Inclusive Engagement in an Undergraduate Core Biomaterials Course for Enhanced Reflective Learning

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Abstract—The ongoing COVID-19 pandemic brought about several challenges in both learning and instructive styles. Chief among these was engagement in classrooms that were remote, in-person or switched between the two due to quarantine periods. In a content centric biomaterials core course, here we describe an ‘inclusive engagement toolkit’ that combines peer-supported learning with a structured reflection of learning objectives that allowed learners to be engaged at high levels and take responsibility for their own learning and course progression.

Keywords—Inclusion, Engagement, Reflection, Muddy points, Biomaterials, Continuous feedback.

CHALLENGE STATEMENT

In Spring 2020, courses transitioned abruptly to remote instruction with little time for preparation or adjustment to a new mode of instruction due to the COVID-19 pandemic.11 In Fall 2020, remote and online learning were adopted widely with students attending several classes online. Learners and instructors alike had mixed perceptions of remote learning, weighing accessibility positively but motivation for engagement and increased anxiety negatively.7 The switch to remote learning prompted significant innovative strategies in the biomedical engineering classroom.10 As the pandemic continues on in 2021 and 2022, an increase in flexible access to learning modules was adopted, owing to COVID-19 exposure or infection induced quarantines. Flexible learning here is defined by classrooms that held synchronous face-to-face lectures in a physical classroom, while accommodating a percentage of learners remote access via Zoom synchronously, or providing learners with recordings to be accessed asynchronously. This posed an interesting challenge for instructors to design coursework that could facilitate inclusive engagement of both in-person and remote learners, including those that switched between the two modes mid-semester. Additional layers of complexity stemmed from having to simultaneously take into account the anxiety of in-person/remote interactions and the changes in learning trajectories induced by the pandemic in its early stages. Biomedical engineering education has relied on content centricity and peer teaching to facilitate engaged learning and development of critical thinking skills. To meet the challenges of learner engagement remotely and in-person, content absorption, and retention during Zoom fatigue3 and in-person lectures, creative methods were urgently required. Emerging considerations also need to include learning inequities due to learner diversity in how people engage differently in-person and with digital technology.4,6 Here, we describe the implementation of an “inclusive engagement” toolkit that was adapted to promote reflective and inclusive learning and increase learner engagement to accommodate a variety of learning styles.
NOVEL INITIATIVE

The ‘inclusive engagement’ toolkit proposed here is primarily for instructors. It was deployed in an Introduction to Biomaterials course. This is a fall semester required junior level core course for all individuals in the Texas A&M University Biomedical Engineering program. The course ran as a 75-min synchronous lecture twice weekly offered via Zoom, or in-person. The typical attendance for the class was ~120 students, spread across two sections (split approximately to 60 students per section for each lecture). The first offering of the course by this instructor was entirely remote via Zoom in Fall 2020. In Fall 2021, the course was offered primarily face-to-face. However, due to local surges in COVID-19 cases due to emerging variants, a small percentage of learners (3–12%; 4–15 students) either attended lectures remotely and synchronously or had access to lecture recordings to view asynchronously. This number varied, and many learners cycled through remote attendance or in-person attendance during the course of the semester. The inclusive engagement toolkit was a combination of small-group learning in the middle of every lecture, along with a reflection and ‘muddy point’ submission individually at the end of class (Fig. 1). The toolkit is visualized as steps in the figure and is described in detail below. All aspects of the inclusive engagement activities were associated with credit (up to 20% of course credit), which was graded only for completing or participating in the activity, and not for accuracy, described at the end of the toolkit. This provided an extremely low stakes way to participate/engage with lecture material that did not involve the traditional model of speaking up or asking questions in a big classroom.

There were a total of 25 lectures, spread out over 14 weeks of the semester: all lectures were recorded and made available on the learning management system for students to view asynchronously if and when needed and provided similar opportunities for reflection. Both during in-person instruction and during remote instruction, the instructor had phenomenal instructional support in this class, in the form of either a graduate teaching assistant or a senior undergraduate peer mentor. Instructional support personnel attended at least one section of a lecture, ensuring that there was at least one additional instructor totaling to two facilitators for ~60 students. The lectures were designed to teach the fundamentals of materials structure, and how structure determined material properties which could ultimately be related to biomaterial performance and choice of biomaterials in medical devices and applications. The instructor structured each lecture as follows (encompassing the inclusive engagement toolkit, Fig. 1): (i) presentation of learning objectives from the lecture (~5 mins); (ii) biomaterials concept with problem-solving or case studies (~20

FIGURE 1. Structure of each lecture that deployed the inclusive engagement toolkit—each lecture began with 5 mins of introduction of the day’s learning objectives. A biomaterials concept was then taught for approximately 20 mins, following which guided small-group discussions were facilitated in groups of 4. During in-person learning, groups of no more than 4 students worked together at a table, or in breakout rooms on Zoom. Instructors and instructional support personnel like graduate teaching assistants or undergraduate peer mentors walked the room/surfed breakout rooms to participate in group discussions, or provided assistance as requested. The second half of the class involved the introduction of a second biomaterials concept, following discussion-based learning or problem-solving facilitated by the instructor. At the end of every lecture, 5 mins of reflection was prompted. The learning objectives from the day were re-shared, and learners were asked to reflect on how well learning objectives were met. Students were encouraged to share what aspect of class was most confusing, and if not, what they enjoyed most, allowing for reflection. At the end of class, the instructor curated all reported ‘muddy points’ and created small on-demand videos and helper modules that learners could additionally asynchronously engage with on the learning management system. Ultimately, this toolkit also allows a redesign for the next lecture’s learning objectives.
mins); (iii) small-group work (maximum of 4 students) to facilitate peer-learning in breakout rooms or in the classroom (~ 15 mins); (iv) biomaterials concept with discussion-based learning or problem-solving (~ 25 mins); (v) reflection on learning outcomes and submission of “muddiest points” from the lecture (~ 5 mins). Outside of the activities programmed inside the classroom, the toolkit also included critical components that took place outside the classroom. These included the following: (i) instructor provided discussion boards that opened four times, evenly spread through the entire semester, that facilitated an additional layer of engagement via the learning management system; (ii) instructor review of student reflections and muddy point feedback, and creation of helper modules and muddy point videos as additional resources; and (iii) student engagement with helper modules and muddy point videos on the learning management system.

**Beginning of class with introduction and presentation of learning outcomes:** This activity took approximately 5 minutes at the beginning of every lecture, where the instructor presented learning outcomes for the specific lecture. Examples of learning outcomes are provided in Table 1 and were outlined as precise and actionable statements.

**Midpoint of lecture with small-group work:** Every lecture had built in small-group work that ran for ~ 10–15 mins, to facilitate peer-learning and interactions within small groups, to remove the pressure of contributing to the entire classroom. The group work was designed with 3–4 short questions that allowed students to process the biomaterials concept that was taught prior to the group work—questions were either concept questions or problem-solving-based questions that allowed students to debate and interact with one another. At the end of the group work module, there was a brief discussion with the instructor solving or answering the questions, which were occasionally volunteer-student led. During in-person offerings, students worked in small groups of 4 around a table. During the remote offering, students were in breakout rooms on Zoom with the ability to share a whiteboard or access to online collaboration tools like Google Jamboard. Examples of group work questions from lectures that matched with learning objectives presented above are shown in Fig. 2. The instructor and instructional assistant moved through the classroom (or breakout rooms) to answer questions, or provide help when requested. The instructor moved through the entire classroom at least one time, checking in on students during group work to allow for collaboration while maintaining respectful conversation and engagement.

**End of lecture with structured reflection:** Every lecture ended with 5 mins of reflection upon the learning objectives put forth, and how well they were met for each individual student, and the opportunity to submit one or more muddy points via a google form. Reflection were prompted with the following statement: “Reflect on your ability to perform the following, and submit your google form.” The following was usually a presentation of the learning outcomes/objectives set forth at the beginning of the lecture period. Two additional reflection opportunities were provided to learners: (1) “What aspect was most confusing today?” (2) “If nothing was confusing, what did you most enjoy about class today?”

At the end of the class, a significant contribution on the instructor’s behalf is required in reviewing reflection responses and curating cohesive thoughts of what learners considered muddy points. The instructor curated all the muddy points at the end of the lecture and created short video modules (~ 2–4 mins in length) for common concepts that were noted as ‘muddy’ within a few hours of the lecture. These muddy point videos were both posted on Youtube, and linked to the learning objective pages within each lecture module, to allow students to view them on-demand. Additionally, based on the reflections provided by students, the instructor created an additional helper module page within the day’s lecture providing additional resources and answers to questions that students brought forth.

**Grading scheme for inclusive engagement:** All activities associated with this toolkit were graded, accounting for 20% of course grade. Offline asynchronous discussion modules (4 total across the semester) accounted for 6% of course grade. Participation in small-group work (defined by submission of a google form, which could be done even while attending remotely) accounted for 8% of course grade. Submissions of reflections accounted for 2% of

| TABLE 1. Examples of learning outcomes presented in this course. |
|---------------------------------------------------------------|
| "At the end of this lecture, you should be able to describe how the chemistry of polymer structures determines its property" |
| "At the end of this lecture, you should be able to relate how temperature and polymer thermal properties determines elastomeric behavior" |
| "At the end of this lecture, you should be able to relate graphically how solid solutions strengthening makes metals stronger" |
“At the end of this lecture, you should be able to describe how the chemistry of polymer structures determines its property”

Predict the biodegradability of the following polymers:

1.

2.

3.

4.

5.

“At the end of this lecture, you should be able to relate how temperature and polymer thermal properties determine elastomeric behavior”

In lightly crosslinked polyurethanes, an elastomer at 87°F (30°C, Tn = 55°C)...

“At the end of this lecture, you should be able to relate graphically how solid solution strengthening makes metals stronger”

In response to engagement and participation, an overwhelming majority of students (94.2% of respondents during remote instruction; and 96.3% during in-person instruction) indicated that they were engaged over 70% of the time, and 74.4% (remote) and 80% (in-person) of the respondents were engaged over 90% of the time. 76.7% of respondents found the ability to provide and receive feedback via ‘muddy points’ very or extremely useful. Ultimately, 99% of the respondents agreed that the course helped them learn concepts and skills stated in the course objectives, tied to ABET learning outcomes of being able to formulate complex engineering problems and solve them. We believe that the ‘muddy point’ module contributed to several of these positive outcomes for multiple reasons: (i) the short video modules were not repetitive like lecture recordings and were tailored to address specific points of confusion; (ii) muddy point video modules were hosted online and made available on-demand for students to view at their convenience through their learning management system; (iii) the opportunity to submit muddy points was non-interactive and removed the anxiety of having to speak up in a crowded classroom; and (iv) the on-demand format accommodates different learning styles. Students indicated that the “muddy point videos were a critical resource” that were extremely helpful for studying, and they “helped clarify many concepts” and “gave a much better understanding of difficult points.” This is not particularly surprising, since the concept of learners self-reporting muddiest points has been linked to...
higher levels of responsibility, increased engagement, a better understanding of their own learning including in the BME classroom.\textsuperscript{1,2} The opportunity of having muddy point submissions tie into the 5-min reflection of learning objectives additionally aided in students being able to take responsibility for their own learning, and providing the instructor with the ability to evaluate learners’ understanding of a topic, also evidenced in other materials courses.\textsuperscript{12}

Importantly, a unique aspect of the muddy point-based reflections was the significant opportunities it provided to the instructor at the end of every lecture. The instructor was able to reflect on their own teaching style, and content delivery and how that impacted student learning outcomes in a given lecture. This afforded the opportunity for the instructor to redesign and adjust learning outcomes as well as teaching styles in subsequent lectures to fit individual learners and global feedback. The curating of muddy points from students provided an opportunity for the instructor to provide feedback, in the form of helper module designs and muddy point videos. The role of instructor feedback in the engineering classroom is very well reviewed and connected to positive student actions and learning.\textsuperscript{5}

An overwhelming majority of students appreciated group work in the middle of the lecture, finding tremendous value in their ability to learn alongside their peers in a non-competitive setting. Student feedback related to group work was always positive, including specific comments like “Group work always helps me reorient myself in understanding difficult topics,” and “Being able to discuss challenging topics with my table group during group work helped me wrap my mind around concepts I initially struggled with.”

Learners (both remote and in-person) felt that working with peers allowed them to “help validate my work, or if there are discrepancies, are kind at showing me where the error in my reasoning was so I can learn better.”

This module was beneficial to promote inclusive engagement for several reasons, chief among them being the opportunity for social growth centered around teamwork and problem-solving—during remote instruction, group work provided a much needed break and opportunity for social interaction; during in-person instruction, a refreshing opportunity to interact closely with peers. Problem-based learning has been implemented in the BME classroom for at least two decades, but team-based collaborative learning adds an added advantage of increasing student engagement and performance and is focused on the learner.\textsuperscript{9,11} The group work actively allowed learners to apply the content they learned in the previous module toward a collaborative problem-solving environment. This mode of collaborative learning also promotes learner motivation and active learning.\textsuperscript{8}

Overall, we believe that the deployment of the entire toolkit that involved group work, the ability to reflect upon their learning objectives and submit muddy points, was extremely advantageous together. The opportunity for self-reflection in a structured manner during remote or in-person learning along with the collaborative aspects of peer-supported learning allowed learners in this biomaterials learning to engage at high rates, and take responsibility for their engagement and learning, especially during the COVID-19 pandemic. It also centers a learner in the moment, to evaluate their own understanding of course content. Advantageously, from an instructor perspective, curating “muddy point” videos provided critical feedback and improved empathetic and inclusive design for future re-offerings of the course. In future, the instructor envisions being transparent and explicit about the purpose of both the “group work” and “muddy point reflection” modules, to assess student perspectives in future years.

\section*{CONFLICT OF INTEREST}

The author has no conflict of interests to declare.

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