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Lessons Learned in Designing Active Learning Modules for the STEM Classroom

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For students to become real partners in their education, they must shift from a model of passive absorption of knowledge to one of active participation in constructing knowledge. To encourage this shift, I have designed a variety of active learning modules for my introductory chemistry classes, from short participation polls to full-length case studies. When well-implemented, in-class activities can be a valuable experience for students to practice applying their knowledge with instructor guidance. In this report, I will share both successes and challenges encountered in designing student-friendly active learning modules in an introductory science course.

Introduction

The prevailing constructivist theory of education suggests that learning occurs when a person builds a model of knowledge within their own mind (Chi, 2009). Importantly, this is a process accomplished by the learner, not the teacher, who only facilitates or guides the "construction". Unfortunately, many students tend to regard learning as a passive process of absorbing knowledge rather than an active one of discovering and creating knowledge. If their classes involve primarily sitting and listening to lectures, this idea can be reinforced. This is particularly damaging in the sciences, where hands-on experimentation and problem-solving are core skills. Laboratory work naturally provides active engagement with science, but students often perceive a disconnect between what they do in labs and what they hear about in lectures. To help bridge that gap and shift students away from a passive model of learning, the "lecture" classroom must also involve active participation. A growing body of pedagogical research supports the idea that active learning elements such as group problem-solving, case studies, or guided inquiry can improve student performance and satisfaction in STEM courses (Freeman et al., 2014; Hein, 2012; Lewis & Lewis, 2005; Lyon & Lagowski, 2008). However, these gains can be subtle and are often found to depend heavily on implementation (Hein, 2012; Williamson & Rowe, 2002). For the educator first exploring the use of active learning techniques in their classroom, it can be daunting to choose or design activities that are most effective.

Herein, I offer one new professor's perspective on incorporating significant active learning components in the college STEM classroom, with "lessons learned" of both success and failure. Specifically, I have designed a variety of active learning modules for General Chemistry, from short participation polls to full-length case studies. Along the way, I have assessed student feedback on the effectiveness of activities versus lectures. Over five semesters of teaching introductory chemistry, I have seen student perceptions improve to where many now rank in-class activities as one of the most valuable parts of the course. From my own perspective, I have found in-class activities–properly implemented–to be an effective way to promote student engagement, target critical thinking and problem-solving skills, and draw interdisciplinary connections with my subject.

Institutional Context

Bellarmine University is a small (2500 undergraduate), private, liberal arts and sciences university in the Catholic tradition. General Chemistry is a two-semester introductory chemistry course that covers "fundamental ideas about what matter is and how material properties and reactions follow from the structure of matter at the atomic scale" (Bellarmine University, 2019). This is a foundational course for most students majoring in the physical or health sciences, and multiple sections are taught each semester. At Bellarmine University, a typical section of General Chemistry includes a maximum of 40 students for lectures (50 minute classes 3 times a week) and 16 students for labs (4 hour sessions once a week). The lab and lecture portions of the class are taught separately.

I have been responsible for teaching two to three lecture sections of General Chemistry per semester since beginning as a faculty member in the fall of 2017. At that time, various strategies had been used in the General Chemistry curriculum but traditional lecture instruction was the primary form of delivery. Therefore, incorporating significant active learning components to the course has been an important goal for me as a teacher and for our program generally. The active learning strategies discussed here have been designed for classrooms of fewer than 50 students; however, many of them may be adaptable to larger classrooms (see, for example: Lewis & Lewis, 2005; Lyon & Lagowski, 2008).

Overview of Strategy

The incorporation of active learning modules into the General Chemistry classroom may serve a number of purposes:

- Break up large chunks of lecture time to maintain student attention

- Quickly identify and address student misunderstandings and difficulties
- Give students practice solving problems and thinking critically
- Provide peer learning experiences
- Allow professor to act as guide or tutor rather than lecturer
- Highlight applications of class topics to other fields

In the following sections, I will discuss three examples of active learning modules I have used to serve these goals: Socrative Class Polls, Guided Practice, and Group Case Studies. They are organized in order of the length of time required for each activity, from shortest to longest.

To gauge the effectiveness of active learning components in my General Chemistry classroom, I solicited student feedback in the form of class surveys given on the last day of each semester (four semesters of data total). In these surveys, students were asked to rank various components of the course (lectures, activities, textbook, etc.) according to the question "How helpful was this to your learning?". From these surveys as well as student comments on official University course evaluations, I was able to gauge student perceptions of different types of active learning components and see changes as the activity design evolved. I will present these results in the "Student Perceptions" section below.

Short Activity: Socrative Class Polls

Short in-class activities (10 minutes or less) may be used at the beginning of class to introduce a topic, in the middle of class to break up a long lecture, and/or at the end of class for concept review or a formative assessment. "Clicker questions" are one popular technique for this, where students submit answers to a multiple-choice question using a "clicker" device, then the class results are displayed to the instructor in real time. These quick concept-checks are valuable for identifying student difficulties and addressing them immediately, as well as for engaging all or most of the class, even in a large group of students (Caldwell, 2007). However, students must buy "clicker" devices and remember to bring them to class. Socrative.com is an online polling platform that offers a similar functionality but without these disadvantages – the site is free to use and students can answer questions using their mobile devices.

In my General Chemistry classes, I have used Socrative for short anonymous polls to gauge student understanding and guide class reviews. To run a Socrative activity, I give students a five-letter code to log into the "Quiz", then their answers are tracked in real time by the platform. When enough students have answered, I display the percentages at the front of the room and explain the solution. There are multiple options for the instructor on how to run the poll – for example, it can be anonymous to encourage students to give honest answers, or names can be required and the results exported for grading. The Socrative platform is highly flexible in creating longer or shorter polls, with multiple options for questions type. The real-time answers and feedback help students see how they are doing relative to their peers and self-identify gaps in their knowledge, while the instructor receives immediate data about how well the class as a whole is grasping course content (and not only those students who sit in the front row). It is easy to catch and address misunderstandings, yet without "calling out" any particular student.

Additionally, I found Socrative polls invaluable during the COVID-19 shutdown of Spring 2020, when my General Chemistry courses moved abruptly online (Christianson, 2020). Rather than making virtual class sessions pure lecture, I wrote Socrative Quizzes that allowed me to guide students through a set of concept questions and practice problems. Because the polls were all online, students could log in remotely and participate in the class activity even from afar. This kept students engaged in something more than just looking at a screen during our remote class sessions. Even in a virtual classroom, I can highly recommend the Socrative platform as a way to include active learning!

Medium-Length Activity: Guided Practice Examples

Problem-solving and quantitative reasoning are essential skills for STEM students to master, and working practice examples at the board is a common approach to teaching these skills. Since I have been teaching General Chemistry, "more practice examples" has been a constant refrain among student feedback comments! On one hand, working examples for students is desirable to demonstrate scientific problem-solving strategies. However, if students only watch their instructor solve problems, this can easily become "teacher-centered." Additionally, students can become dependent on copying down the instructor's solutions, such that they cannot see how to approach a problem different than the particular examples chosen in class. To make practice examples more "student-centered," it is necessary to involve learners more intentionally in the problem-solving, while still modeling the strategies they need.

One way I have approached this is by providing "Guided Practice" worksheets to my students when I present example problems in class. Each worksheet is separated into two columns, with the example problem text written on the left and space for notes on the right, as shown in the example in Figure 1 below. Students are instructed to follow along with my solution and/or solve problems themselves as we address the example set as a class. At the front of the classroom, I display the same problems on a projection slide and work through them on the whiteboard. Since the text of the problems is given to the students, they do not have to spend time copying down text from the slide and can pay attention to the problem-solving itself. In a set of at least two related problems, I will work one fully, then ask students to work a second example independently or with a partner. Then, I ask a volunteer to talk me through their solution as I reproduce it at the board for the whole class. These activities can be made relatively short, with only a few problems, or long enough to cover an entire class period. The instructor can also be flexible in how many examples they solve versus having students solve, depending on time constraints. Students in my classes have perceived Guided Practice activities very positively. It seems to fill their need for "more examples" while also shifting them from passive to active participation.

Guided Practice: Stoichiometry and its Applications
CHEM 103

Follow along and write in notes and solutions as we work through these problems as a class!

Problems	Notes/Solutions
Antacids: "Milk of magnesia" is sometimes used to neutralize stomach acid (mostly HCl) according to the following equation: $Mg(OH)_{2\,(s)} + 2\,HCl_{(aq)} \rightarrow 2\,H_2O_{(l)} + MgCl_{2\,(aq)}$ How many grams of HCl will a 400-mg tablet of $Mg(OH)_2$ neutralize?	

Figure 1. Example of part of a Guided Practice worksheet.

Long Activity: Group Case Studies

Group-based activities are often recommended as high-impact teaching practices; systems such as POGIL ("Process Oriented Guided Inquiry Learning") and PLTL ("Peer Led Team Learning") are touted for enhancing student performance and increasing inclusivity and student confidence (Hein, 2012; Lewis & Lewis, 2005; Lyon & Lagowski, 2008). In the absence of dedicated TAs or peer leaders for my classroom, I have implemented a less extensive program of team-learning experiences by the use of group case studies in General Chemistry. For these activities, which typically last a full class period (50 minutes), I have students form groups of 3-4 to solve a problem or set of problems related to a realistic scenario. These scenarios are chosen to highlight real-world applications of class concepts, draw connections to other disciplines or societal issues, and expose students to potential careers in science. Selected examples of case-study scenarios include:

- An iron/steel company deciding whether it will be profitable to build a mine on a new ore vein
- A team of doctors choosing medication for a patient and calculating the needed dose
- A team of engineers determining the necessary operating pressure for a new ammonia-production plant
- An art conservator authenticating a Renaissance painting by pigment analysis
- Two friends wondering how quickly a French stew will cook in a pressure cooker
- The NFL investigating the 2015 "Deflategate" incident

Case studies have a number of advantages as active-learning modules. They are fully student-centered, requiring students to practice not only problem-solving and critical thinking but communication and teamwork in their group. The instructor, circling the classroom with advice, is able to interact more personally with students and identify areas of difficulty. When students practice applying their knowledge in the classroom with the professor as a guide rather than a grader, it provides a safe place for them to tackle problems, struggle, ask questions, and try again. Tying in applications, careers, and societal issues that students care about helps them see the value in what they are studying and gives them a chance to bring different perspectives to the table.

In my experience, however, long group activities are most likely to have pitfalls in their implementation. Chief among these is timing them correctly so that they fit within a single class session. In my first semester using case studies, I often (unintentionally) made them too long or too difficult for students to complete by the end of class, leading to frustration. Often, student groups had trouble getting started on the problems and would sit for ten minutes or more without making progress until I intervened directly. These problems were eased by redesigning case studies to be more streamlined, with only one or two major tasks to complete. It is also essential to build in enough time for scaffolding–at least an introductory explanation of the scenario and review at the end of the study. Walking students through the first part of a case study problem before breaking out into groups can help get their problem-solving gears turning. During the activity, the instructor should be vigilant in circling the room to monitor groups' progress and offering help to those who are stuck. Finally, there should always be at least five minutes left at the end to review solutions as a class. Designing good case studies can be challenging, but ultimately they can be very rewarding for students.

Student Perceptions

Over the first two years of using active learning components in my General Chemistry I and II courses, I surveyed students, asking them to rank different components of the course on a Likert scale of 1 to 5 according to the question "How helpful was this to your learning?" Between 50 and 60 total student responses were obtained each semester, representing 65-90% of students across all relevant sections of the course. A chart of selected results is shown below in Figure 2.

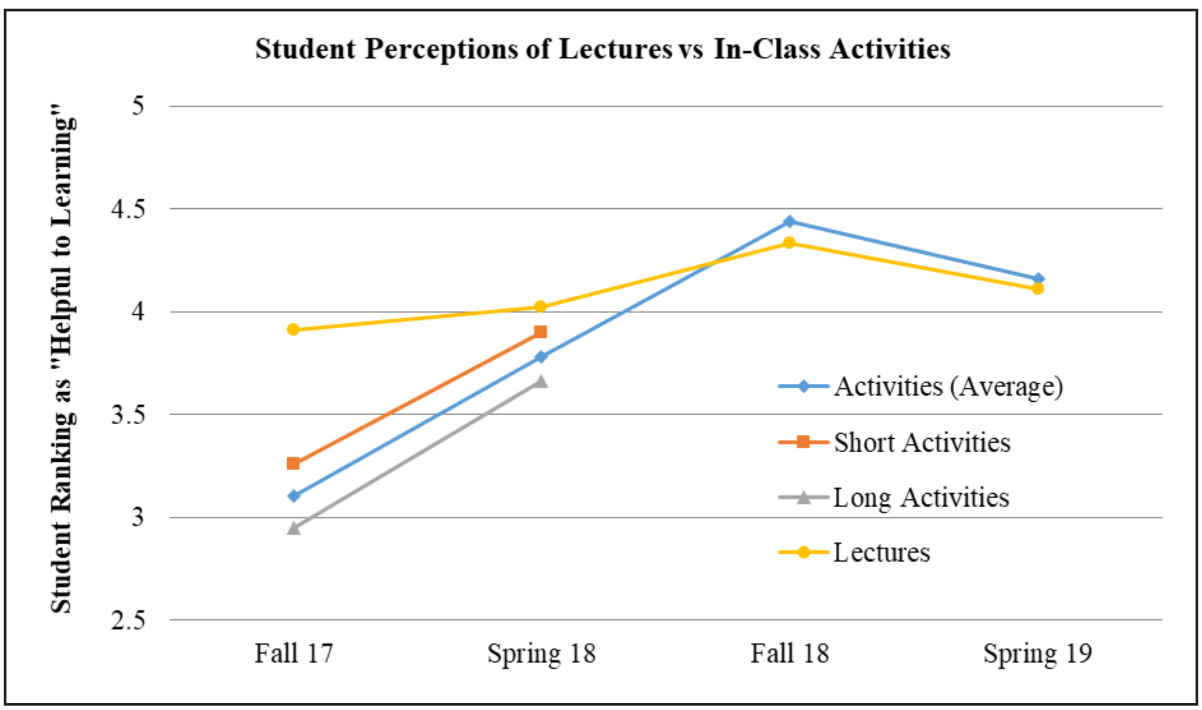

Figure 2. Trends in student perception of lectures versus in-class activities over four semesters of General Chemistry I and II. Rankings are on a Likert scale with 1 being "Not at all helpful", 3 being "Somewhat helpful", and 5 being "Very helpful" to student learning. In the first two semesters, short and long activities were ranked separately, but subsequently were grouped together as "in-class activities".

In the first semester, in-class activities were poorly received, particularly class-long group activities, which were ranked 2.95 on average–more unhelpful than helpful! Student comments revealed that they did not see the relevance of these activities to the class as a whole, were frustrated by activities that were too long to complete or review, and generally felt them to be a waste of class time. While this was disappointing, it provided insights about what students value. Students did not necessarily enjoy in-class activities for their own sake–they did appreciate getting practice on problem-solving and looking at material in a different way, but only if they perceived it as directly related to material that had already been introduced or that they expected to be tested on. It should be admitted that students' conception of "what is helpful to learning" is often conflated with "what is helpful to passing the test," but either way students need the relevance of activities to both learning objectives and assessments to be made clear to them. Student comments also revealed the importance of guidance and review/feedback on activities; they became frustrated when they fumbled their way through an activity, then ran out of time to go over a solution. This was up to me as the instructor to provide more robust scaffolding at the beginning and end of activities and streamline them to be more easily completed in class time.

In the second semester, I made substantial changes to activities to respond to these student concerns. I prioritized shorter activities and redesigned long case studies to be more streamlined and scaffolded. I also more intentionally explained to students the purpose of activities and matched their content with that on graded assessments. The result was that students perceived them much more favorably, though still well below their rating of lectures. In the following year (beginning the course sequence again with a new group of students), I continued to fine-tune the design of activities along the same lines. With the continued improvements, in-class activities were regarded highly by students, who now ranked them as high as or higher than lectures on the Likert scale. This may serve as an encouragement to instructors who try incorporating active learning without immediate success!

Conclusions

Active learning techniques can be a valuable tool for the STEM classroom when well-designed. From the student perspective, active learning can provide variety in their classroom experience, giving them a chance to engage with class material in a different way. However, it is up to the instructor to implement activities well so that students understand their objectives and have sufficient support to complete them. In my General Chemistry courses, despite a rocky start, I have seen student perceptions of in-class activities improve to where many now rank them as one of the most valuable parts of the class. Among the lessons I have learned in designing both short and long in-class activities are the following list of "dos" and "don'ts" in Figure 3.

Do:	Don't:
• Explain purpose of in-class activities to students • Break up long lectures with short activities • Keep in-class activities "low-stakes" and their graded aspects (if any) clear • Walk around the classroom to monitor progress and give advice • Scaffold longer activities with a short lecture and discussion of instructions and expectations • Leave time to review activities as a class after students complete the task • Adjust activity length based on student abilities • Make activities relevant to student interests: applications, issues, and/or careers	• Expect students to appreciate the value of active learning without your guidance! • Leave graded aspects of activities (if any) unclear or unstated • Begin an activity without at least a short scaffolding lecture or example • Provide written instructions without explaining them verbally • Make group activities too long to complete in a class session • Allow student groups to sit confused and doing nothing

Figure 3. "Dos and Don'ts" of In-class Activities

With judicious design, in-class activities give students the chance to think independently and use prior knowledge to explore something new–maybe even something interesting! Ideally, active learning encourages students to see themselves not as information sponges, but as constructors of their own understanding.

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