Evolution of Biomedical Engineering Students’ Perceptions of Problem Solving and Instruction Strategies During a Challenge-Based Instruction Course

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Abstract: Collaborative teams of engineers and learning scientists have developed challenge-based instruction modules for a number of Biomedical Engineering (BME) courses, ranging from optics to microbiology, biotransport, and biomechanics. One key piece of anecdotal evidence employed to block the development and implementation of additional challenge-based courses is students’ resistance to the new and/or unfamiliar pedagogy. We addressed this common narrative by assessing students’ opinions toward both completing open-ended challenge problems and the components of a self-determined ideal biomedical engineering course at regular intervals during a challenge-based biotransport course. Two biotransport courses were studied (29 and 21 students), where the first author conducted and analyzed all observation and survey data and the second author was the course instructor. Taught by the same instructor, one session was offered as an accelerated study-abroad experience, and one was offered on-campus during a standard semester. Observation of student engagement, as a function of student and professor activity, revealed that aspects of the challenge-based instruction model (i.e. challenge solving, group work) significantly enhanced student engagement in the class. Students demonstrated concurrent development of content expertise and innovative problem solving ability during the course. Before, during, and after the challenge-based instruction course, students identified that the open-ended challenges characteristic of the instruction model were motivating, engaging, and interesting. Students also consistently preferred homework and examination problems derived from real world examples that require creativity and are solved collaboratively within teams. Our results, which emerged from a novel student-centered, instruction-sensitive survey instrument, affirm that students prefer challenge-based instruction to lecture pedagogy. From the perspective of education policy, we believe these results support the increased incorporation of challenge-based modules in new and evolving biomedical engineering classes.

1. Introduction:

Engineering educators have the important task of preparing their students to apply the fundamental knowledge, obtained in the academy, to solve complex and diverse problems in their field(s). To legitimize this student-centered goal, as well as hold accredited engineering programs accountable facilitating students’ development of technical and non-technical skills necessary for engineering practice, the Accreditation Board for Engineering and Technology (ABET) has maintained engineering student outcomes[2]. While there is much debate over the ideal teaching strategies and classroom environments to facilitate students’ growth in innovative problem solving, there is consensus that such growth is essential to the engineering profession [3].

In 2000, a multi-institution, interdisciplinary team (VaNTH) of researchers developed challenge-based instruction modules for biomedical engineering courses, ranging from biotransport, to anatomy, or optics[4-7]. A key philosophical component of these modules was to shift emphasis away from memorization and repetition of facts and instead emphasize students’ ability to apply new knowledge innovatively[8]. A major research institution in the southwest US has offered a challenge-based biotransport course annually, as both an accelerated (5 week) study abroad experience in the United Kingdom and as a standard on-campus course. This course, taught by
the second author, utilizes real world scenarios or “challenges” as a lens through which biotransport content is delivered, practiced, and assessed.

From a position of curriculum development and education policy, we recognize that inquiry-based learning (IBL) (i.e. challenge based instruction, problem/project based learning) are non-standard in engineering teaching. There are a plethora of rationales provided for this low rate of adoption, including insufficient faculty-teacher preparation to execute IBL, time constraints on professors in their teaching role, and necessity of direct instruction to establish previously unknown, fundamental engineering relationships for students[9, 10]. One challenging piece of anecdotal evidence, however, is that students prefer traditional pedagogy (i.e. direct instruction, lecture) and will resist IBL[11]. The purpose of this study was to assess students’ preferences for class and instruction methodology. Comparison of students’ opinions (and the evolution thereof) in two distinct environments (standard on-campus, and accelerated study-abroad formats) provided qualitative and quantitative evidence for areas of challenge and synergy with IBL and semester structure.

The goal of this study was to assess the following sequence of hypotheses systematically:

1. Students’ preferences for class style and instruction methods are in alignment with the ideology of challenge-based instruction.
2. When offered a full semester course by challenge-based instruction, students’ preferences will shift, in greater magnitude, toward challenge-based instruction.
3. By the end of challenge-based biotransport, students will identify more strongly as practitioners within the engineering field.

It was beyond the scope of this study, which was a mixed-methods case study, to compare challenge-based and traditional instruction. Assessment of inquiry-based pedagogy, relative to lecture and other traditional teaching methods, has been studied extensively[4, 12-17]. Herein, we draw upon qualitative and quantitative data to posit explanations for the initial state and evolution of biomedical engineering students’ preferences for class structure and instruction style. We also discuss unique attributes of the study abroad and/or on-campus setting, which acted in a cooperative or conflicting manner with the challenge-based instruction paradigm.

2. Literature Review:

2.1 Resistance to Change in College Engineering Education: Focusing on the influence of education, learning, and social-behavioral research on engineering teaching practices, a recent survey by Borrego et al. demonstrated that faculty awareness far outpaces adoption of known student-centered practices. For example, while 82% of engineering deans were aware of student-active pedagogies, only 71% claim that department faculty members have adopted such practices. Even more dramatically, 96% were aware of the benefit of interdisciplinary capstone projects, but only 56% incorporated them in engineering classes[9]. If educators are aware of superior teaching practices, supported by experimental evidence, why are these practices not standard in engineering programs?
In an additional survey by Besterfield-Sacre et al. faculty, department chairs, and deans were independently surveyed and asked in open-ended fashion to identify opportunities for faculty professional development and rewards, to improve the incorporation rate of identified student-centered instructional practices [10]. The researchers then grouped the responses into the format of the Four Categories of Change Strategies model [18]. Interestingly, numerous responses fell into the categories of curriculum and pedagogy, developing reflective teachers, and disseminating policy. For example, respondents identified faculty and graduate student seminars as an effective way of disseminating policy, new curriculum, and teaching pedagogy. They felt that teaching portfolio programs, or faculty participation in the development of instructional materials would increase teacher introspection. Despite identifying these seminars and portfolio programs as useful venues for professional growth, however, only 36.5% of faculty attend a teaching workshop, and 19.7% write educational materials/curricula annually. None of the professor, department chair, or dean’s responses were categorized into the “shared vision” category [10].

This lack of shared vision is likely responsible for the observed disconnect between innovation and adoption. Looking in more detail at the open-ended responses from the survey conducted by Besterfield-Sacre et al. faculty are more concerned with necessary administrative actions, whereas chairs and deans identify interventions for individual faculty. For example, faculty identified the need for curriculum grants, policies to incentivize innovative instructional practices, incentives for professional development, and additional faculty teaching seminars. In contrast, chairs and deans suggested additional assessment of teaching, faculty development of additional teaching plans and materials, and college-wide discussions on teaching innovation. While there were numerous common suggestions, such as translation of industry work into the classroom and considering reallocation of department funds for teaching materials, each group disproportionately identified actions that they want the other party to complete [10, 11].

Instead, from the student-resistance angle, numerous studies have suggested that students resist participation in active learning. Such reports on active learning in engineering education date back to the 1990’s, and imply that the significant difference between active learning pedagogy and students’ expectations for college teaching are to blame for the resistance [19]. More recent studies have also offered that confounding factors, such as class size, classroom setup, diversity of inquiry approaches, and instructor participation level, significantly alter student engagement in active learning activities [11].

However, in contrast with these reports of student resistance, numerous reports in multiple disciplines have demonstrated the effectiveness of inquiry-based learning in science and engineering classrooms [4, 16, 17, 20]. Some of the most cited reports studied inquiry learning in biology or physics, but many are also engineering-focused [6, 21, 22]. In the following sections, we will focus on reports of inquiry learning in engineering, and biomedical engineering in particular. We believe this will highlight the need for a study addressing biomedical engineering students’ classroom preferences and expectations in the current day.

**Challenge Based Instruction and Inquiry Based Learning:** One particular approach to inquiry-based learning is challenge-based instruction. Challenge-based instruction is particularly amenable to genuine engineering contexts, as problems solving is paramount to the engineering profession [3]. In challenge-based instruction, a complex and/or perplexing question is posed, where students must call upon a combination of previous knowledge, life experience, educational resources (i.e. textbook, instructor, web), and more to arrive at a suitable solution. The solution
of these challenges can occur in a linear or iterative manner, depending on the realistic constraints of a class. However, iterative solving, which takes into account practical engineering constraints, peer and instructor feedback and more, can facilitate metacognitive thinking which contributes productively to student learning.

**Challenge Based Instruction in Biomedical Engineering:** Because of the VaNTH program, there is substantial literature on challenge-based instruction, applied in the biomedical engineering domain. A meta-analysis of the literature generated under this project determined that challenge-based modules (within a standard engineering class) or entire challenge-based courses improved students’ innovative problem solving ability while simultaneously conveying technical content at a similar (or greater) level than lecture pedagogy [4]. The ‘improvement’ exhibited by students in challenge based courses was particularly apparent when assessments of transfer were used. A particular previous study compared students’ development of routine and innovative knowledge in a challenge-based biotransport course to a traditional biotransport course at a peer institution. This study identified that the students who participated in the challenge-based course obtained a similar level of content expertise and a superior ability to apply the knowledge in new or unfamiliar contexts [23]. In this study, we hypothesized that students in challenge-based biotransport would successfully transfer the problem-solving framework, developed over the semester, to alternate content areas. This framework, developed by the second author, is termed the Generate Ideas Method (GIM), which is an expert-oriented method for approaching complex or unfamiliar problems [24].

**The Generate Ideas Method:** The GIM consists of three main components (Figure 1). In the first, an initial considerations step, students dissect the challenge prompt for important information, insights, and directional guidance, and then organize and document their thoughts. An important aspect of the initial considerations step is the legitimacy it gives students’ daily life experiences, observations, and previous knowledge within which any new content is ultimately situated. During initial considerations students sort through the available information to establish an initial hierarchy of relevance and importance and to identify if there are any materials key to subsequent analysis that appears to be missing. After formulating the problem, students move on to the second step, analysis, that involves identifying and defining the system(s) being studied, and interactions that occur between the system(s) and the environment. Conservation laws (i.e. mass, energy, momentum) frame the challenge’s phenomena within rational physical constraint, and guide mathematical definition and assessment of the system using constitutive equations. Once the resulting governing differential equations are identified, students examine their solution methods by synthesizing or solving the expressions. The most noteworthy aspect of the analysis steps in the GIM is that it prioritizes students’ ability to access, contextualize, and employ new information and mathematical expressions. This emphasis contrasts with the common notion of content memorization as a focus of learning.
The key postulate of this study was that once students have achieved mastery of the structured problem-solving framework inherent in the GIM, they would readily transfer it to alternate content areas. Transfer, a term used to describe students’ ability to access and apply skills or processes attained in one domain context to solve problems within another, is widely considered a principal goal of education[8]. We argue that parallel to the process of skill transfer is also confidence transfer. Essentially, students that master the problem solving frameworks presented in the biotransport course will not only successfully transfer the skill to alternate content areas, but also will do so with enhanced conviction.

Theoretical Foundations: The ideology behind the GIM, and challenge-based instruction more broadly, is the How People Learn model. Developed by Bransford et al., this work establishes the fundamental centers of learning (i.e. learner center, assessment center, community center), as well as thoughts on designing learning environments for maximizing learning [8]. A second foundation is that of learning for understanding, articulated succinctly by Wiggins and McTighe [25]. The focus of greatest importance herein, is the idea that instructors must focus on a “big idea for understanding” and design learning activities that reinforce the big idea, while providing access to the range of educational materials and/or facts that are important, not to memorize, but with which to gain familiarity. A final theoretical foundation, which did not factor into the experimental design but was important to analysis and comparison between on-campus and accelerated-abroad class formats is caring theory [26]. This caring theory is based in Vygotsky’s zone of proximal development of influence [27], that an instructor and student must establish a common ground, or reference point, in order to establish a learning task. This work on caring theory has traditionally been conducted in the child psychology realm, but it is theoretically

Figure 1: Graphical depiction of the Generate Ideas Method (GIM). The GIM is designed to facilitate the iterative, expert-like solution of previously unfamiliar open-ended challenges. Adapted from ([1])
sound and greatly applicable to higher education. Placed into the context of engineering education in accelerated-abroad and on-campus formats, each affords a different context for student-instructor relationships that affect the effectiveness of teaching and learning.

3. Methods:

This study, and the methods presented in this paper, were reviewed and approved by the University Institutional Review Board at UT Austin (study number 2017-03-0017). Informed consent was requested from, and given by, all students enrolled in the class. The first author had no teaching role in the biotransport course, offered students a full explanation of the study scope, collected all data, and obtained informed consent. The second author was the course instructor and was blind to students’ participation decision until the completion of the course to avoid bias. Students were not compensated in any way for participation in this study.

3.1 Population and Course Description: Students in each class (abroad and on-campus) were full time biomedical engineering students enrolled at a large research institution in the southwest US. Students came to the class from a variety of backgrounds, with a range of interests. The accelerated, abroad version of this biotransport course was conducted over a five week period at a university in the United Kingdom. Students enrolled in this course made the trip from their home institution (southwest US), along with the course instructor, to the U.K. The first author conducted all data collection and research analyses at both locations (U.K. and U.S.), while the second author was the instructor for both the accelerated, abroad and on-campus sessions. Both courses were taught under the same course name (Biotransport), with the same textbook, a syllabus adapted only for the time constraints of each course format, identical homework assignments, and similar exams. A sample biotransport challenge problem, which was characteristic of homework and exam format, is given in the Appendix.

3.2 Observation:
The first author, according to the Behavioral Engagement Related to Instruction (BERI) protocol[28], conducted in-class observations. Briefly, the first author recorded an observation note every five minutes, at the initiation of a given interval. First, the number of students exhibiting disengaged behavior were tabulated, which could include, but was not limited to, unrelated electronic device usage, off-topic discussion with peers, or physical disengagement. Second, the class activity was categorized according to the nature of the instructional activity (i.e. content-oriented lecture, storytelling, group work, challenge problem solving, student presentations, routine example solving, instructional transition) and any relevant teaching-tools employed (i.e. board writing, electronic media). Regression analysis of observation data, collected for the accelerated abroad course only, provided insight into the impact of in-class activities facilitated by challenge-based instruction on student engagement. With student disengagement as the response variable, the observation categorical variables and the following numerical variables were included for control purposes (class number, time). The entirety of every class session was observed, qualified, and recorded (2130 minutes total).
3.3 Interview:
The first author interviewed a random sample of six students twice during the abroad course (after classes 3 and 13 out of 17) and once more than two months following the final exam to assess transfer of problem-solving frameworks to biomechanics problems. A sample biomechanics challenge prompt, which was used in these interview settings, is given in the Appendix. Interviews were conducted one on one, so that students solved problems independently, and were each twenty minutes in duration. To control for problem content three biomechanics challenges were used, where two out of six students completed each problem during each interview session. At the completion of the study, each student solved each challenge exactly one time. All interviews were audio and video recorded for subsequent analysis. The transcripts of these interviews were especially pertinent to this study, because students were asked to comment on their problem solving strategies employed. This provided significant qualitative evidence to students’ sense of confidence and efficacy in problem solving.

3.4 Survey
Students’ attitudes and opinions toward solving open-ended challenges were assessed using a survey instrument administered by the first author at the beginning, midpoint, and end of the course. Surveys were administered to students from both the abroad and on-campus classes. This survey used semantic differential scales to allow students to identify the position on various continua that their current feelings toward problem solving resided (i.e. from motivated to indifferent, from comfortable to intimidated).

3.5 Statistical Analysis
Unless otherwise specified, averages and error bars represent the distribution mean and standard error, respectively. On semantic differential scales, the flat surface of an arrow represents the point of complete agreement (-100 or 100). Statistical analyses were conducted using GraphPad PRISM (ANOVA, t-test) or R (regression and related analyses). Points of statistical significance are noted with asterisks (*p<0.05, **p<0.01, ***p<0.001, #p<0.05 with the null hypothesis of a neutral response).

4. Results:

4.1 Class and Instruction Preferences
Class format affected students’ evolution of instruction and class preference. However, the majority of preferences and opinions were static, unaffected by class location, and favorable to challenge-based pedagogy. Students universally and significantly identified that they preferred homework, quiz, and exam problems, which were derived from the real world (Fig 2), as well as problems which can be completed collaboratively (Fig 2). Additionally, over the course of completing the challenge-based biotransport course, students’ preferences evolved to prefer problems that were qualitative and/or had multiple correct answers (Fig 3). Students did not exhibit significant preference for creative or procedural problems (Fig 3).

Differences were observed, in the magnitude and evolution of class preferences between students in the abroad learning experience and on-campus class. Students enrolled in the on-campus
course preferred unit-specific homework and exam problems, while students in the accelerated course exhibited no preference for problem scope. Additionally, students in the abroad course felt more favorably about creative problems (versus procedural) than the on-campus students.

Students enrolled in both the on-campus and accelerated abroad biotransport classes identified that challenge-based biotransport was more interesting than the classes that they had taken previously (Fig 4). Students in the abroad course said that the course was more work intensive and stressful than their previous classes at the semester midpoint. Both their stress level and opinion of the class workload dissipated over the course of the second half of the semester, which we attribute to increased comfort and familiarity with the accelerated semester workflow. This attribution was supported further by that students in the on-campus course, which utilized the same course materials delivered by the same instructor, found the course less work intensive and less stressful than their previous classes (which were the same previous classes taken by the abroad accelerated students).

Figure 2: On campus and accelerated abroad students’ preferences for homework, quiz, and exam problems. Students preferred problems derived from the real world that are solved collaboratively. Abroad students exhibited no preference for cumulative or unit-specific problems, whereas on-campus students preferred unit specificity.
Figure 3: Students exhibit no preference for qualitative or quantitative problems, although their preferences trended in the qualitative direction. Students were neutral toward creative and procedural problems, and became more familiar with problems that had multiple correct solutions.

Figure 4: Students universally said that challenge-based biotransport was more interesting than classes they had taken previously. Stress and work intensiveness were more significant in the abroad learning environment, although both levels decreased over the course of the semester.
4.2 Student Engagement and Problem Solving Strategies

Regression analysis of students’ engagement in class activities during the abroad biotransport class revealed that active learning activities, facilitated by the challenge-based instruction paradigm, increased student engagement in the class. Challenges (p<0.05) and group work (p<0.01) significantly increased student engagement, whereas other lecture-based pedagogies supported by the challenge-based paradigm (i.e. transitions, student presentations, routine examples, storytelling) neither enhanced nor detracted from engagement (Fig. 5).

Students developed and retained the GIM problem solving framework over the course of the accelerated semester. Students used the GIM model to solve biomechanics problems in an interview setting (biomechanics content was chosen because it was from a class taken previously by all enrolled students, but was separate from the context in which the GIM was taught) (Fig 6). This framework was retained and applied successfully to solve biomechanics problems for up to 2 months post-class completion (later time points were not tested).

In an illustrative comment during the final class survey in the abroad class, one student offered, “[Now] I don’t immediately jump to solving [a problem], but think about how to approach it and often find several ways to [solve] it. If one way doesn’t work, I’m not thrown off and can work to find another solution. The GIM model has provided me a structured approach to engineering problems that I can utilize in other classes and my research.”

The observed trend in the retention and application of GIM problem solving strategies follow nicely with the progression of students’ preference toward qualitative, creative problems, solved collaboratively, with many correct answers (Figs 2 and 3). We believe this correlation, while not necessarily causative, offers evidence that enhanced familiarity and confidence in problem solving with the GIM helped shift the students’ preferences for homework, quiz, and exam problems.
4.3 Attitudes and Opinions toward Problem Solving
In addition to questions probing students’ attitudes and opinions toward homework, quiz, and exam problems, we also asked questions regarding students’ confidence and comfort with solving open-ended challenges. These questions followed the same semantic differential format as questions assessing class preference.

Students agreed that open-ended challenges made them feel motivated and interested. Students’ confidence level, assessed through commentary on comfort and confusion, trended toward a greater level of confidence and assurance, in both the abroad and on-campus settings, over the course of the semester. Students in both settings found challenges engaging, although that engagement level dipped over the course of the semester for the on-campus student. Students became less concerned for the time necessary to complete and open-ended challenge over the course of the semester in both settings, although the abroad students were less concerned about the time commitment for problem solving than the on-campus students.

![Figure 7: Students in both the abroad and on-campus settings found challenges motivating and engaging. Their comfort with solving open-ended challenges increased significantly over the course of the semester. Interestingly, the on-campus students’ engagement level decreased slightly over the semester.](image-url)
4.5 Engineering Identity:
Students in both the on-campus and abroad biotransport classes identified more strongly as practitioners of the engineering field after the semester than beforehand. The enhancement in engineering identity was more pronounced for students in the accelerated abroad biotransport course than the on-campus course. Students’ sense of self-identity within the engineering field did not differ significantly from their perception of peer engineering identity.

Figure 9: Self-assessed development of engineering identity during challenge-based biotransport. Students, following both standard and accelerated challenge-based biotransport courses identified more strongly as practitioners of the engineering field.
Interestingly, when students’ survey responses (Data Figs. 2,3,4,7,8) are stratified by response to the identity prompt substantial differences emerge between engineering identity groups. This analysis was not conducted for the abroad course, as no probe of engineering identity was asked in their introductory surveys. For this stratified analysis, students who identified a neutral, or “a little bit” more like and engineer on the 7-point Likert scale were separated as “low identifiers,” and those who said “more” or “much more” of an engineer were labeled as high identifiers.

In contrast with what the expectation of an engineering student, these “high identifiers” preferred problems that were more creative, cumulative, and qualitative, that had more answers that are correct. They were more comfortable, engaged, interested, motivated, and assured of self-efficacy in solving engineering challenges. Our observation herein is somewhat preliminary, as the size of the low-identifying sample was small. We cannot conclude whether the challenge-based instruction model shifted the class preferences of high-identifying students toward those in greater alignment with creative engineering problem solving, or if those who already had such preferences (that were correlated with low-identification in pre-class surveys) had significant enhancements in their engineering identity during the course.

5. Discussion
5.1 Biomedical Engineering Students’ Preferences for Class and Instruction:
Students developed innovative problem solving ability over the length of the course, and readily applied it to new engineering contexts in interview and survey settings. From students’ commentary during surveys and class observation, we believe that initial difficulty with challenge prompts is derived from unfamiliarity with approaching problems without a prescribed solution process. This leads to the initial belief that the challenges are “harder” than routine problems, as well as some early dissatisfaction that in-class examples differ in context and scope from homework’s challenge prompts. Over time, students’ familiarity with approaching open-ended challenges increased. As this happened, they became much more confident in their ability to approach biotransport, biomechanics, and alternate biomedical engineering challenges. From students’ comments, we concluded that mastering the GIM model was of paramount importance to this transition, as it usefully organized their prior knowledge and innovative thinking in a suitable manner for application to new problems. This manifested across all tested content domains as students’ Biotransport challenge performance improved over time, concurrent with a greater frequency of students applying suitable GIM analyses to novel biomechanics problems in interview settings.

Students find open-ended challenge problems engaging, motivating, and interesting. The real-world applicability and the collaborative and creative nature of their solution also suits students’ class structure preferences. With deliberate practice in problem solving and a framework within which to operate (GIM model), challenge-based instruction became the students’ preferred class structure. When asked, in open-ended format, to offer advice to another professor who will teach Biotransport in the future, students specifically commented to keep both the challenges and the GIM.
5.2 Relevant Observations and Reflections Regarding Class Format:
In this paper, we identified and analyzed an array of evidence for the effectiveness of challenge-based instruction that we collected during and immediately following classes conducted both on-campus and in an accelerated study abroad experience. Many aspects of the abroad experience were unique, important to the student experience, and when viewed within the lens of caring theory potentially explanatory for students’ different experiences in the two environments. Prior to abroad departure, the instructor invited all of the enrolled students to his home for an orientation, panel discussion, and a picnic lunch. Upon arrival, a sense of student community within the class quickly established, with housing arrangements, tours, and social activities that facilitated mutual experiences, conversations, and friendships. In between scheduled class and informal homework sessions, students went together to lunch, where the first author was also present, and participated in dialogues ranging from the class work to career plans, summer travel, generic complaints, and current events. Students had the opportunity to discuss their respective backgrounds, interests, goals, aspirations, and challenges with the instructor during class trips, formal dinners at the beginning and end of the course, and small-group dinners. Undoubtedly, the individual student-instructor relationships developed and the learning community established and positively influenced learning. Within the framework of caring theory [26], the way the course instructor came to know each student as an individual established a position with each of his or her zone of proximal development. Applied within the engineering problem-solving context, the instructors’ knowledge and familiarity with each student as an individual enabled better content delivery, more relevant framing of problem statements, and richer in-class discourse.

The rich interpersonal relationships developed during the accelerated abroad learning model are not realistic during the constraints of a standard semester. It is not surprising, likely because of these relationships, that students enrolled in the abroad class felt more favorable toward challenge-based instruction and creative problem solving more generally. It is nonetheless encouraging that, on the same assessments, probes of opinion, and determinations of self-efficacy, that on-campus biomedical engineering undergraduates still responded so positively to challenge-based pedagogy.

6. Conclusion:
Students prefer challenge-based instruction, as compared to lecture pedagogy. Solving open-ended challenges, as a part of exams, homework assignments and class exercise, led to higher levels of class engagement, increased aptitude toward solving biotransport challenges, enhanced confidence toward solving biomedical problems from multiple content domains, and a general shift in class preference toward those employing challenge-based instruction. These results, in synergy with existing literature on challenge based instruction in BME[4], provide evidence to support continual integration of challenge-based modules in engineering curricula. We hope that the student-centered, content-specific nature of methods in this case study can serve as a basis for unique and instructive assessment of active learning environments in engineering.
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8. References


9. Appendix

**Biotransport Challenge Problem** (From [13])

Every year in the US there are thousands of accidents at restaurants in which hot beverages are spilled onto customers causing scald burns that are severe enough to require hospitalization. In the most extreme cases, death results. A small fraction of these accidents result in law suits against various parties involved in the food service industry, the most publicized being the infamous McDonald’s case in which a jury awarded an elderly New Mexico woman more than 2 million dollars in 1994. Part of the public outcry to this case was based on the concept that spilling a cup of coffee is such a trivial event that it could not be worth such a large legal settlement. **Thus, the focus of this challenge is to answer the question “How dangerous is it to spill a cup of hot coffee into your lap?”**

You may use the following information in your analysis. The Coffee Brewers Association recommends that coffee be held at a temperature of 185 °F for serving to customers, although a recent survey of the food service industry indicates the actual temperatures at fast food restaurants is somewhat lower. Many of the scald accidents occur while customers are seated in their vehicles at fast food drive-thru windows. A typical container contains 8 oz of liquid. The clothing worn by customers varies over a broad spectrum depending on geographic location and time of year, activity of the customer in conjunction with the visit to the drive-thru, and customer life style.

A consideration inherent to the issue of how dangerous is spilled coffee is how the level of danger can be modulated by altering the coffee temperature. For example, a recent scientific study demonstrated that the preferred drinking temperature of coffee is 140 °F. Thus, it is appropriate to ask how a progressive reduction in serving temperature would change the injury hazard associated with a spill.

**Biomechanics Challenge Problem** (From Interviews)

Throwing the shot put is one of the classic events for track and field competition. A round steel ball (called the shot) is thrown with a pushing action, giving rise to the verb “putting.” Competitors must start and remain within a seven foot diameter circular area during their putting motion. There is a wooden stop board along the front circumference of the putting circle to aid the putter in restraining their momentum toward the direction of the put while completing the throwing motion. The athlete must rest the shot close to the neck and keep it tight to the neck while throwing. The shot must land within a 37.92° angular sector from the front part of the putting circle. For collegiate and international competitions the men’s shot weights 16 pounds, and the women’s weights 8.82 pounds (4 kg). High school males use a lighter shot at 12 pounds.
The world record of 75’ 10¼“ is held by an A&M graduate, Randy Barnes. The world record for high school of 81’ 3½“ is held by Michael Carter of Dallas.

The shot put has been an Olympic event since the initiation of the modern games in 1896, although records document predecessor sports, such as throwing an 18 pound stone in Scotland, that date from the 15th century. Accordingly, the shot put has been the subject of intense and extensive analysis of technique with the objective of improving performance. Two primary putting techniques are used. One is called the “glide” in which the athlete generates a linear motion across the circle before putting the shot. The second is called the “spin” technique in which the athlete generates rotational motion across the circle before putting the shot. In both cases the technique involves developing a joint momentum of the athlete and the shot and then transferring as much of the energy as possible from the combination to the shot as it is thrown.

An issue long debated has been what is the best angle at which the shot should be thrown to achieve the greatest distance. Undoubtedly, in high school physics you did a simple analysis that showed the optimum angle for releasing a projectile to achieve maximum distance is 45°. However, analysis of champion shot putters has shown the best angle to be in the range 37 – 38°, although sports analysts have had a very difficult time explaining why. Your challenge is to perform an analysis of the shot put using generate ideas to identify the factors that must be considered in determining the optimum putting angle. This is a complex, dynamic problem, so I do not expect you to fully solve it. But, you should be able to make substantial progress through the first three steps of generate ideas, plus to identify areas in which you need to augment your knowledge and skills. Meaningful free body diagrams will be very important.