[X]position, Vol. 3, October 2018

NEXT-GENERATION TEACHING METHODS IN CHEMISTRY CLASSROOMS: DO THEY REALLY MAKE A DIFFERENCE?

Hamilton, Natasha

Submitted May *2018*; Reviewed June *2018*; Accepted July *2018*

Copy Edited by Selma Crecente García

ABSTRACT

As technology progresses, many educators seek to incorporate next-generation teaching methods into undergraduate chemistry courses. Chemistry classes require the mental manipulation of abstract ideas and college-level critical thinking abilities; for these reasons, proponents of alternative teaching methods see chemistry as a perfect testing ground for their tools. Advocates of these methods hail flipped lectures, concept maps, online homework systems, and clickers as the educational tools of the future. Many traditional lecturers, however, are hesitant to adopt these methods, questioning whether new technologies are truly as effective as claimed. Review of the current research found that some of these next-generation teaching methods made little to no impact on chemistry comprehension compared to traditional lectures and assignments, while others significantly improved accessibility and reduced student withdrawal rates. Nevertheless, although they may improve student and teacher experiences in other domains, the efficacy of some next-generation teaching methods have yet to impact long-term student success in undergraduate chemistry courses. This literature review critically assesses the efficacy of alternative teaching methods used in undergraduate chemistry education, and discusses the validity of claims that these methods definitively improve the student's experience and long-term retention of chemistry.

INTRODUCTION

Prominent academics consider chemistry a notoriously difficult subject for most undergraduate students (Akkuzu and Uyulgan, 2016; Bhattacharyya and Bodner, 2005; Gray, 2014; Seery, 2015a) as it involves the mental manipulation of abstract ideas. It is suggested that such a nuanced subject may pose a great obstacle for students who may not have developed the tools for college-level critical thinking in their secondary education. A student without this skill set could find it difficult to visualise the connection between different topics or understand the theory behind molecular interactions. In the same way that scientific progress evolves over time, the methods of scientific education necessitate constant revision and updates in both content and delivery.

For these reasons, proponents of alternative teaching methods see chemistry as an ideal discipline for their tools. For the purposes of this review, alternative teaching methods will refer to any classroom activities or assignments outside of a traditional lecture, paper homework assignments, quizzes, and examinations. Popular alternative teaching methods include flipped lectures, concept maps, online homework, and the use of audience response systems, also known as clickers.

FLIPPED LECTURES

Overview

A flipped lecture is a teaching model in which material that would have traditionally been conveyed during the class is now learned at home, leaving the class time open for other activities. The lecture content is given to the students in a format accessible outside of the classroom, often in the form of recorded screencasts (Seery, 2015a). These consist of an instructor's voiceover added to their traditional PowerPoint presentation and are intended to be viewed online before the scheduled class session (Seery, 2015b). Depending on the software used, the instructor may also draw or write on the slide in the same manner in which they would draw on the whiteboard. When a screencast is not used, a lecturer may videotape themselves speaking to a camera in front of a whiteboard to demonstrate concepts.

This teaching ensures that students already have the necessary background knowledge needed to complete practice problems before entering the classroom. Since the students are now already familiar with the lecture material, the instructor can devote class time for more active learning methods. Instead of utilising passive learning methods such as listening to a lecture or watching a demonstration, students are engaged in question and answer sessions and work through assigned practice problems. As lectures now occur outside of class, and practice problems that would have been considered homework are completed in class, the events taking place during class time and personal time are now 'flipped'.

One of the advantages of this method is that the student is freed from time restrictions. They can view the lectures whenever they want and as often as they wish. Certain individuals may enjoy taking in new material first thing in the morning, while others find it difficult to stay alert before 9 or 10am. The former student may enjoy viewing the lecture at 8am in the morning, while the latter may choose to view it in the afternoon when they are more alert. In a traditional morning lecture, the latter student may have had a more difficult time retaining the material, and this difficulty is reduced by the flipped lecture method.

Natasha Hamilton, College of Medical, Veterinary and Life Sciences, 2345780H@student.gla.ac.uk

The online format also allows the student to personalise the pacing of the lecture to fit their needs. If a professor is notorious for speaking very slowly, the student can increase the playback speed and speed up the lecture without hindering the progress of other students. Conversely, if the professor is speaking too quickly, a student can decrease the playback speed, or pause the lecture as they catch up with their note-taking, and continue once they are ready. If a student is confused about a particular topic, they can rewind the lecture and watch that portion again until they understand it, or repeat the entire lecture as often as they want. This ability to adjust the pacing of lectures increases the accessibility of the content, and may be more helpful for students with disabilities or health issues who may need to take breaks more frequently or repeat sections of a lecture.

When listening to a traditional lecture, a student may have a question and interrupt the professor to ask it. However, multiple interruptions delay the lecture and prevent the entire class from progressing. In a flipped lecture format, class time is most commonly devoted to practice problems and answering questions (Seery, 2015b). Students work on practice problems individually or in groups, and can ask for assistance from the instructor whenever they need help. As the teacher rotates around the room, students have the opportunity to ask questions regarding the lecture they viewed previously in addition to the practice problems. This flipped lecture format allows students to engage with the material and the instructor in an active manner during the class, fostering valuable critical thinking skills.

One disadvantage of this format is that the initial setup of a flipped lecture is much more time consuming for an instructor to prepare than a traditional lecture. Should a lecturer decide to switch to a flipped lecture format, they must set aside additional time necessary to record and publish the lecture. However, it is important to note that instructors often teach the same course to multiple sections in a single semester or teach the same course over the span of many years. If this is the case, then the time investment of preparing the flipped lecture may actually be more worthwhile than expected. Once all the lectures are recorded for the course, the videos can be saved for use in future courses or posted publicly on websites like YouTube. This widens the accessibility of the material to anyone with an internet connection. Lecturers that have chosen to publish their flipped lectures on YouTube have found it rewarding to see the global impact of their teaching and receive comments about which topics were unclear (Christiansen, 2014). Although a lecturer may find the task arduous during the initial year of implementation, they can save the recordings for the future, thus decreasing the amount of time needed for preparing lectures in the following years.

Another criticism of the flipped lecture format is that students may not take the time to watch the recorded lectures or that if they did watch the lecture, they may not show up for class since they have already learned the material on their own. These possible unintended consequences would undermine the benefits intended by the flipped method, as both the online recordings and class time are essential components of the format.

Research Review

Several studies have been implemented to assess the efficacy of the purported benefits of flipped lectures in undergraduate chemistry courses, and respond to the concerns posed by critics. It has been proven that chemistry courses with a flipped component had an increase in higher grades due to student improvement (Yestrebsky, 2015) and a higher student retention rate (Reid, 2016), both as a result of the flipped lecture method. An increase in lower grades also arose in flipped classrooms due to the increased retention rate (Seery, 2015b): the flipped lecture model increased accessibility of the content to such a degree that students that would have ordinarily dropped the class chose to carry on. As a result they earned lower grades than their peers, but their choice to remain in the course and continue the subject is a positive one wholly due to the benefits of the flipped method (Seery, 2015b). While flipped lectures alone may not be able to take a failing chemistry student and turn them into an outstanding one, they can turn a good chemistry student into a better one, and give a student who believes they are unable to attain a level of competence in the subject the confidence to continue pursuing it.

Flipped lectures were also found to enhance both algorithmic and conceptual thinking among chemistry students (Reid, 2016; Weaver and Sturtevant, 2015). It is interesting to note that the thought process enhanced by flipped lectures differed depending on the background of the student. Reid (2016) assessed the efficacy of the flipped lecture model in a first-year general chemistry course and discovered no difference between the standardised chemistry test scores of students in the flipped classroom and the control classroom. However, the students in the flipped classroom had a statistically significant increase in the accuracy of algorithmic questions (Reid, 2016). Initially, these findings appear to contrast those of other investigators. For example, Weaver and Sturtevant (2015), who also assessed the efficacy of the flipped lecture model in a general chemistry course, found that students showed a statistically significant increase in the conceptual understanding of chemistry (as opposed to algorithmic understanding). The key difference between the two investigations is that while they both studied the effect of flipped lectures on first-year general chemistry courses, Weaver and Sturtevant (2015) studied a class containing only chemistry majors, while Reid (2016) studied a class containing only non-majors. Thus, the difference in the type of critical thinking that was enhanced depended on the background of the student.

Chemistry majors are well-practiced in the art of algorithmic thinking, but often lack conceptual understanding of the subject (Bhattacharyya and Bodner, 2005). This was evidenced by a study composed entirely of graduate chemistry students, which found that intelligent and hard-working students who received high marks in their chemistry studies still lacked conceptual understanding of significant topics (Bhattacharyya and Bodner, 2005). While this investigation occurred prior to those assessing flipped lectures, those graduate students may have had a more solid conceptual framework of chemistry, had they taken flipped chemistry courses during their undergraduate studies. Conversely, the non-majors in Reid's (2016) investigation who may have been more familiar with conceptual learning found that flipped lectures improved their algorithmic abilities. These examples demonstrate the potential of flipped lectures to provide additional support in the skills a student is currently weak in.

In class evaluations, students praised the flipped lecture model (Christiansen, 2014; Reid, 2016; Seery, 2015b). In one study, 81% found it more helpful than a traditional lecture, 6% found it unhelpful, and 13% were indifferent (Smith, 2013). Those that found it helpful were particularly appreciative of the chance to view the lectures on their own time and repeatedly view topics they were unsure about (Yestrebsky, 2015). They felt that it saved more time in the long run and resulted in better retention of the material. The few that did not like the flipped lecture had packed schedules that did not allow adequate time for viewing lectures outside of class, or felt that online lectures unnecessarily limited the amount of interaction with the instructor (Christiansen, 2014; Seery, 2015b).

These concerns are legitimate issues. Students with responsibilities outside of academia such as family duties or multiple jobs, may find a flipped lecture burdensome. Transitioning to a flipped classroom can be a difficult adjustment for some students, and frustrating to those with little free time. Instructors may also wonder if it is worth the effort of making screencasts without the assurance that students will actually view the lectures on their own time. The latter issue has been raised by multiple investigators (Christiansen, 2014; Seery, 2015b; Yestrebsky, 2015) and it was found that although it took three times longer for an instructor to prepare a flipped lecture versus a traditional lecture, over 90% of students watch the flipped lecture before class (Seery, 2015b). In addition, the self-reported adherence to the viewing schedule as well as the subsequent increase in the grade distribution observed indicated that it was worth the time (Yestrebsky, 2015).

Summary

Considering the quantitative data available from these investigators and the evaluations provided by students and instructors, flipped lectures are a useful alternative teaching method. They are definitively responsible for significant skill enhancement, grade improvement, student retention, and class satisfaction (Christiansen, 2014; Reid, 2016; Seery, 2015b; Weaver and Sturtevant, 2015; Yestrebsky, 2015). It is an excellent method for relaying information to a large group of students and increasing the amount of interaction with the instructor in a large class. However, this structure may marginalise students with heavy responsibilities and time commitments outside of the classroom. Furthermore, it may distance the instructor from the students who do not take the initiative to ask questions during the class sessions (Seery, 2015b). An instructor seeking to implement a flipped lecture will likely see an increase in grade distribution and higher satisfaction rates, but may also see an increase in lower grades. This should not alarm the instructor as it is a natural result of the presence of students who would have previously dropped the course. The instructor should take the time to reach out to these students and encourage them in their pursuit of the subject, and ensure they are aware of additional resources such as office hours and campus tutoring services. Instructors should also tell students who are concerned about time limitations to meet with them to ensure that the structure of the course does not unfairly punish students for factors that are truly beyond their control.

CONCEPT MAPS

Overview

Concept mapping is a technique involving the creation of a visual map of how topics are connected to one another. It is increasing in popularity in chemistry classrooms as an answer to complaints that topics taught in introductory chemistry courses lack cohesion (Akkuzu and Uyulgan, 2016; Boyd, 2007; Gray, 2014). With a detailed concept map, it is possible to see in an instant how a topic like electronegativity is related to other topics like acid/base chemistry, periodic trends, and ionic/covalent character, proving that the three topics are not as disjoint as they appear and thus cementing their relevance (Boyd, 2007). This method is different from practice problems, which give students an opportunity to practice a particular skill, and is not intended to be a substitute for it. Rather it seeks to force students to think critically about why they are learning these topics and how they relate to one another, in order to help them recognise how skills from multiple topics may be needed to solve a single problem.

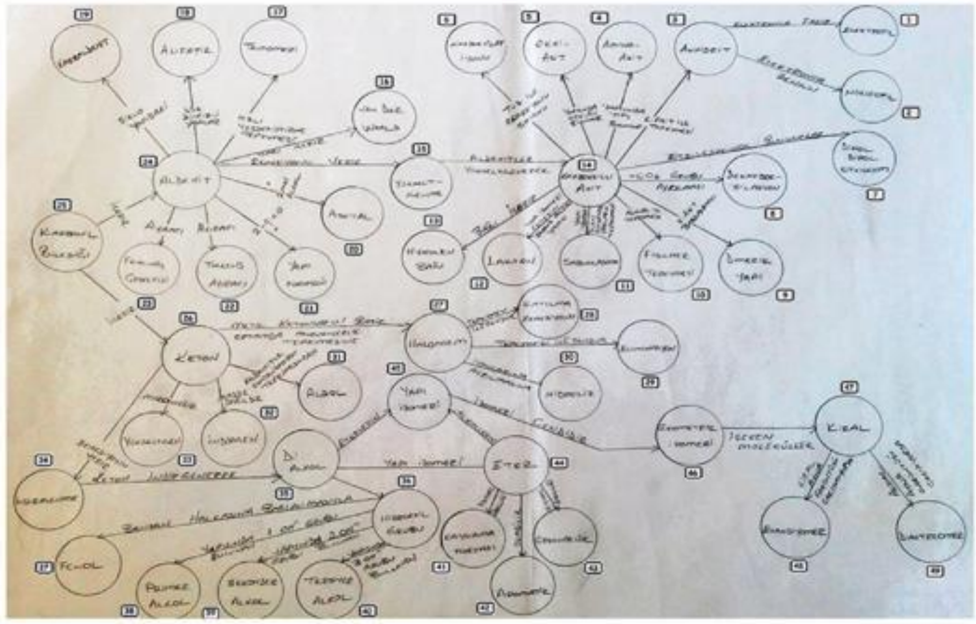
These maps are drawn by hand or with the assistance of a computer program, and the proponents of this method emphasise that the act of creating a diagram like this solidifies the relationship between these topics in the mind (Akkuzu and Uyulgan, 2016). They highlight the point that learning is all about making connections between otherwise disjoint topics, and that concept mapping is intended to provide an easier way to see these connections. This "big-picture" look at chemistry topics is clearly beneficial to students. Instructors who are already familiar with these connections can look at a student's concept map and immediately recognise any errors in their reasoning. Regarding examinations, repeated conceptual errors can penalise a student heavily for the same reasoning mistake. Another advantage of concept maps is that they bring these errors to the surface early on and clue the instructor into new ways the material may be misinterpreted by pupils. A hand-drawn concept map obtained by Akkuzu and Uyulgan is shown in Fig. 1 while a computer-generated concept map obtained by Gray is shown in Fig. 2.

However, the main disadvantage of concept mapping comes from the amount of time needed to create a comprehensive concept map. It can be time consuming for a student to make detailed maps, and it is also time consuming for an instructor to grade them. If the instructor chooses to assign a concept mapping assignment as homework, it is vitally important that these concept maps are assessed for possible errors. Since concept maps that are created by the student inherently reveal their depth of understanding, they clearly show the areas in which a student is weak. If a student's map includes errors and these errors go unnoticed, the incorrect connections will be solidified in their mind and may be the source of future difficulties.

Research Review

There have been several case studies involving this method in both secondary school and undergraduate chemistry courses (Akkuzu and Uyulgan, 2016; BouJaoude and Attieh, 2003; Gray, 2014). While nearly all investigations into concept mapping found a general increase in the ability to verbalise how and why certain topics in chemistry are related, the methods used to create the concept map had an impact on its efficacy.

Unlike the flipped lecture, concept maps did not result in an overwhelming increase of student approval. While many students found it helpful, incorporating concept maps into the curriculum did not improve student's attitudes towards chemistry or student retention in chemistry classes (Gray, 2014). Test scores increased slightly as a result of the enhanced ability to visualise connections, but not significantly (Gray, 2014). This situation changed when concept maps were created using digital software rather than being hand-drawn: in this case, test scores increased dramatically. This is because using online software increased the students' ability to make more connections, and gave them flexibility to add topics whenever and wherever they wanted by diminishing the constraints of a single piece of paper (Gray, 2014). Using digital software also saved time as a concept map could be created more quickly than with a pencil and paper.



Translation of concepts and examples from Turkish to English	
1.Electrophile	26.Ketone
2.Nucleophile	27.Haloform
3.Anhydride	28.Substitution rxn.
4.Amino acid	29.Elimination
5.Oxyacide	30.Hydrolysis
6.Carboxylate ion	31.Aldol
7.Dipole-dipole interaction	32.Reducer
8.Decarboxylation	33.Oxidizer
9.Dimeric structure	34.Reduction
10.Fischer reaction	35.Dialcohol
11.Saponification	36.Hydroxyl group
12.Lactone	37.Phenol
13.Hydrogen bond	38.Primary alcohol
14.Carboxylic acid	39.Secondary alcohol
15.Oxidation	40.Tertiary alcohol
16.van der Waals	41.Boiling point
17.Tautomeri	42.Aromatic
18.Aliphatic	43.Solubility
19.Carbaldehyde	44.Ether
20.Acetal	45.Structural isomer
21.Structure Formula	46.Geometrical isomer
22.Tollens reagent	47.Chiral
23.Fehling solution	48. Enantiomer
24.Aldehyde	49. Diastereomer
25.Carbonyl compound	

Figure 1: Hand-drawn concept map and corresponding topic list from a student example in Akkuzu and Uyulgan, 2016

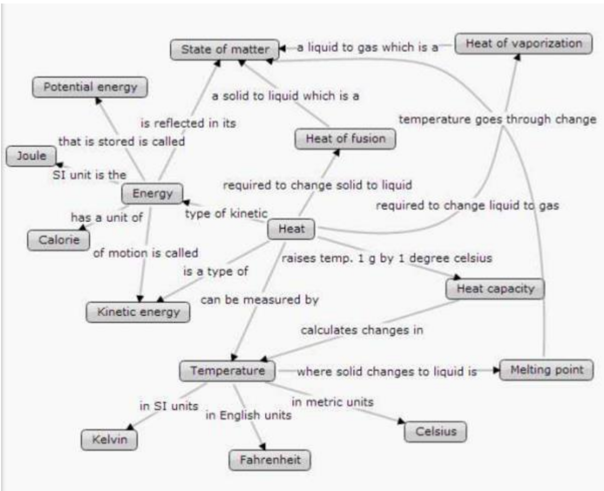


Figure 2: Concept map created using CREONTO computer software from (Gray, 2014)

These findings are corroborated by the perplexing results obtained by BouJaoude and Attieh (2003) over a decade earlier. In their 2003 investigation, the students who created concept maps verbalised their value, but did not demonstrate a drastic increase in test scores. It was observed that high achieving students who made concept maps had lower scores than high achieving students who did not make concept maps (BouJaoude and Attieh, 2003), while low achieving students who made concept maps showed an increase in test scores in comparison to low achieving students in the control group (BouJaoude and Attieh, 2003). It can be hypothesised that a more significant increase in test score would have been achieved if the students in BouJaoude and Attieh's (2003) investigation had the opportunity to use computer software to aid them in their concept map creation. In the discussion at the end of their investigation, the authors stated that: 'Most interesting was the students' suggestion to use computers to make the presentation of concept maps clearer and the task of constructing them simpler. In fact, using computers in constructing concept maps is a current trend in science education that has the potential to improve the quality of concept mapping and consequently achievement in different subject areas.' (BouJaoude and Attieh, 2003, p.13). In light of the findings from Gray (2014) showing that the largest increase in test scores was apparent when computer software assisted concept map creation, BouJaoude and Attieh's (2003) prediction of the potential of computerised concept maps was correct. Thus, the lack of drastic improvement after the introduction of concept mapping in 2003 may have been due to the fact that paper concept maps were used instead of digital ones.

To effectively incorporate concept mapping into a chemistry course, students should be provided with software to create a concept map along with a list of key terms they ought to include. There are several online concept map platforms such as LucidChart, MindMup, and SmartDraw which offer different concept map designs and storage options at varying costs at the institutional level. As the course progresses, drafts of these concept maps should be submitted for review to ensure all the connections are correct. Over time, the maps will increase in size in proportion to the amount of information covered. This aspect reinforces the time consuming nature of concept maps. With a small class, analysing all these concept maps might not seem like such an ordeal, but as these maps get more intricate, the amount of time spent poring over the assignments may not be worth the time.

Summary

Concept maps might be a good resource for instructors to recommend at the beginning of the year, with the offer to review the concept maps of any student who brings one to office hours. If the use of digital concept mapping software is possible then this resource should be made available to the students to decrease the time-consuming nature of the task on both students and educators. If the idea of a concept map is introduced in a class, an instructor ought to make multiple short reminders to the students throughout the course to show their current concept maps in office hours so that they can receive feedback. Whenever students come in to office hours asking about the connections between topics or they fail to demonstrate knowledge of how and why reactions proceed on quizzes and exams, instructors can remind them of concept maps as a resource. Emphasis should be placed on the idea that concept maps grow along with a student as a measure of the depth of their understanding, and that no pupil should feel embarrassed at presenting a small or partially completed map.

ONLINE HOMEWORK

Overview

Online homework is also seen as a promising technological resource to chemistry educators. Instead of assigning practice problems out of a textbook, the University pays for an institutional subscription to an online homework platform containing problem sets whose length, topic, and difficulty can be adjusted by each instructor to suit the needs of their class. Students can type in their answer and receive automatic feedback as to whether or not their answer was correct, along with the option to try the same problem again. These platforms come with multiple features; for example, a student can attempt a similar problem for extra practice, have a set number of attempts, and be given randomised questions from a large question bank in order to minimise the chance of one student sharing answers with another.

These platforms have numerous advantages as it saves instructors hours of time since grading is done automatically. The automatic feedback and multiple attempts encourage students to focus on accuracy instead of completion, and minimise the gap between the error made and the feedback needed to correct it. An instructor can use the success rates of the online homework as a tool to gauge the overall progress of the class. However, there are many other aspects of online homework that educators may overlook. A key disadvantage of these online homework platforms is how easy it is to use unauthorised resources a.k.a. cheating. Particularly in the sciences, many questions are reused and can easily be searched on Google. The first result may be the answer to the exact question that was asked, or a similar question with exact wording but with different numerical quantities. Large PDF files containing answers to entire assignments can be found quickly and easily. To a student pressed for time, it would be much quicker to plug in the quantities from their own problem into a solution found on Yahoo Answers, and submit the answer. There are entire websites devoted to creating answer banks for all the questions included in these platforms, such as Chegg and Slader. There are even answer bank websites specifically targeted to a respective online homework platform such as WebAssignGenius.com for WebAssign homework answers. Websites like Slader and Yahoo Answers are free because those providing answers to homework questions have no particular incentive to do so. But the most comprehensive resources such as Chegg or specialised resources like WebAssign Genius are private for-profit businesses requiring a paid subscription to access their resources. The existence of these profit driven resources widens the gap between students of higher and lower socioeconomic statuses, as there is little standing in the way of a student with greater economic capital from paying for answers provided by subscription-based companies. These subscription services are legal, well-advertised, and give a definite advantage to those students who can afford it. In difficult courses like organic chemistry, students are willing to fight for every last point. It is much more difficult to cheat the system with paper homework, as a student must adequately demonstrate their train of thought on paper in order to receive full credit. But by formulating computer-graded questions, one also increases the likelihood of computer-generated answers.

Research Review

Numerous studies have shown that students who used online homework systems for chemistry assignments had no statistically significant academic difference over students assigned paper homework for the same course (El Labban, 2003, Richards-Babb et al. 2011; Todd and Cole, 2003). Even when comparing a basic online homework system to a more advanced and complex one there was no significant statistical difference between the performance of students in either method (Huesgen, 2012).

Certain studies have partially addressed the issue of how much easier it is to cheat on online homework vs. paper homework. This is a factor that educators ought to keep in mind if a large discrepancy is seen between online homework and exam grades. In fact, it has also been found that a high performance in online organic chemistry homework assignments has absolutely no correlation on subsequent examination performance (Smithrud and Pinhas, 2015). Low scores in online organic chemistry homework correlate to low exam performance, but a student who has scored highly on the online homework assignments may perform just as poorly as those who had low scores in the online homework (Smithrud and Pinhas, 2015). The investigators also described a key difference between general chemistry and organic chemistry online homework assignments. Namely, that organic chemistry homework often requires the use of drawing programs to answer problems regarding mechanisms. Due to the nature of these visual-oriented questions, it is much more difficult to create numerous equivalent variations of the same questions (Smithrud and Pinhas, 2015). Thus, in homework platforms allowing multiple attempts it is possible to get the correct answer via trial and error rather than actual effort. The lack of variation also makes it easier for students to collaborate with one another on assignments intended for individual practice and assessment. The same study also discovered that students who took the time to handwrite the solutions to online homework problems had a better understanding of the content and as a result received higher exam scores. The investigators noted that completing homework twice, both on paper and online, was undesirable for many students, and advocated for the use of software that involves the use of a stylus so that students can experience the benefits of motor memory, while instructors can experience the benefits of online grading (Smithrud and Pinhas, 2015).

Homework assignments can be useful to instructors to pinpoint which topics their class is having difficulty with: if the instructor is aware of a widespread difficulty in a certain area, they can tailor the lectures to support the needs of the students. But widespread use of internet resources may inflate homework grades higher than the student's actual capability - this practice may leave the unsuspecting instructor dismayed and unprepared for the difference between homework and exam grades. When a majority of the class utilises search engines to help their grades, the instructor's benefit of homework assignments is irrevocably lost. This factor limits the accuracy of online homework as a tool to gauge actual understanding and progress.

Summary

Online homework may result in significant benefits for instructors. However, implementing such methods in chemistry courses has a high risk of unintended negative outcomes such as the unforeseen use of online resources and false success as a result of trial and error, particularly in the realm of organic chemistry. Due to the fact that online homework in itself is comparable to paper homework, using an online homework platform may widen the socioeconomic divide as students from higher socioeconomic backgrounds utilise paid subscriptions for answer databases. Investigations specifically assessing the effect of answer bank websites and subscriptions on homework scores among chemistry students could not be found, but such research would be helpful in determining the true scope of these practices. For these reasons, assigning paper homework appears to be the more ideal option for organic chemistry assignments if the instructor can handle the volume of grading. If this is difficult, it would be worthwhile to utilise the help of teaching assistants to grade paper homework until a more varied online organic chemistry homework platform is developed.

CLICKERS

Overview

Audience response systems encourage student interaction with the instructor during the lecture. These can be through clickers or apps on a student's phone that allow them to respond anonymously to multiple choice problems displayed on the board (Shea, 2016). The instructor can receive the results of the poll in real time, and display the resulting distribution of answers for the class. This technology can be used to gauge how well the class understands the material that was just relayed to them, and can let the instructor know if they need to slow down, repeat a topic, or can move the class along more quickly (Gibbons et al. 2017).

Instantaneous feedback is a significant advantage as it allows the instructor to alter the pace and content of their lecture while in the middle of it. If the students are having trouble understanding the topic and a majority of students answer a poll incorrectly, the instructor immediately knows they need to repeat themselves instead of charging ahead with the next topic. Should the students answer the question correctly, the instructor can be comfortable increasing the pace (Gibbons et al. 2017). The disadvantages of this system are minimal as smartphone applications have recently become the solution for unnecessary expenditures on dated clicker devices (Shea, 2016).

Research Review

There are many reports supporting the use of response systems in the classroom, citing the short-term benefits of using the technology to quickly determine the understanding of the class, along with an increase in grade distribution as a result of using clickers. But until 2012, no study had ever assessed if there was a long-term benefit for students who were in classes that used clickers. Gebru's 2012 study definitively proved that in the long run, students who were in chemistry classes that used clickers did not show any improvement over students who were in chemistry classes that did not use clickers.

In Gebru's 2012 investigation, both groups of students were tested using the standardised American Chemical Society exam issued seven months after the completion of the first semester of general chemistry. The use of the standardised exam removed any advantage of taking exams from an instructor whose testing style is familiar. On a standardised ACS examination, both groups performed at the same level, and since many previous studies on the efficacy of clickers measured improvement based on the instructor's own exams, it follows that the use of clickers improves a student's grade in the class but not their overall chemistry knowledge. This is because the regular use of clickers in the classroom allows students greater exposure to questions similar to the ones that will be on the exam. Any student that has had the opportunity to try out practice exam problems in class will naturally do better on exams than a student that has not been exposed to them. The influence of the clicker in improving test scores is not because of the instructor's adaptation of the lecture to real time student feedback, but due to students' exposure to practice exam problems prior to the actual assessment. In the words of the investigator: "Neither clicker nor online homework systems significantly improved students' long-term content retention of General Chemistry I course material." (Gebru, 2012, p.3)

Thus, the efficacy of the clicker in the classroom is dependent on whether you are assessing the increase in student grades or the increase in student learning and retention of the material. If the former, then this method is extremely beneficial, but one must keep in mind that it makes little to no long term impact on the latter. It seems that the instantaneous nature of clicker technology is a better tool for the teacher to adapt their classroom to the needs of the students, than for the students to gain a better understanding of the material.

As technology progresses, the range of question types available on clicker platforms also increases. Newer platforms support question formats where the student can type in an answer and the answer distribution appears as a word cloud, or select a particular atom on a molecule pictured. (Shea, 2016) These new question formats allow the instructor to ask more conceptual questions which are essential to the practice of organic chemistry. However, even with these expanded applications, some instructors still favour low-tech solutions, even after using the next generation clicker software. In a response to Shea's 2016 technology report describing the ways next generation clickers are being used in organic chemistry classrooms, one instructor detailed the use of small whiteboards shared within small groups in their classroom as preferable to the next generation clicker system (Horowitz, 2016). In their classroom, the instructor would display a question, give the groups a little time to write down their answer, and then hold up their whiteboard when finished. The instructor could walk around the classroom observing the groups, and this process was found to be extremely helpful as it was easy for the instructor to tell which students were struggling or apathetic. Observing the written responses also gave the instructor a more detailed glimpse into the way students processed the question and arrived at their answer. This was successfully implemented in a class size of 80-100 students, and the instructor was able to interact with groups individually and break down the barrier between the professor and the pupil. While the newer clicker system did give better feedback than the traditional clicker system (Shea, 2016), it reinforced the distance between the instructor and the student, and the convenience of the technology limited the instructor's perception of the extent to which students truly understood the concept.

Summary

Instructors in favour of clickers enjoy the convenience of asking questions to a large number of students simultaneously and receiving instantaneous feedback, while those against it see it as new-fangled technology with little benefit for students. A compromise may be a valuable option. The whiteboard system proposed in Dr Horowitz' 2016 commentary on clickers achieves the same goal as next generation clickers, while providing a better understanding of the extent to which the class understands the material. Students using this method would also benefit from physically working through additional practice problems instead of choosing from a set of predetermined answers.

A student's understanding of chemistry will not be helped nor hindered by the clicker, but its lack of influence on long term understanding of the material itself proves it a mediocre alternative to other low-tech solutions such as using a whiteboard. Instructors looking to include practice problems throughout their lectures will likely see a similar impact from whiteboard or clicker usage.

CONCLUSION

Of the alternative teaching methods assessed in this review, it can be concluded that flipped lectures have the most evidence to support its claim as a highly effective alternative method of teaching chemistry. It increases accessibility of difficult concepts, increases performance, and provides additional support for weaknesses. Concept mapping is also effective at helping students connect the dots between initially disjoint concepts, but may not achieve the desired effect unless computer software is used to create it. Without specialised software it may not be practical to assign concept mapping to a large group of students, but there are plenty of options for institutions looking to provide this opportunity to students. Online homework is an excellent idea to hasten student feedback and minimise instructor burden, but still has many loopholes that students can exploit for better grades. With respect to the field of chemistry, online homework may be better suited for general chemistry instead of organic chemistry, as current platforms have a limited ability to randomise questions and prevent the success of trial and error approaches. More research is needed in the area of online homework to discover how many students may be using paid subscription databases or online answer banks in order to find solutions to homework problems, and to assess the true impact these sources have on student homework grades. Finally, while clicker use may increase student scores, it has been proven to have no effect on the long-term chemistry knowledge of the student.

ACKNOWLEDGMENTS

The author would like to thank Dr Jessica Bownes from the University of Glasgow for her encouragement and guidance throughout the production of this article, as well as Dr Balasingam Murugaverl from the University of Denver for his insight and support.

REFERENCES

Akkuzu, N.; Uyulgan, M. A. An epistemological inquiry into organic chemistry education: exploration of undergraduate students' conceptual understanding of functional groups. *Chem. Educ. Res. Pract* 2016*, 17*, 36-57.

Bhattacharyya, G. and Bodner, G.M., 2005. " It gets me to the product": How students propose organic mechanisms. *Journal of Chemical Education*, *82*(9), p.1402.

BouJaoude, S. and Attieh, M., 2003. The Effect of Using Concept Maps as Study Tools on Achievement in Chemistry.

Christiansen, M.A., 2014. Inverted teaching: Applying a new pedagogy to a university organic chemistry class. *Journal of Chemical Education*, *91*(11), pp.1845-1850.

Cole, R. S.; Todd, J. B. Effects of Web-based multimedia homework with immediate rich feedback on student learning in general chemistry. *Journal of Chemical Education* 2003, *80*, 1338.

Earl, B. L. Concept maps for general chemistry. *Journal of Chemical Education* 2007*, 84*, 1788.

El-Labban, W.N., 2003. Assessment of the effect of online homework on achievement in chemistry.

Gebru, M. T. The Effects of Clickers and Online Homework on Students' Achievement in General Chemistry, ProQuest Dissertations Publishing, 2012.

Gibbons, R.E., Laga, E.E., Leon, J., Villafañe, S.M., Stains, M., Murphy, K. and Raker, J.R., 2017. Chasm crossed? Clicker use in postsecondary chemistry education. *Journal of Chemical Education*, *94*(5), pp.549-557.

Gray, N. Development of a concept exploration based teaching methodology for undergraduate chemistry education, ProQuest Dissertations Publishing, 2014.

Horowitz, G., 2016. Comment on "Beyond Clickers, Next Generation Student Response Systems for Organic Chemistry". *Journal of Chemical Education*, *93*(11), pp.1829-1829.

Huesgen, B. D. Impact of an Online Homework Program on the Achievement of College Students Enrolled in First Semester General Chemistry, ProQuest Dissertations Publishing, 2012.

Reid, S. A. A flipped classroom redesign in general chemistry. *Chem. Educ. Res. Pract* 2016*, 17*, 914-922.

Richards-Babb, M., Drelick, J., Henry, Z. and Robertson-Honecker, J., 2011. Online homework, help or hindrance? What students think and how they perform. *Journal of College Science Teaching*, *40*(4).

Seery, M. K. ConfChem conference on flipped classroom: student engagement with flipped chemistry lectures. *Journal of Chemical Education* 2015a*, 92*, 1566.

Seery, M. K. Flipped learning in higher education chemistry: emerging trends and potential directions. *Chem. Educ. Res. Pract* 2015b*, 16*, 758-768.

Shea, K. M. Beyond clickers, next generation classroom response systems for organic chemistry. *Journal of Chemical Education* 2016*, 93*, 971.

Smith, J.D., 2013. Student attitudes toward flipping the general chemistry classroom. *Chemistry Education Research and Practice*, *14*(4), pp.607-614.

Smithrud, D.B. and Pinhas, A.R., 2015. Pencil–paper learning should be combined with online homework software. *Journal of Chemical Education*, *92*(12), pp.1965-1970.

Weaver, G.C. and Sturtevant, H.G., 2015. Design, implementation, and evaluation of a flipped format general chemistry course. *Journal of Chemical Education*, *92*(9), pp.1437-1448.

Yestrebsky, C.L., 2015. Flipping the classroom in a large chemistry class-research university environment. *Procedia-Social and Behavioral Sciences*, *191*(2), pp.1113-1118.