 1996). Once identified, these contradictions are considered an opportunity for development.

Of particular interest to this study are the "tools" of online homework assignments and class tutorials as practised in the "community" of tutorial groups and tutors in the face-to-face setting and online assignments with their associated "rules" (Figure 1). Rules refer to the constraints that regulate the components and operations within the system. Division of labour refers to the roles and relationships within the community that affect task division (Lee et al., 2021)

AT has been used to guide diverse studies in a chemistry education context (Hite & Thompson, 2019; Lee et al., 2021; Van Aalsvoort, 2004). It is particularly useful as a lens to examine relationships within a learning activity system to redesign learning activities for educational development (Lovatt et al., 2007).

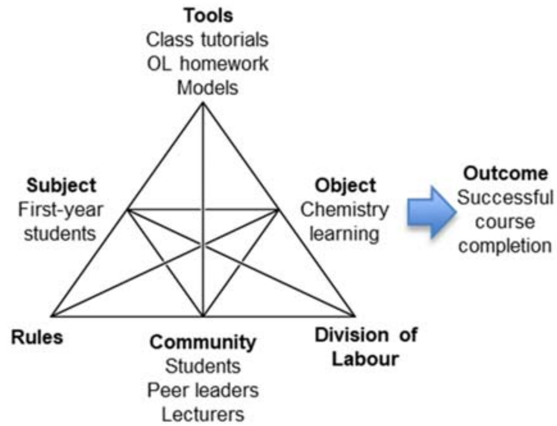

Figure 1. Engestrőm's activity theory applied to introductory organic chemistry learning support.

The Context

The context of this study is the 7.5-week organic chemistry component of a second-semester general chemistry course at a large research-intensive university in South Africa. It serves approximately 1400 students in three different lecture groups (3 sections) with the groups mixed and divided into 5 groups for laboratory sessions. The class is primarily a service course for biology majors (1000) and some students in the physical and mathematical sciences (300) but includes about 60 students who will complete three years of chemistry, 15 of whom will complete four years or more.

Increasing student enrolment meant that our laboratory capacity was exceeded resulting in the need to divide the class in half and offer laboratory sessions once in two weeks. In order to continue to support student learning weekly, students who were not attending a laboratory session in a particular week were required to attend a large class tutorial (150 students in a 450-seat lecture theatre). To help both groups of students to keep up with the pace of the course, we adopted a blended learning approach in which students who were participating in a laboratory session in a particular week had to complete online homework that mirrored the content of the class tutorial. Thus, on a rotation basis, students alternated between attending a class tutorial and completing online homework.

Course design

The large class tutorials were designed for full active learning incorporating aspects of Peer Led Team Learning (Robert et al., 2016). Peer leaders were selected from our limited pool of senior undergraduate and postgraduate students to provide a tutor to student ratio of approximately 1:25. Peer leaders were trained to scaffold student learning using short probing questions to draw on students' prior knowledge and to develop students' reasoning skills (Kulatunga & Lewis, 2013). A structured worksheet of problems aimed at developing conceptual understanding and reasoning skills was prepared for each tutorial since in less structured environments students may limit their questions to only what is perceived to be necessary to pass the examination (Lovatt et al., 2007). Where appropriate, the worksheets required the use of hand-held chemistry models to translate between representations or compare relative energies of alternative conformations. Students were encouraged to form groups to work on the problems during the tutorial session and to ask each other before asking for help to use peer leader time more effectively. Furthermore, once a group of students had been assisted, they were requested to assist fellow students in the vicinity. Since each student only attends three tutorials, we avoided allocating students to specific groups with a specific peer leader as there was insufficient time to overcome the social anxiety of being in a group with unknown people, shown to impede peer learning (Eren-Sisman et al., 2018). Each venue had a more senior peer leader who started the session by giving pointers for approaching the first problem. These leaders paced the group and highlighted core issues at the end of each section of the worksheet. At the end of each 2-hour tutorial session, students wrote a test covering the tutorial content and the content of the previous tutorial.

Our textbook's online learning platform was used for the online homework. To discourage copying answers from others, questions were grouped into pools so that each student got a unique combination of questions. To align the online homework with the class tutorials, the question database was supplemented with questions from the class tutorial worksheets. Most of the questions were open-ended with a number requiring the students to draw organic structures, minimising the chance of getting correct answers by guessing and allowing students to benefit from using Chemdraw (Morsch & Lewis, 2015). During completion of the online assignment, students could check their answers for correctness twice for each of two attempts. Full worked solutions were made available one hour after the assignment closed. The limited immediate feedback and delayed full feedback were intended to encourage students to develop their understanding through working out their own answers rather than obtaining answers from elsewhere (Sinapuelas & Stacy, 2015). These assignments carried a small grade incentive to encourage completion (Parker & Loudon, 2013). After the assignments' due date, they became available for study attempts without affecting student grades.

The weekly assignments (class and online) were designed to help students engage with the core concepts of organic chemistry (Table 1). This cross-over tutorial design with two groups of students (α and β) alternating between face-to-face tutorials and online homework for the six topics, gave both groups equal opportunities to receive explicit guidance in using hand-held molecular models in a face-to-face setting. It is important to note that no new information was presented in the class tutorials or online homework. Rather, they extended the theory taught in large lecture classes. These two forms of learning support served as opportunities for students to apply their knowledge to new problems.

Table 1. Crossover course design to support the learning of core concepts covered in lectures

Tutorial Topic	*Group α*	*Group β*	*Models used in F2F by Group*
T1: Hybridization, bonding & structure	Online	Face-to-face	β
T2: Conformational analysis	Face-to-face	Online	α
T3: Stereochemistry and isomerism	Online	Face-to-face	β
T4: Curved arrows in mechanisms	Face-to-face	Online	Models not used
T5: Reactions and synthesis	Online	Face-to-face	Models not used
T6: Monosaccharide structures	Face-to-face	Online	α

Methods

A quantitative approach with an experimental design was used to investigate associations between the modality of learning support and performance. Students were randomly assigned to one of two groups (α and β) and the group was either required to attend a face-to-face tutorial session or complete an online assignment on the same topic. This quantitative approach followed a pseudo-crossover design: Intervention A, not B, followed by intervention B, not A, repeated twice more, or the other way around, where A and B are class tutorials and online homework assignments respectively (Table 1). Semester tests or the final examination were used to assess student performance for the preceding tutorial topics (Figure 2).

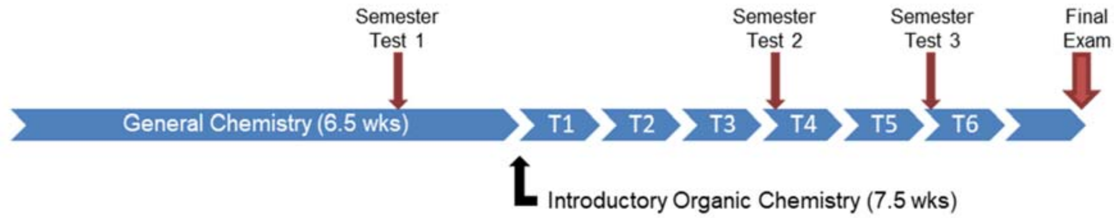

Figure 2. Timeline with the placement of assessments in the blended course.

Student participants

Ethical clearance for this study was granted by the Ethics Committee of the Faculty of Natural and Agricultural Sciences at the university where the study was done (EC 160720-057). The whole class was randomly allocated to α and β groups according to the course design. A description of the research project was presented to the students in the online sign-up for a lecture workbook. Students were invited to participate in the study and could give their informed consent by ticking a box which 90% of the class agreed to do. The remaining 10% completed the same activities embedded in the instructional design, but their records were not included in this study. The sample was reduced to those enrolling for the module for the first time and excluded the students transferring from the extended programme who would already have covered some of the content of the module. This gave a sample size of 667 students of whom 328 (49.2%) were in group α and 339 (50.8%) in group β. Independent samples t-tests using prior performance in tertiary level chemistry, verified equivalence of the two groups.

Data collection and analysis

Student attendance of class tutorials was ascertained from marks entered for the tutorial tests. Student completion of online homework was monitored by homework grades in the LMS. Questions in the summative assessments were structured according to the tutorial topics, individual student marks for each question in these assessments were captured and the records of students who did not form part of the sample were removed by the researchers. Where a student had not attended the class tutorial or was exempted from the online homework, their records were removed from the corresponding question in the common summative assessment.

IBM SPSS Statistics, Version 24.0 was used for the analyses. The average mark (mean %) and standard error of the mean for the α and β groups were calculated for each topic. Sample sizes varied slightly for each topic based on class tutorial attendance and online homework activity. Independent samples t-tests for equality of means were performed for each topic to investigate whether the differences in the means based on tutorial modality were significant.

To gain insight into aspects of digital access, peer learning and use of feedback in the online homework environment, three questions were added to a post-course evaluation using the test tool in the LMS. About half (341) of the students participating in this study completed the survey.

Results

A comparison of the mean performance for α and β groups showed that for five of the six topics, there was moderate to convincing evidence (Albright et al., 2009) that the group that attended a face-to-face tutorial outperformed the group that completed online homework (Table 2).

Table 2. The effect of modality on performance					
Topic	*Performance*		*Difference in means* *Δ F2F-OL*	*Effect size* *d*	*p-value*
	Group α	*Group β*			
T1: Hybridization, bonding & structure	60.4 (1.2)	**65.4 (1.2)**	4.9	-0.23	0.003
T2: Conformational analysis	**59.5 (1.5)**	55.6 (1.4)	3.9	0.15	0.058
T3: Stereochemistry and isomerism	47.8 (1.3)	**51.3 (1.2)**	3.5	-0.16	0.049
T4: Curved arrows in mechanisms	**58.2 (1.2)**	57.7 (1.1)	---	0.02	0.781
T5: Reactions and synthesis	60.2 (1.4)	**66.3 (1.3)**	6.1	-0.26	0.001
T6: Monosaccharide structures	**49.8 (1.5)**	45.2 (1.4)	4.5	0.18	0.029
Performance presented as mean % with standard error. Bold indicates that the group attended the class tutorial.					

In particular, for the topic of *Hybridization, bonding and structure* (T1) and the topic *Reactions and synthesis* (T5), there is convincing evidence (p-values of 0.003 and 0.001, respectively) that the mean performance of the two groups differed significantly. The mean performance for these topics was also higher than for the other four topics.

All four of the topics (T1, T2, T3, T6) that included the use of hand-held models in the class tutorials showed improved performance for the group that attended the face-to-face sessions even though the questions for the two modalities were comparable. The evidence for a significant difference in the topic of *Conformational analysis* (T2) was moderate, falling outside the 95% confidence interval but within the 90% confidence interval. This topic included translation between line structures and Newman projections and chair conformations as well as the assessment of relative energies of different conformers. The topics of *Stereochemistry and isomerism* (T3) and *Monosaccharide structures* (T6) had the lowest means indicating that these were the most difficult for the students.

Given the overall benefit of the class tutorials on student performance, it is surprising that there was no significant difference of learning modality on student performance in the topic of *Curved arrows in mechanisms* (T4). The mean student performance for the two groups demonstrated that the topic was of intermediate difficulty compared to the other topics.

While the differences in the means for the two groups were significant at the 0.05 level of significance for four of the six topics, the effect sizes were small, based on the standard deviation (SD) guidelines provided by Cohen (Cohen's *d* and Hedges' *g* are practically identical and range between 0.16 and 0.26). However, caution should be exercised in interpreting the guidelines since Cohen offered these SDs as a general rule of thumb that might be followed in the absence of knowledge of the area (Thompson, 2007; Durlak, 2009). Educational researchers have indicated that effect sizes around 0.20 SD's are of interest when they are based on measures of academic achievement (Hedges & Hedberg, 2007). Evans and Huan (2020) identified a median effect size of 0.10 SDs across 130 experimental studies that reported on learning outcomes. There is a growing consensus among researchers that effects that are small by Cohen's standards are often large and meaningful in the context of education interventions.

To consider these results in light of activity theory, it is clear that we have two different activity systems, one for the class tutorials and one for the online homework. The system for the class tutorials is readily described from class observations. By contrast, the activity system for the online homework is not as easily described, but the three survey questions did provide some insight: All students had access to appropriate devices and connectivity and made use of multiple settings provided by themselves or the university to complete their online homework (Figure 3). The internet café option was not the primary option for any of the students. The proportion of students who used campus facilities and campus wi-fi is noteworthy as these options would have fallen away for subsequent cohorts due to campus closures during the Covid-19 pandemic.

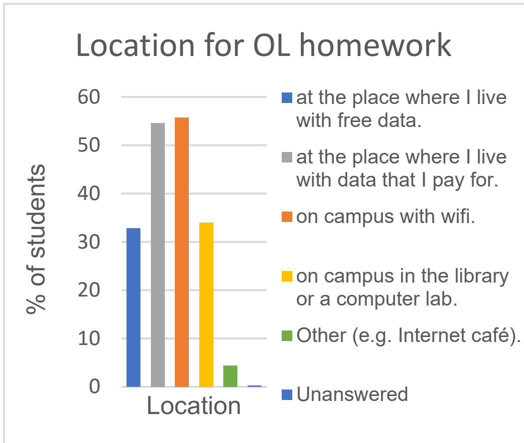

Figure 3: Student responses to where they did their online homework.

Since peer learning was an integral part of the class tutorials, we probed for the use of peer learning while completing online homework. As shown in Figure 4, more than 80% of students reported working alone, indicating a general absence of peer-learning during completion of the online homework assignments.

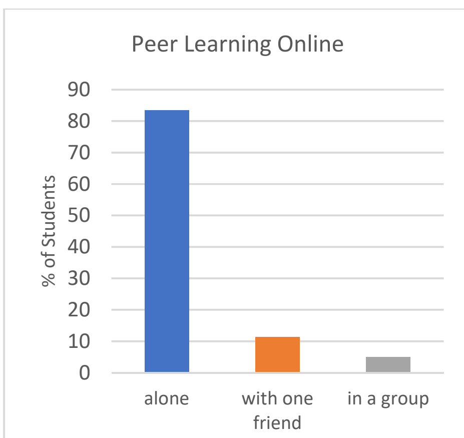

Figure 4: Student responses indicating the level of collaboration online.

One of the benefits of online homework is built-in feedback. Feedback regarding whether answers were correct or not was provided during assignment engagement, but the full feedback with model answers was only made available one hour after the assignment closed. Relevant to understanding whether the students utilised this built-in feedback, Figure 5 shows the students' answers regarding their use of the solutions after the assignment had closed.

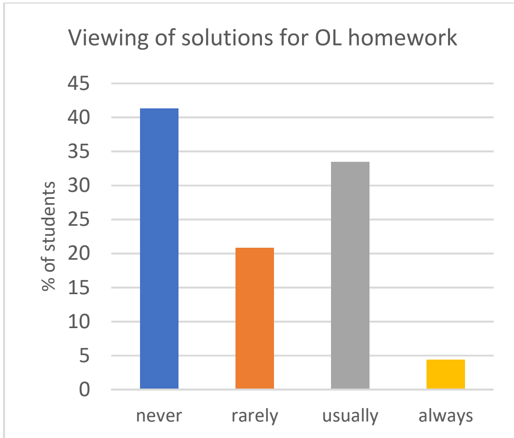

Figure 5: Indication of students' use of solutions to online homework.

More than 60% of the students reported that they made no or limited use of this feedback (Figure 5), limiting their opportunity to learn from their mistakes. Only 37% of students regularly (usually or always) made use of the feedback. By contrast, solutions to problems were discussed during the class tutorials.

Discussion

Our pseudo-crossover experimental design, not common to education research, provided an opportunity to compare two learning support modalities across the timespan of the course. In answer to our research question "What is the impact of the modality of tutorial support on student performance?" the results show that class tutorials supported learning better than online homework. The small effect sizes are not surprising given the diversity of the group. Kraft (2020) argues that one can expect larger effect sizes from more homogeneous samples. The effect sizes between 0.16 and 0.26 represent percentile gains of between 6% and 10% on the mean performance of students who attended the tutorials, over the online cohorts. In view of the literature on educational research, this can be considered as having educational value and "of policy interest" (Hedges & Hedberg, 2007, p.77). South Africa has a diverse population and students come to university differently prepared for tertiary studies. This difference would not readily be overcome by tutorial modality, yet the modest improvement is worthwhile and can make a difference between passing and failing for many students.

The class tutorial and online homework activities were designed to cover the same content. With a single exception in the first tutorial, all questions in the class tutorial worksheets could be duplicated online. This was possible because the online homework made use of Chemdraw, allowing students to draw structures (Morsch & Lewis, 2015). To understand the differences in performance, we compared the two learning systems through an activity theory lens.

An evaluation of the large class tutorial activity system revealed explicit rules for engagement: students had to engage in peer learning. These rules were mediated by the peer leaders. Learning was socially constructed with an obvious community of students, peer leaders and lecturers, each working towards the common outcome of learning according to a pre-determined division of labour. The tools for the class tutorials are readily described in terms of the role of the worksheet, the use of handheld models and the tutorial test.

The role of peer learning in the activity system for online homework is less obvious. From students' self-reported data, we deduced that peer learning was not part of the online homework activity system. Consequently, the community for online learning for most students would have been limited to the individual student, with the technology platform, rather than another person, acting as the mediator of learning. By using question pools to reduce the copying of answers (Smithrud & Pinhas, 2015), instructors may have unintentionally propagated an implicit "rule" that online homework should be completed individually, discouraging peer learning. The two modalities, therefore, differed substantially in terms of rules, community and division of labour. This difference is considered to be a "contradiction" in activity theory, and thus to be seen as an opportunity for development. Consequently, we suggest that peer learning should be encouraged during engagement in online homework and this should be done by making rules for appropriate peer engagement explicit.

Levels and types of feedback also differed between the two systems. During class tutorials, students could readily ask questions and get feedback. The solutions to the problems were discussed and misconceptions were identified. Feedback is a known affordance of face-to-face settings and with the help of trained peer learners can be implemented in large classes (Jerez et al., 2021). In the online system, limited feedback was available to the students while working on a problem in the form of correct/incorrect indicators, but the full feedback was not immediate. The full feedback was only available an hour after the assignment closed. The results show that most students did not make full use of this delayed feedback. The rich feedback given during class tutorials and the limited use of feedback associated with the online homework could have contributed to the overall improved performance of students who attended class tutorials.

Another affordance of learning chemistry in face-to-face settings is assistance with the use of hand-held molecular models (Mohamed-Salah & Alain, 2016). The use of models formed part of the rules for student engagement with peer leaders in the class tutorials. Peer leaders insisted on the construction of the appropriate model before assisting students. From the reluctance of students to build models in class, we infer that very few would have made the effort to build models to solve online homework problems. Instruction in the use of molecular models incorporated in the large lectures attended by all students was insufficient to develop competence in use of these models. The use of models was relevant to four of the six tutorial topics and could have contributed to the difference in performance for those topics. All students had equal F2F opportunities to develop a three-dimensional conceptual understanding of two-dimensional representations, since both groups attended two class tutorials that incorporated molecular models in the instruction albeit on different topics

As we compared the different topics in answering our second research question "Which tutorial modality (face-to-face versus online) is more successful for each topic in the organic chemistry syllabus?" we had anticipated that some topics may have benefited more from class tutorials and others from online homework. While it was not surprising that the four topics requiring three-dimensional visualization were better supported by class tutorials, there was no topic in which online homework was more effective.

For the topic of *Curved arrows in mechanisms*, there was no difference in performance by learning modality. In this topic, class teaching focused on the use of the curved arrow formalism rather than the reproduction of learned mechanisms associated with specific reactions. Similar to the questioning style reported by Flynn (2017) students were asked to (1) draw the curved arrows of a reaction step, given the starting materials and products; and (2) draw the products of a reaction step, given the starting materials and electron-pushing arrows in unfamiliar reactions. As the course progressed and students were taught new reactions in lectures, the mechanisms of these reactions were used as an opportunity to practice the use of curved arrows. This teaching approach in lectures may have given the students who did not attend a class tutorial on the topic an opportunity to become familiar with the curved arrow notation, removing the advantage associated with class tutorials.

In comparing the association between topic and learning modality, we found that the topics with the biggest difference in performance were those with the highest means. This shows the value of face-to-face tutorials for improving learning and performance for easier topics. Such improvement may encourage students while they take time to develop a conceptual understanding of the more challenging topics. The most difficult topic of *Monosaccharide structures* draws together aspects of all the other themes, from bonding, conformation, stereochemistry, mechanisms, and reactions in the cyclization of the monosaccharides to hemiacetals. Large class tutorial support lifted the mean performance for this topic to 50%.

Limitations

This quantitative experimental study has shed light on the impact of modality on the outcome of student performance in a specific context. The reasons for the difference in performance are not clear, being inferred from three survey questions probing the online learning environment and observation of the class tutorials. A follow-up qualitative study is needed to uncover how the students experienced the two learning environments. Such a study could elicit the student voice to identify the reasons behind the effect on performance.

Implications for teaching and research

Given the significant benefits of class tutorials on student performance, lecturers should be cautious about adopting online learning support instead of face-to-face sessions. As far as possible, some face-to-face engagement that incorporates peer learning and reasonable access to a more knowledgeable person should be built into the course design. Where online homework is used to relieve pressure on venues and manpower, care should be taken to encourage the use of peer learning and engagement with feedback. Furthermore, those topics which are more reliant on personalized instruction and feedback, such as those which require use of manipulatives such as models in organic chemistry, should be privileged for face-to-face tutorials.

Jonasson (2000) contends that a qualitative approach to data collection and analysis is required when using activity theory to design student-centred learning environments. Students could be given the opportunity to experience both learning environments and their feedback used to identify and compare the affordances and hindrances of each modality. Optimally blended courses could then be designed to harness the affordances of both modalities specific to organic chemistry.

Conclusions

We compared the impact of large class tutorials and online homework on student performance using an experimental research design. The study revealed a statistically significant difference in performance in favour of the group that had attended a class tutorial for most topics in introductory organic chemistry. Online homework did not lead to better performance than face-to-face support for any topic.

Although offering tutorials to large classes is costly and logistically challenging, the results show that lecturers of large classes should resist pressure to replace all tutorials with online homework. Funding for class tutorials, especially the employment of peer leaders, should be prioritized. Consequently, care should be taken to design the course to use face-to-face time optimally. Class tutorials should include meaningful peer learning with trained peer leaders who can give appropriate feedback and models should be used for organic chemistry.

When students cannot be accommodated in class, online homework could be used to keep them engaged in a blended course design. Approaches to translate the peer learning culture developed in a face-to-face setting to online activities could be investigated. Furthermore, optimizing the online offering for specific content less sensitive to the need for personal instruction and peer learning would enable class time to be used optimally.

Acknowledgements

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