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Curiosity and Connections (Entrepreneurial Mindset) in BME Sophomore Design

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Introduction

A contemporary approach to meeting the educational needs of students focused primarily on job prospects can potentially be enhanced by seeking to instill the entrepreneurial mindset.[1] The Kern Foundation defines students as having the entrepreneurial mindset when they: "have a constant curiosity about our changing world and employ a contrarian view of accepted solutions; habitually connect information from many sources to gain insight and manage risk; and create value for others from unexpected opportunities as well as persist through, and learn from, failure."[2]

To ascertain whether these qualities contribute to an entrepreneurial mindset and/or whether these qualities improve students' job prospects, we are seeking to quantify our ability to (a) identify markers that can be correlated with these qualities, and (b) whether we can find teaching strategies that improve student mastery of them. Thus, in our biomedical engineering (BME) curriculum, we chose a currently offered BME course that can be used to quantify students' curiosity and ability to make connections – two of the qualities of the entrepreneurial mindset. Further, we seek to determine if we can devise a teaching method to improve students' abilities in these areas.

For this study we chose a sophomore-level BME product design and development laboratory course that has its students create an alpha prototype of a blood glucose measurement device. The blood glucose monitor was selected because it is ubiquitously recognized as a biomedical device and because design of a blood glucose measurement device requires application of at least one critical component of almost every required class in the BME curriculum. Unlike how other engineering courses are typically graded, due to the forward-looking nature of the course (showing how content from future BME courses fits into a biomedical design), the course cannot be graded for accuracy of the design. Instead, students seeking to earn an A must demonstrate curiosity about the information that can be learned from the technical models. For these reasons, this sophomore-level design course has been chosen for this study as potentially being well-suited for teaching and assessing curiosity and making connections (two of the three Kern elements of an entrepreneurial mindset).

This sophomore-level design experience is often the first taste that BME students get of the attention to detail required to be successful in engineering, and students' enthusiasm for this course likely suffers because of that. This course, which has been offered each semester since 2012, is the second course in the BME curriculum that introduces students to the mathematical roots of engineering and demonstrates the attention to detail required to successfully complete engineering calculations. Almost all students entering our BME curriculum believe that BME graduates conduct research, and many of these students have unrealistic notions about the amount of attention to detail required in a research career. Because of these perceptions, the course often comes as a shock to students in the class because of the mismatch between the students' expectations and the reality of engineering. Although retention at the university of students entering in our BME program is very high (~95% after freshman year remain at our university, ~85%-90% remain after the second year), many of these students switch to majors other than BME (frequently out of engineering altogether). For these reasons, some students exhibit low enthusiasm for this course content, and this likely dampens their curiosity for the learning opportunities presented by the course. Because we believe that the course teaches invaluable skills and though processes, we seek to enhance students' curiosity about this subject matter despite what appears to be structural reasons why many students exhibit low enthusiasm and low curiosity about his subject matter.

This study was designed to accomplish two main goals. First, we sought to determine if we could robustly quantify curiosity and making connections through any of several metrics observed in this sophomore design course. Initially we measured many aspects of the students' observable behaviors; but, as will be described below, we quickly realized that observing aspects of the students' behavior and topics of conversation/questions during open-ended design exercises were the most revealing in these regards. The second goal was to conduct at least one intervention designed to affect student curiosity and connections to determine if our measurements of curiosity and connections would be sufficiently robust to compare different experiences meaningfully. Our long-term aims are to determine if interventions in our curriculum can enhance the curiosity and connection-making of our students.

Methods

The course is a 1-credit lab format (2.83 hours, once per week) in which the instructors begin with a mini-lecture (~30-45 minutes), followed by approximately 1.5 hours of students working interactively in teams, and finally by students completing a brief report on their activities.

Observations were made on three different weeks in two sections on each week (total of 6 sessions observed). The first two weeks of observation were performed prior to the implementation of the intervention designed to affect curiosity and connections. The first of these weeks included an exercise in which students were asked to mathematically model glucose regulation in physiologic conditions, type I diabetes, and type II diabetes. The second week's exercise asked students to draw a 6-panel cartoon depicting the important steps of how amperometric glucose sensing works. The third week of observations was of an intervention designed to enhance student curiosity and connections (the developers of this instructional strategy call it "jigsawing"[3]). The assignment for the third week's session asked the students to calculate the amount of glucose oxidase enzyme needed to achieve approximately a 0.1μA current from the electrode when in contact with a "normal" blood glucose reading and to detail a chemistry protocol for how to immobilize that amount of enzyme on the electrode surface.

Jigsawing was conducted by randomly assigning each student into three groups, which were each instructed by an undergraduate teaching assistant (UGTA). The first group of 1/3 of the students was instructed in how to use the Sigma-Aldrich website to find pertinent information about glucose oxidase. Another 1/3 of the students were instructed by a UGTA in how to calculate the rate of an enzymatic reaction and how to convert a mol/s value of electrons generated by a reaction to Amperes. The third UGTA instructed the final 1/3 of students in how to read a basic research paper methods section and how to find the seminal research paper describing how to immobilize glucose oxidase enzymes on an electrode. This assignment was taught in previous semesters as an individual learning experience and was not a jigsaw exercise and, in those previous classes, students had been instructed in all of the basic background needed to complete the exercises. This initial instruction period (approximately 30 minutes) ended with students in each group having completed a short crib sheet so that they had the information needed from their segment of the jigsaw. At the beginning of the class, students had signed in to a computer by typing their name into an Excel spreadsheet. That spreadsheet was designed to assign each students to one of the jigsaw groups and a team number. After the initial instruction period, students from the three different jigsaw segments gathered in their group numbers (numbers corresponded to locations in the classroom, so it was easy for them to find each other). Students were instructed to help each other complete all sections of the overall assignment, and students were told that all assignments would be individual assignments (written by the student turning it in) but that they should work together as a team to generate the understanding they needed to complete that assignment. This work occupied the remainder of the lab period. In the case of this assignment, there was a second week, which started with another short introduction by the instructor to the entire class clarifying any questions from the previous week and helping students understand how the different parts of the jigsaw fit together to accomplish the overall exercise. Then students completed the exercise before leaving class in the second week.

During these lab sessions, we made many observations that could potentially inform us as to how many students were measurably curious and how many were observed to spontaneously make connections. We recorded the attendance as well as observed the number of students coming in late or leaving early. We then semi-randomly selected 7 students in each session for closer observation. There are 7 lab benches in the room in which the class is conducted, and before looking at the students working at that bench the observer chose a number (1-9) and counted that many in from the end of the bench to select the student for observation. That student was observed as unobtrusively as possible, and a tally sheet was annotated to record the observable behavior of the student that might indicate curiosity: asking questions, note-taking, independent research, focus, and engagement. The same tally sheet was used to record the student's behavior in many ways that might demonstrate making connections: discussing similarities of information from a previous class, processes used in industry, a future course, or other information sources. In addition to this tally sheet, free-form notes were recorded by the observer. After a short period of unobtrusive observation (the students were aware that the observer was watching, and this might have affected their behavior), the observer would engage the student by asking the student to describe his/her work or asking specific questions to elicit particular behaviors not observed spontaneously.

Tally sheet annotations typically took the form of +1, 0, or -1 for each behavior, indicating the student exhibiting that behavior spontaneously (+1), upon prompting (0), or not even exhibiting the behavior upon prompting (-1). Behaviors not observed but not attempted to elicit with prompting received no annotation. It is possible that a student could be curious or making connections but not verbalizing these or showing them in any visible way, so there is a possibility of false negatives. An example of using this scoring method is attempting to observe making connections between the mathematical modeling of glucose homeostasis with the Conservation Principles course, in which most students are co-enrolled. If a student is observed to be looking at course notes, Blackboard information, asking the UGTA about how to apply a mass balance, etc. he/she would receive a “+1” annotation. If the student did not exhibit any of those behaviors, the observer would ask a question about the form of the equation being input into Matlab – attempting to prompt the student to realize that the “accumulation = in – out” format is familiar to him/her from Conservation Principles – if he/she does, the observer would note a “0”. If, even after prompting, the student did not make that connection, the observer would annotate a “-1”. In some cases, after conducting these observations, the observer would openly ask the student whether he/she were curious about or interested in the material being covered in the exercise or overall course. Likewise, the observer asked selected students whether they saw connections with other courses in the curriculum, relevance to industrial practice of biomedical engineering, or other topics of interest.

Results

Absences for the initial two weeks’ sections were 4/45, 2/42, 1/45, 1/42 (morning and afternoon labs on the first week of observation and second week of observation). The greater absence rate on the first week of observation may have been because it was the second week of a 2-week exercise. The information about the assignment was explained in class in the prior week; thus, perhaps the additional students did not see the purpose in being physically present in class the day of the observation. Another metric records how long into the lab period teams stay. Approximately 2.25 hours into the 2.5 hour lab period, attendance was 18/45, 20/42, 33/45, 35/42 for the sessions observed. The number of students who remained for almost all or all of the lab period was approximately 40%-50% for the first week of observation and was higher for the second week of observation (73%-83%). Based on observation, it seems likely that students finished and submitted their assignment earlier in the class period for the first week of observation (which was the second week of the first 2-week exercise); whereas, the second week of observation was a 1-week exercise, thus the students needed to finish their assignment for that week in class on the same day it was assigned. This probably explains why students remained for a longer time period during the second week. Another complicating factor is that the afternoon lab session is followed by another course in the same room for which many of the students are registered. These students seem to remain for the full lab period, but this may be more because of the convenience of waiting for their next class to start. Thus, although duration of attendance in the class was initially hypothesized to be a way to measure the students' desire to learn additional course material, these other confounding factors may make duration of attendance a poor indicator of curiosity.

For the students that were present at each of these times, 7 from each section/session were observed more carefully for signs of curiosity and making connections (total of 28 students observed across the 4 sections/sessions). On average 1/7 students in each section (4/28) asked questions of the UGTAs or colleagues that were not directly about the worksheet assigned. 15/28 showed generally good focus/engagement in their work, but 9/28 exhibited poor focus/engagement as exhibited by frequently checking his/her cellphone, looking at a non-relevant website, playing a videogame, or leaving lab as soon as it was practical to do so. Students in these sections did not exhibit curiosity by looking up information beyond what was directly relevant to the worksheet, although 5/14 students did ask questions about non-amperometric methods of measuring blood glucose in the second week of observations, which may have been prompted by a question in the assignment.

After this observation period, students were asked directly whether they were curious about the topic being covered in the course. Additionally, the UGTAs were asked for their impressions regarding their students' curiosity about the material being covered. Most students gave polite responses indicating some curiosity about the material, but 3/28 students gave answers that included specific information about which they were curious. The UGTAs estimated that approximately 10% of the class were truly interested in the material and were going above and beyond the expectations for the assignment. They estimated that approximately 1 student per 3-student team (~33%) were interested in the material but not curious enough to expend significant energy to go above and beyond the assignment's expectations. (The first estimate from the UGTAs (~10% of the class were truly interested in the material) matches the 3/28 students who gave answers indicating specific information content about which they were curious.)

Connections were tallied by listening to what the students discussed or watching what the students were working on to determine if they were connecting the exercise in this course to information obtained in a different class, a previous session of this course, or some other information source not specifically indicated by the instructors or worksheet. In the first week of observations, 2/14 students made connections without prompting – one to the physiology course and the other to an article on the instructor's research related to the topic. After observing for a while, we asked the students whether they perceived any connections between their current work in this course and other aspects of biomedical engineering. At that point, 6/14 additional students (total of 8/14, including the 2/14 who made connections without prompting) recognized connections to other courses in the BME curriculum (e.g., differential equations, conservation principles) and previous sessions of this course (e.g., the variables being solved were blood glucose and rate of change of blood glucose).

Based on these initial observations, an intervention was devised to attempt to improve upon the curiosity and making connections exhibited by these students. We sought to find an intervention that required only control over what happened in this specific course and in this particular session of the course. Because most of our metrics for curiosity relate to participation in various forms (engagement with the exercise, discussion with teammates/UGTAs, looking up information), we decided to introduce cooperative learning through the jigsaw technique. Previously this has been used in various ways including online courses.[4] The jigsaw was implemented as described above in Methods: class divided into thirds, approximately 45 minutes of instruction by a UGTA for each group, one member from each group assigned to each team, and then teams had the remainder of the lab session to work on their assignment in teams.

Observations were conducted in the jigsaw sessions, as had been conducted before. 2/87 students were absent (sum of both sections observed) and 1/87 came on time but left before the instruction period was completed. One of the two absent students arrived approximately 45 minutes into the session. The attendance at the 2.25 hour mark was actually worse than the attendance prior to the jigsaw (approximately 35% remained at 2.25 hours into the lab session); however, attendance at the 2.0 hour mark was much better (79/87) than the 2.0 hour mark attendance prior to the jigsaw (no data were recorded at the 2.0 mark for the pre-jigsaw sessions, but the investigators' recollections are that it was essentially identical to the 2.25 hour mark for those sessions – data reported above). Thus, most students left the class between 2.0 hours and 2.25 hours.

Other metrics of curiosity were all substantially greater than in the pre-jigsaw sections. Of the 14 students observed, 7/14 were asking questions of UGTAs and/or classmates (compared to 4/28 prior to jigsaw), 5/14 were looking at various websites with information beyond what was required for the exercise (compared to 2/28), and only 1/14 exhibited poor focus/engagement (compared to 9/28). Anecdotally, immediately after breaking from the UGTA/instructor-led portion of the period, the discussion among classmates increased noticeably from being fairly quiet to most teams talking with each other about the exercise until about the 2.0-hour mark of the period. As mentioned above, many teams started leaving just after the 2.0 hour mark, so this may indicate that those individuals were not very curious but stayed until that point to get information from their classmates.

The jigsaw technique was explicitly designed to guide students to connect their activities in this exercise with other courses in the BME curriculum: biology (obtaining information about the glucose dehydrogenase enzyme), chemistry (protocol for immobilizing the enzyme on the electrode), and physics (converting from enzymatic reaction rate to electric current imparted on the electrode). It seemed that almost all students saw these connections so, when prompted, students were able to see the connections between this exercise and those topic areas. The rate of students making spontaneous additional connections to other material was the same as prior to the jigsaw technique (2/14). Thus, although the jigsaw technique successfully prompted students to make connections, it did not have a clear effect on spontaneous connection-making.

Student responses to the jigsaw technique was mixed. Some students were enthusiastic about the jigsaw because it allowed them to gain more expertise in a sub-section of the material prior to needing to work on the exercise. However, other students were negative about the jigsaw; most of these cited issues with teammates not understanding their portion of the content or not participating fully in completing the exercise with the rest of the team (we hope to add assessment of team dynamics in future iterations of this course). UGTAs noted that one of the three topic areas (chemistry protocol for immobilizing the glucose oxidase enzyme on the electrode surface) seemed disconnected from the other topics, and this led to students assigned to that topic area often working independently with the thought that they were merely going to copy and paste their protocol onto their teammates' reports. However, the instructions were for each team member to submit individual reports of their own work, which would mean that the student specializing in the chemistry protocol would need to explain that protocol to the teammates – not copy and paste. The following class period clarified this instruction, so perhaps this aspect would go more smoothly in future iterations of using the jigsaw technique.

Discussion and Conclusions

The first goal of this project was to determine robust methods for quantifying (a) curiosity and (b) making connections by undergraduate BME students. We believe that curiosity can be identified by watching what students do and listening to what students say when you give them an open-ended assignment. Students who do much more than the minimum, who look for information sources beyond the required, and students who ask questions that probe deeper and wider than required are exhibiting elements of curiosity. In this study, we found that by these criteria approximately 10%-15% (2/14) exhibited true, spontaneous curiosity and an additional 10%-15% of students (4/28) exhibited some signs of curiosity (but these were related enough to the assigned topic that it was not clear whether these were actually signs of curiosity).

We believe that connections can be identified when students are observed to make statements indicating that they recognized a connection with another course in the BME curriculum, or with a research paper or news article they had read. We observed 2/28 students (~7%) doing this spontaneously and an additional 6/28 (~21%) doing this with prompting (i.e., when they were asked whether they saw connections). Parenthetically, the "true entrepreneurial mindset" requires that students make these connections spontaneously.[5] It is also likely that some students spontaneously saw connections but did not verbalize or show other obvious signs until prompted.

Based on these results, we make two tentative conclusions in this area. First, approximately 10% of the class exhibits the entrepreneurial mindset elements of curiosity and making connections at this stage in the curriculum (approximately their 4th semester). An additional 20%-25% exhibit some curiosity and connection-making when prompted. Secondly, we conclude that observing student behavior in open-ended design exercises is generally good a way to quantify these mindset elements; however, it is likely that we are not identifying some students as curious or as making connections because they may be making connections without verbalizing them or may be curious without acting on that curiosity in a demonstrable manner during the in-class exercise.

The second goal of this project is to determine if there are effective ways to teach curiosity and/or connection-making at this level of the curriculum. Teaching curiosity or instilling curiosity is challenging because an instructor cannot require someone to be curious. The fact that the instructor makes it a requirement means that the students' behavior in response to that requirement is, by definition, no longer curiosity. However, a greater percentage of students looked at websites without being directed to do so by the instructors/UGTAs, asked questions of the UGTAs and classmates, and showed other signs of curiosity when the jigsaw technique was employed as a teaching methodology. Approximately half of the class (50%) were exhibiting behaviors we have identified as being linked to curiosity and connection-making in the jigsaw exercise.

Almost all students saw the connections between the jigsaw exercise and the topic areas for each of the 3 jigsaw topics (biology, chemistry, and physics). Although this is cannot be definitively likened to the spontaneous connection-making that is needed for a true entrepreneurial mindset, we hypothesize that repeated exercises that prompt students to make connections will eventually increase the percentage of students who spontaneously make connections. Likewise, we hypothesize that repeatedly prompting students to exhibit the behaviors associated with curiosity (in this case by providing partial information so students need to ask questions and look up information to meet the requirements of the assignment) will eventually increase the percentage of students who exhibit spontaneous curiosity. We currently have, however, only the above described, single exposure of our students to the jigsaw technique. Thus, we cannot yet make any statistically significant conclusions, but we intend to study our hypotheses further.

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