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Low-Barrier Strategies to Increase Student-Centered Learning

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Low-Barrier Strategies to Increase Student-Centered Learning

Abstract

Evidence has shown that facilitating student-centered learning (SCL) in STEM classrooms enhances student learning and satisfaction [1]–[3]. However, despite increased support from educational and government bodies to incorporate SCL practices [1], minimal changes have been made in undergraduate STEM curriculum [4]. Faculty often teach as they were taught, relying heavily on traditional lecture-based teaching to disseminate knowledge [4]. Though some faculty express the desire to improve their teaching strategies, they feel limited by a lack of time, training, and incentives [4], [5]. To maximize student learning while minimizing instructor effort to change content, courses can be designed to incorporate simpler, less time-consuming SCL strategies that still have a positive impact on student experience.

In this paper, we present one example of utilizing a variety of simple SCL strategies throughout the design and implementation of a 4-week long module. This module focused on introductory tissue engineering concepts and was designed to help students learn foundational knowledge within the field as well as develop critical technical skills. Further, the module sought to develop important professional skills such as problem-solving, teamwork, and communication. During module design and implementation, evidence-based SCL teaching strategies were applied to ensure students developed important knowledge and skills within the short timeframe. Lectures featured discussion-based active learning exercises to encourage student engagement and peer collaboration [6]–[8]. The module was designed using a situated perspective, acknowledging that knowing is inseparable from doing [9], and therefore each week, the material taught in the two lecture sessions was directly applied to that week's lab to reinforce students' conceptual knowledge through hands-on activities and experimental outcomes. Additionally, the majority of assignments served as formative assessments to motivate student performance while providing instructors with feedback to identify misconceptions and make real-time module improvements [10]–[12].

Students anonymously responded to pre- and post-module surveys, which focused on topics such as student motivation for enrolling in the module, module expectations, and prior experience. Students were also surveyed for student satisfaction, learning gains, and graduate student teaching team (GSTT) performance. Data suggests a high level of student satisfaction, as most students' expectations were met, and often exceeded. Students reported developing a deeper understanding of the field of tissue engineering and learning many of the targeted basic lab skills. In addition to hands-on skills, students gained confidence to participate in research and an appreciation for interacting with and learning from peers. Finally, responses with respect to GSTT performance indicated a perceived emphasis on a learner-centered and knowledge/community-centered approaches over assessment-centeredness [13].

Overall, student feedback indicated that SCL teaching strategies can enhance student learning outcomes and experience, even over the short timeframe of this module. Student recommendations for module improvement focused primarily on modifying the lecture content and laboratory component of the module, and not on changing the teaching strategies employed. The success of this module exemplifies how instructors can implement similar strategies to

increase student engagement and encourage in-depth discussions without drastically increasing instructor effort to re-format course content.

Introduction

There is a growing body of literature that supports an educational shift from being instructor-centered to student-centered, especially regarding science, technology, engineering, and mathematics (STEM) curriculum [14]. Student-centered learning (SCL) strategies have been linked to improved student learning and increased student satisfaction [1]–[3]. As a result, a large number of educational and governmental bodies have called for an increase focus on SCL in STEM curriculum [1], and have even invested a significant amount of time and money toward the research and development of SCL practices [14].

However, increased research in effective teaching strategies have been met with minimal translation toward real change in current undergraduate STEM teaching practices [4], [14]. Despite some faculty expressing a desire to improve their teaching, many barriers have been identified that contribute to the lack of change seen thus far. Faculty have expressed a lack of time, training, and incentives to enhance their teaching methods, especially at institutions that promote a "research-first" culture [4], [5], [15]. In addition to these barriers, many faculty admit that it is simpler to maintain a didactic lecture-based approach to disseminating knowledge. As many instructors teach as they were taught, referred to as apprenticeship of observation [16], traditional lecture-style teaching can often be viewed as sufficient for educating students [3].

Regardless of the underlying causes that lead to resistance in changing teaching strategies, there is a clear need for reform [1], [5], [14], [15]. Therefore, efforts should be made to identify ways to implement low-barrier SCL strategies which will enhance student learning without impacting instructor preparation time or requiring major revisions to existing course material. The purpose of this paper is to demonstrate how we implemented a series of low-barrier SCL strategies, informed by learning theory and evidence-based practices, to positively impact student learning and offer clear examples of how these individual strategies can be implemented in a university course without recreating content.

Design and Implementation of Module

In this paper, we present an example of a short 4-week module, an introduction to tissue engineering, developed in an instructional incubator [17]. The purpose of the incubator is to provide early career faculty and graduate students with the opportunity to be mentored in instructional design and implementation of new undergraduate biomedical engineering curriculum (modules) informed by learning theory and evidence-based practices. This tissue engineering module was designed and implemented by a graduate student teaching team (GSTT) of three. The first two authors were members of the GSTT, while the third author was the instructor for the incubator. The purpose of the module was to help undergraduate students learn critical skills identified by stakeholders, such as sterile technique, cell culture, biomaterial design, experimental planning, and quantitative analyses. Further, the module sought to aid students in the development of important professional skills, such as problem-solving, teamwork, and communication. During module design and implementation, a variety of SCL teaching strategies (Table 1) were applied to achieve the learning outcomes within the short timeframe of the module (Figure 1). A detailed description of implementation follows below.

Table 1. Summary of SCL techniques and their methods of implementation.

SCL Technique	Interventions
Situated Perspective	• Concepts discussed in lectures map directly to hands-on experiments (authentic learning experiences) and expected experimental outcomes
Active Learning	• In-class participation credit • Discussion-based lectures facilitated in student groups - Review questions - Problem-solving exercises
Mixed-Mode Assessment	• <u>Formative</u> (credit for completion, feedback provided) - Post-lab assessments - Perusall reading assignments • <u>Formative-Summative</u> (graded based on rubric, feedback provided) - Lab notebook checks • <u>Summative</u> (graded on rubric) - Pre-lab quizzes - Final lab report
Responding to Student Feedback	• Mid-module evaluation by student responses to survey (anonymous) • Instructors reviewed feedback then discussed identified areas of improvement and planned for change with students

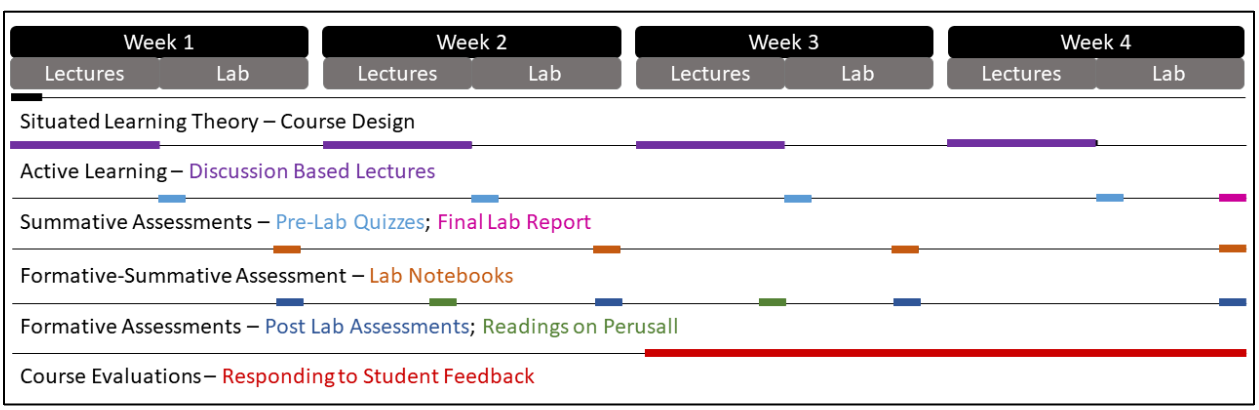

Figure 1. Timeline of SCL strategy implementation throughout 4-week module.

Situated Perspective in Module Design

An important component of our module design was the use of a situated perspective to influence the development of lecture and lab content for the module. From a situated perspective, learning is viewed as a movement from peripheral participation to full participation in a sustained community of practice [9], [18]–[20]. In this module, the two first authors served as the instructors in the module and as members of the tissue engineering community of practice who helped students become increasingly skilled actors in the community via participation in authentic learning experiences [19]. Using this perspective, module material was designed based on learning in practice, which allowed students to first learn about specific skills and concepts in lecture, then directly apply these skills or observe these concepts during hands-on experiments in lab sections. Each lab section incorporated skills learned in the previous experiments, allowing students to reinforce their new skills and build upon what they had already learned. To help students become more independent, we gradually decreased the experimental guidance given throughout the module so that they could increase their comfort with the material and technical skills and pursue a role in the tissue engineering community if they chose to do so.

Active Learning and Discussion-Based Lectures

Numerous educational studies [2], [4], [6], [7], [21]–[23] have shown that active learning exercises can positively influence student learning, with many focusing on STEM fields. Active learning strategies allow students to take on a more engaged role in their education, often encouraging processing and application of course material [4]. In our module lectures, active learning was incorporated via discussion-based activities to encourage student collaboration and peer-to-peer learning. These activities included beginning each lecture with a set of review questions that were discussed with the class and incorporating problem-solving exercises into the lectures. We reasoned that the review questions would be important for reminding students what they had already learned, which would help them more easily connect previous topics to the new material being introduced in the lecture. Further, informal collaborative group learning has been shown to improve student learning by allowing peers to address each other's misconceptions or gaps in understanding [8]. In addition to the benefits of peer-to-peer learning, we also reasoned that collaborative group learning may help to overcome previously reported student resistance to active learning strategies [2], [22]. We facilitated collaborative learning [24] through student group discussions of review questions and problem-solving activities. Then, students who volunteered were asked to summarize the groups' discussions for the class. While calling on random students may promote individual accountability, we had volunteers answer questions and provide summaries during class discussion to reduce the anxiety students may feel as a result of cold calling [25], [26]. Additionally, students were given participation credit for being actively involved in group discussions to encourage student participation.

Inclusion of Formative and Summative Assessments

There are various strategies instructors can employ to encourage a classroom environment that helps students focus more on learning the material and less on achieving a high grade. One example, discussed previously, is offering credit for participating in classroom discussions. However, participation points do not always equally serve diverse student populations and can be a source of stress for some students [25], [26]. Another method that can ease students who are hesitant to voice their opinions, for credit, is the incorporation of low-stakes formative assessments. Formative assessments are assessments designed to help elucidate students' knowledge to both the instructor as well as the student. Information collected via formative assessments should feed back into continuous course improvement and student learning [11].

Therefore, we incorporated methods of formative assessment into our module to supplement the more traditional summative assessments and give students more opportunities to get feedback other than in-class discussions. Formative assessments were given to students in two ways: post-lab assessments and reading assignments using an online platform. For post-lab assessments, students were asked to briefly summarize, in their own words, what was done in the experiment and what the purpose of the experiment was for that lab section. This assignment was graded solely on completion, providing a low-stakes assessment for students to reflect on what they have learned. At the beginning of the following lecture, misconceptions identified in the post-lab assessments were briefly addressed with the students, which was important in giving students the opportunity to identify their own misconceptions and areas for improvement [11], [12]. We also required students to complete online readings using a collaborative e-reader, Perusall (www.perusall.com), which allows students to see and respond to each other's questions and comments directly on a shared PDF. For each reading, students were required to make one new comment and respond to another student's comment. This assignment was only graded for completion, which was intended to promote discussion of the material and enable students to articulate their questions about the scientific literature. On the day the assignment was due, popular comments and common questions were discussed with the students at the beginning of the lecture.

We also incorporated a combined formative-summative assessment in the form of weekly lab notebook checks. Lab notebooks were collected at the end of each lab section and graded based on a provided rubric. We chose to grade this assignment to promote the habit of properly keeping a formal lab notebook, which is often challenging for people of all educational levels. After each lab, notebooks were collected and graded. We left comments in the lab notebooks to provide feedback, such as areas where students received full points and where improvements were needed to gain full points in the future, which gave students the opportunity for weekly improvement. Additionally, we incorporated traditional summative assessments in the form of pre-lab quizzes and a final lab report. The pre-lab quizzes were used to evaluate student knowledge and motivate students to prepare for lab experiments. The summative final lab report was intended to allow students to think critically about the knowledge learned in the module and synthesize that knowledge into one report. Students were provided with a rubric for the final lab report to illustrate instructor expectations.

Module Evaluations and Responding to Student Feedback

In addition to formative assessments to evaluate and improve student learning, it is important to assess student satisfaction with the course overall. This is most effective when done throughout the course to allow for corrective actions and improvement. In these kinds of assessment, it is not enough to simply inquire from students about the progress of the course. It is essential to respond to student feedback in a way that makes them feel heard [27]. In our module, we gauged student satisfaction with an optional, short mid-module evaluation that asked only two free response questions: what instructors were doing well and what instructors could improve on. After collecting the feedback from students, we gathered as a teaching team to review student responses and formulate strategies for change. Then, we discussed our plans for making changes to specific material to improve the second half of the module with the students to determine if they thought our plan would be successful and gain additional student feedback to consider.

Methods

Fifteen undergraduate students ranging from freshman to senior level (40% male, 60% female) were enrolled in the module. Students were asked to anonymously respond to surveys before the start and after the conclusion of the module. Pre-module surveys focused on motivation for enrolling in the module, module expectations, and prior experience with module topics such as technical skills related to tissue engineering and reading scientific literature. Post-module surveys focused on student satisfaction, perceived learning gains, and graduate student teaching team (GSTT) performance (see Appendix). Specifically, GSTT performance was assessed two ways: 1) student responses to open-ended survey questions and 2) student ratings of the GSTT performance. The open-ended survey questions asked students to share what they felt instructors did well and could improve on in the future. Students rated the GSTT performance on a five-point Likert-like scale (1-never, 2-sometimes, 3-about half the time, 4-most of the time, 5-always) of questions based on Bransford, Brown, and Cocking's How People Learn (HPL) framework [11] to identify if students felt instructors taught the module as assessment-, learner-, or knowledge/community-centered [13] (Table 2). The HPL framework is a validated framework that is useful for improving student learning by assessing graduate instructor teaching performance. We specifically chose to use this framework as a means of providing the GSTT with feedback on their ability to translate theory to practice and create a more learner- and knowledge/community-centered learning environment given our goal of enhancing student learning through SCL strategies. Thematic analysis of qualitative data was performed to identify common themes among student responses to open-ended survey questions [28].

Table 2. Survey questions related to the HPL framework [11], adapted from Zhu et al. [13].

During the module session, the graduate student teaching team…	
Learner-Centered	1. Addressed my individual needs or concerns 2. Helped me and my partner(s) when we needed assistance 3. Provided responses that guided me in problem-solving 4. Motivated me to continue learning 5. Facilitated my communications with professors or other course staff 6. Acknowledged that learning engineering concepts can be challenging at times 7. Translated theoretical knowledge into practical skills 8. Provided verbal feedback about my progress
During the module session, the graduate student teaching team…	
Knowledge/Community-Centered	1. Emphasized learning new skills 2. Encouraged a nonthreatening environment where students could ask questions or comment about academic content 3. Fostered a collaborative learning environment 4. Encouraged me to work interactively with other students 5. Helped me understand key course concepts 6. Shared skills I can apply in the future 7. Acknowledged my misunderstanding of a concept

	8. Related content of the course to a big picture 9. Encouraged students to learn from each other in class 10. Asked questions to make me think 11. Explained how to solve specific problems 12. Shared their own practical experience 13. Acknowledged the diverse learning styles of students in the class 14. Applied knowledge to everyday situations
During the module session, the graduate student teaching team…	
Assessment-Centered	1. Acknowledged when I was improving in the class 2. Addressed my concerns about grades in this course 3. Provided written critiques about my progress 4. Provided written critiques to me/my partner about our progress on course deliverables

Results

Student Perceived Learning Gains

In an open-ended question that asked students what they gained in the module, 14 of the 15 students identified learning tissue engineering and/or lab specific technical skills, such as sterile cell culture, 3D hydrogel fabrication, imaging, and quantitative assays. Students expressed a deeper understanding for the field of tissue engineering and greater knowledge of career opportunities in the field. When describing an increased understanding of tissue engineering, students identified specific core concepts of the field of tissue engineering such as an understanding of cell-ECM interactions. In addition to tissue engineering specific skills, students also reported increased professional skills such as how to read scientific literature, work collaboratively and learn from their peers, and design experiments.

Student Engagement and Satisfaction

Overall, students expressed high satisfaction with the module as demonstrated in responses to open-ended questions about module expectations and perceived learning gains. With the exception of one upper-level student who found the module to be more introductory than expected, all students stated that the module meet their expectations, with four students saying it exceeded them. A majority of students described the lectures as engaging and well-designed, and some students identified an emphasis on group work and learning from their peers. Multiple students expressed an appreciation for the amount of hands-on experience they received, something they described as unique to this course. Additionally, many students expressed an increased interest in tissue engineering and the development of confidence to pursue future opportunities in the field.

GSTT Performance

Student responses to the Likert-like scale questions based on the HPL framework [11], [13] indicated that students felt the GSTT taught the module in a manner that was more learner- and knowledge/community-centered than assessment-centered (Figure 2). All 15 students answered that the GSTT *always* 1) addressed student's individual needs or concerns and 2) emphasized learning new skills. Except for one student, who still felt the statement was true *most of the time*, students answered that the GSTT *always* 1) encouraged a nonthreatening environment and 2) helped them and their partners when they needed assistance.

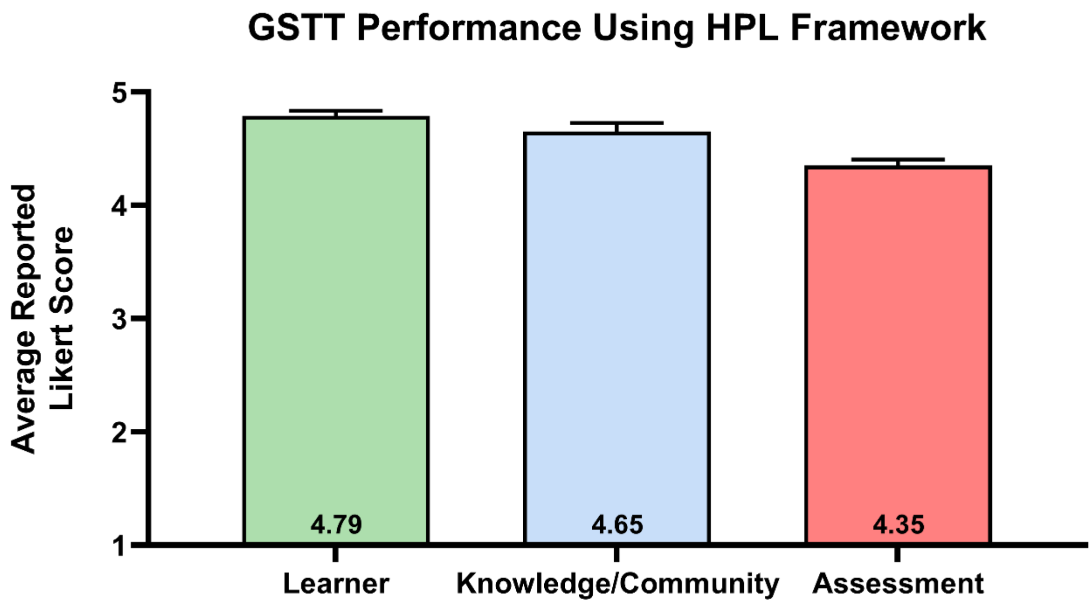

Figure 2: Average reported Likert-like scores of the GSTT performance using survey questions from the HPL framework [11], [13].

Student responses to open-ended survey questions indicated that students were pleased with how the GSTT taught the module. When asked what the GSTT did well, the majority (~87%) of students mentioned feedback that corresponded to positive instructor-student interactions and just over half (~53%) credited the GSTT with creating a positive learning environment throughout the module. Students also stated that they felt the GSTT was knowledgeable, provided clear expectations, and effectively taught complex topics in a manner that was digestible for novice students. Many students stated that they enjoyed the teaching techniques used by the GSTT, especially regarding the lecture portion of the module. Students also reported feeling more comfortable with module topics after the conclusion of the module than when they began the module. When asked what the GSTT could improve on, more than half (60%) of the students did not have suggested improvements for how the GSTT taught the module, with multiple students stating the GSTT taught the module effectively. Critiques of the GSTT focused on wanting more organization amongst the teaching team during the lab sections and improving the delivery of lectures (slower pacing, louder delivery).

Student Recommendations for Module Improvement

Student recommendations for module improvement focused mainly on improving the time management of the lab sections. In fact, two-thirds of students expressed the need for improvement of the lab portion of the module. Students suggested shorter experiments and trying to reduce class size by offering more than one lab section. While it was clear that students wanted more improvement of lab organization, students did state that the GSTT improved the time required to complete each lab and amount of content included in labs in the second half of the module. Additionally, students recommended reformatting the pre-lab summative assessments to more closely align with lecture content or to be open note, so students are rewarded for being attentive during class lectures.

Instructor Perspective

Unlike traditional lecture classes, a variety of SCL strategies were implemented throughout the 4-week module to ensure that the module was addressing the needs of the students. Our goals were to encourage student engagement and reflection as well as understand where students were in terms of their comprehension of the material so that we could provide real-time feedback during the learning process. Length of assessments and reflections were kept short, with the exception of the summative final lab report. For example, post-lab reflection assessments only required students to summarize the purpose of the exercise in less than one page and pre-lab quizzes were no more than five questions. Further, Perusall reading comments were briefly reviewed to quickly gauge students' understanding of the literature and identify areas for clarification. By keeping assessments short, we could quickly skim through student work to identify common misconceptions to be addressed in the next lecture. Overall, most of our time was spent trying to modify lab sessions to fit students' needs while considering available resources, and a smaller portion of time was needed to review student work and formulate a strategy for providing feedback. Though additional instructor effort was needed to quickly provide timely, effective feedback to students, we observed constant improvements in students' ability to answer problem-solving questions, keep detailed lab notebooks, and perform hands-on experiments in lab sessions.

The overall goal of the short, 4-week module was to expose students to tissue engineering content and technical skills in a student-centered environment. We believe that the improvement we observed in student skills in the lab, enhanced performance week to week in their lab notebook and post-lab reflections, and the qualitative student responses from the post-module survey indicated that students achieved the desired learning outcomes for the module. Final lab reports were the main form of direct assessment of conceptual understanding that were graded for accuracy in this module. The reports were summative in nature and focused on students' ability to synthesize the content knowledge gained in the module to interpret experiment results and formulate conclusions. Student performance on the lab reports demonstrated that students had a strong conceptual understanding of the module topics. The average grade for the final lab report was ~92%, and the average grade in the module overall was ~95%. While we purposefully de-emphasized the importance of grades to promote a more learner- and knowledge/community-centered environment, the high average grades on individual assignments as well as for the module overall demonstrate students' attainment of both the technical and professional skills discussed in the intended learning outcomes for the module.

Discussion

From our observations as instructors, students appeared engaged in class discussions and throughout lab sections. Students came to class excited to learn and seemed comfortable interacting with the GSTT. Students showed continual improvement in lab notebook maintenance throughout the module and displayed a strong understanding of core tissue engineering concepts through Perusall comments and in their final lab reports. Students seemed to greatly benefit from the Perusall activity, which allowed students to carefully dissect scientific literature and converse with their peers about interesting topics and unanswered questions.

Though students did have recommendations for module improvement, their feedback had minimal suggestions for changing strategies used to teach the content and focused more on reformatting the lab portion. While some labs were lengthier than planned or at times unorganized, some students expressed that they did not mind staying late. The labs were often longer than planned due to a constraint of resources, resulting in the need for students to share workspace, which we worked to correct by making the lab sections for the second half of the module more student team oriented as opposed to every experiment being done individually. Due to the nature of cell culture and the need to continually re-design experiments throughout the module, some experiments did fail. However, this allowed us to have in-depth conversations with students about the challenges of practicing tissue engineering in the real world. Troubleshooting should intentionally be incorporated into lab sessions to allow students to identify causes for unexpected results, especially when given experimental guidance like detailed protocols [29]. Through these conversations, students were able to come up with problem-solving strategies to approach the experiments differently in the future if they were to pursue a career in the field.

Overall, student responses indicated students were satisfied with the module, especially regarding the module meeting their expectations and helping them obtain skills relevant to the field of tissue engineering. Students gained a deeper understanding for the field of tissue engineering and potential career prospects as well as the confidence to pursue future tissue engineering opportunities. Students also felt the GSTT taught the module in a manner that was more learner- and knowledge/community-centered than assessment-centered. This possibly enhanced student satisfaction and perceived learning outcomes as students were more likely to focus on learning instead of grades. Additionally, student responses also indicate that students seemed to enjoy learning from and interacting with the GSTT, which has been identified as an important aspect of the student learning experience [22], [30]. It has been suggested that the way faculty interact with students can be more influential in student learning than the structure or content of the course itself [22]. Throughout the module, we made efforts to be approachable, teach with enthusiasm, and encourage frequent student-instructor interactions [30].

Though the teaching strategies implemented appeared to result in high student satisfaction and improved student engagement, some of these results could be attributed to the nature of the module itself. For example, this module only had 15 enrolled students with three graduate student instructors which created a small student-to-instructor ratio. This low student-to-instructor ratio allowed for more student-instructor interactions, which students were likely more comfortable engaging in with graduate students as opposed to faculty members [31]. The small class size also allowed us to hold the module lectures in a more informal environment compared to a large lecture hall which likely improved student experience [32]. These attributes of the module may be additional factors that contributed to the observed changes in student outcomes beyond the implemented SCL strategies.

This module serves as an example of how a variety of SCL strategies were used to accomplish specified learning outcomes over a short period of time. Though the conceptualization and design process for creating the module through a team-oriented instructional design sequence [17] may not be directly applicable to instructors looking to adapt current courses, some aspects of the module can be translated to existing courses. In designing the module, content was first developed then modified to incorporate SCL strategies throughout lectures and lab sessions, a process which may be similar to instructors adapting their current courses. For our 4-week module, we purposefully incorporated multiple SCL strategies to have a high impact on student learning. The frequency of SCL techniques in our module is likely higher than what might be observe in a traditional, semester long course. This was made possible because the time spent reviewing student work was distributed among three instructors, making the time management of providing timely feedback more feasible in a short timeframe. In a full-length course, many of the SCL strategies, such as assessments and written feedback, can be less frequent and more evenly distributed throughout the course, making their incorporation more manageable for a single instructor.

The successful implementation of this module helps exemplify techniques instructors can utilize to improve student engagement and learning gains. It can often seem overwhelming for instructors to change the way they teach or transform learning environments through approaches like reformatting a course to be a flipped classroom experience. However, effective change can be facilitated using low-barrier strategies that are more easily incorporated into already established courses, without drastic changes in content or technological interventions. This paper aims to describe the multiple strategies we found productive in our module to help inform instructors who wish to incorporate SCL to varying degrees in their courses. For instructors seeking to incorporate SCL strategies into their existing courses, one or more of the discussed SCL techniques can be adapted to fit various curriculum. We provide a list of suggested strategies below:

- **Situated Perspective**
  - Adapt learning exercises to be rooted in realistic, field specific examples
  - Map lecture content directly to homework assignments
- **Discussion-Based Active Learning**
  - Reformat the beginning 10 minutes of class to start with review questions that are answered via group discussion
  - Incorporate short problem-solving exercises throughout lectures
  - Give students participation credit for being actively involved in class discussions
- **Mixed-Mode Assessments**
  - Use low-stakes formative assessments to identify student misconceptions and provide feedback for improvement
    - Short summaries of purpose of lecture/lab (or a specific aspect of the lecture/lab)
    - Reading assignment annotations
  - Use formative-summative assessments to motivate student engagement as well as provide feedback for improvement
    - Short homework assignments

- Use summative assessments to assess the totality of students' knowledge
    - Quizzes, midterms, finals
    - Final reports, presentations
- **Responding to Student Feedback**
  - Create short, customized mid-course evaluations to probe what students think is going well and what could be improved
  - Then, discuss the common concerns with students and how the instructor plans to change the course moving forward to address these concerns
    - This can be done formally through a survey or informally through class discussion, however, students may be more honest in anonymous surveys

While the ease of implementing these strategies will vary depending on the content already existing for a course, adapting current courses to include one or any combination of easily adoptable SCL strategies specific to the course being taught has the potential to positively impact student learning. Finally, we found that creating a positive learning environment through enthusiastic teaching, student encouragement, and frequent instructor-student interactions improved students' experience in the module and would recommend the use of these strategies in already developed courses as well.

Conclusion

Though SCL strategies have been shown to enhance the experience and learning gains for students in undergraduate STEM courses, instructors are often resistant to changing their already developed curriculum for a variety of reasons. Therefore, it is important to identify low-barrier strategies aimed to increase SCL and encourage instructors to make a change without investing a large amount of time into designing new material or engaging in new technological tools. We have identified a variety of SCL techniques ranging in difficulties and incorporated them into a 4-week module to enhance student learning. Students reported high satisfaction with the module and the GSTT, stating their expectations were met or exceeded. Students provided minimal feedback for module improvements, most of which focused on the organization of what was taught and not the way it was taught. Overall, this paper demonstrates the benefits of incorporating SCL practices into course implementation and provides clear examples of how these strategies could be more easily incorporated into existing content to improve student learning.

Acknowledgements

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Appendix: Post-Module Survey Questions

1. Based on your personal experience and opinions on previous STEM courses, please complete the following sentences and/or answer the following questions as you see fit.

1A. In your own words, why did you enroll in this course?

____

1B. What do you expect to learn or be able to do at the end of this class?

____

1C. Were those expectations met? Why or why not?

____

1D. What I got from the module was...

____

1E. What would you change about the course?

____

1F. Could you explain how you think this course will be helpful to your current goals or career plans?

____

2. The following open-ended and Likert scale questions will ask about your experiences with the graduate student teaching team. These questions will be used to improve future iterations of the course as well as provide feedback for how the team can improve their teaching. <u>Responses to the survey will not be reviewed by the teaching team before final grades are assigned.</u>

2A. What did the graduate student teaching team do well?

____

2B. What could the graduate student teaching team do better?

____

2C. During the Module sessions, the graduate student teaching team...

	Always (1)	Most of the time (2)	About half the time (3)	Sometimes (4)	Never (5)
Fostered a collaborative learning environment	○	○	○	○	○
Encouraged me to work interactively with other students	○	○	○	○	○
Emphasized learning new skills	○	○	○	○	○

Shared skills I can apply in the future	○	○	○	○	○
Encouraged students to learn from each other in class	○	○	○	○	○
Encouraged a nonthreatening environment where students could ask questions or comment about academic content	○	○	○	○	○
Asked questions to make me think	○	○	○	○	○
Acknowledged the diverse learning styles of students in the class	○	○	○	○	○
Applied knowledge to everyday situations	○	○	○	○	○
Shared their own practical experience	○	○	○	○	○
Explained how to solve specific problems	○	○	○	○	○
Helped me understand key course concepts	○	○	○	○	○
Related content of the course to a big picture	○	○	○	○	○

Acknowledged my misunderstanding of a concept	○	○	○	○	○
Helped me and my partner(s) when we needed assistance	○	○	○	○	○
Addressed my individual needs or concerns	○	○	○	○	○
Provided responses that guided me in problem solving	○	○	○	○	○
Motivated me to continue learning	○	○	○	○	○
Translated theoretical knowledge into practical skills	○	○	○	○	○
Facilitated my communications with professors or other course staff	○	○	○	○	○
Provided verbal feedback about my progress	○	○	○	○	○
Acknowledged that learning engineering concepts can be challenging at times	○	○	○	○	○
Provided written critiques about my progress	○	○	○	○	○

Acknowledged when I was improving in the class	○	○	○	○	○
Addressed my concerns about grades in this course	○	○	○	○	○
Provided written critiques to me/my partner about our progress on course deliverables	○	○	○	○	○