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Student-Developed Learning Objectives: A Form of Assessment to Enable Professional Growth

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Abstract

This *Evidence-Based Practice* paper proposes a unique and flexible form of assessment that helps prepare students for a changing world. As technology is rapidly advancing, engineers that are able to adapt to a constantly changing global economy are needed more than ever. Engineering students need to work on developing communication and problem-solving skills early and often. However, these traits aren't easily assessed with a traditional exam and can look different from person to person. To combat this problem, this work suggests a form of assessment which allows students to demonstrate learning in ways that further their own professional goals and benefit the world around them.

This assessment process consists of three main components: student-developed learning objectives, classifying objectives using Bloom's 3D Taxonomy of Learning, and demonstrating success through external value. Each of the three components are discussed in depth. Successful students using this model have produced peer-reviewed publications, conference presentations, awards, new businesses, and grant funding. To quantify what students are learning, what makes successful students, and how this type of learning can be supported, learning objective data from 28 students were collected during a semester to explore the different pathways that students choose. This work defines the learning objective creation process, explains how it is used for assessment in a cardiovascular engineering course, and suggests how to implement this assessment strategy in other courses. Example learning objectives from a variety of students are presented and discussed, as well as general trends and takeaways.

Introduction

As technology and the age of information continue to evolve, the need for engineers that are trained both technically and professionally is greater than ever. ABET calls for an engineering curriculum where students learn how to communicate effectively, work on teams, problem solve, and understand how to gain new information when needed [1]. Similarly, the National Academies paint the picture of "the Engineer of 2020" who has skills in leadership, communication, and creativity. The Engineer of 2020 practices resiliency, agility, and lifelong learning [2]. On top of that, an extensive study done in [3] looked at information from over 16,000 participants and over 36,000 job postings to discover what engineering employers are looking for; they reported that thinking creatively, solving problems, and designing solutions were among the top competencies that employers want from their engineers. This study also determined that the biggest factor that differentiates between an ordinary and extraordinary engineer is the ability to devise processes. In other words, employers want engineers that understand what skills they possess, how to use these skills and apply them, and when to work on developing new skills and knowledge to solve problems.

Throughout all of these examples, two themes emerge: a need for engineers that have professional skills and the ability to learn and improve. Not only should students grow in their technical and professional skills, but they should also grown in awareness of what competencies they have, what they need to work on, and how to improve. This work presents a flexible way for students to work on a wide variety of skills and gives them the responsibility of guiding their learning. The assessment strategy has students develop learning objectives throughout the duration of the course; the students decide what they will learn, to what level they will learn it, and how they will demonstrate their learning. This requires students to learn how to define a problem, assess what information they will need to acquire, and apply the knowledge and competencies they gained to develop a solution. Just as engineers capture design requirements to direct their work, students write learning objectives to frame their coursework.

Background information about the pedagogy and theory that guides this work is presented, followed by general information about the learning objective creation process. Next, the structure of a cardiovascular engineering course that has used this assessment form will be discussed, including how learning objectives were monitored and assessed. Results from the course will then be presented and final thoughts will be discussed about lessons learned and how this work could be applied to other courses.

Background

In the world of engineering (and beyond), an ability to innovate is of the utmost importance. However, traditional high-stakes assessments have been shown to squelch innovation both for the instructors organizing the course and the students that are working within the boundaries of the course [4]. Therefore, work is being done to design assessment that allows for student freedom with strategies like project-based learning and learning portfolios [5]. These forms of assessment derive from work on open-ended learning environments and self-regulated learning. Open-ended learning is a pedagogical approach that harnesses students' intrinsic motivation to learn [6], and self-regulated learning is when students make goals and evaluate their learning in order to practice metacognition [7]. Many researchers have found benefits when implementing more opportunities for student-directed learning both in higher education [8–11] and the K-12 system [12]. Giving students ownership and flexibility increases motivation [8, 10], improves student engagement [8, 13], helps with information retention [13, 14], and promotes lifelong learning [14, 15].

However, difficulties can arise from reforming assessment because of the open-ended nature, effecting both evaluators and students. Evaluators may struggle in being consistent and fair when grading multiple types of assignments [14], and they may also struggle with getting support from potential stakeholders [13, 14]. Students may struggle with the high level of freedom and autonomy, especially when they are used to working in a more traditional educational system [10, 13]. Therefore, this work aims to set standards in self-directed learning objectives, demonstrate success and benefits for a variety of stakeholders, and provide ways to better support students.

Learning Objective Creation Process

The assessment process has three main components: 1) Students develop their own learning objectives and share them with the class and instructor, 2) Students use Bloom's Taxonomy to help illustrate to what level they will learn each of their desired objectives, and 3) Students will be assessed based on the amount of external value they achieve through their objectives.

Student-Developed Learning Objectives
Normal assessment usually has instructors develop learning objectives and ways to assess that those learning objectives are met. However, in this form of assessment, students fill this role. While working on a project and learning course content, students are expected to write learning objectives that explain what they will learn, to what level they will learn it, and how they will demonstrate it. By writing learning objectives, students are taking part in the process of metacognition, which helps solidify both content and skills [16]. To give students ideas for objectives, categories are given to the students from which they can choose. These categories are shown in Appendix A and range from literature review to data collection to conference presentations to business models.

Bloom's Taxonomy
Because of the large amount of freedom when writing objectives, Bloom's 3D Taxonomy of Learning [17] is used to help provide students with scaffolding. In the first week of class, students are taught about the taxonomy (shown in Figure 1) and learn about how to build from low-level to high-level learning. Students start by showing low-level learning (e.g. writing a report that shows understanding of concepts) which then builds into high-level learning (e.g. publishing a paper about the creation of an experimental procedure). Classifying learning with Bloom's 3D provides structure while still allowing for student freedom.

Figure 1: Bloom's 3D Taxonomy adopted from [15]

External Value
Assessment in the course is done by measuring external value, which consists of 1) providing value outside the classroom, and 2) some sort of external review from the scientific community or end-users. For example, an in-class presentation would be lower external value than presenting at a business pitch competition. Other examples of external value are shown in Table 1. Students feel invested because they have the freedom to choose a form of external value that most closely aligns with their personal and professional goals, and they are able to work on meaningful solutions that benefit their community.

Level of external value	Examples
Low	Tests, quizzes, homework, in-class surveys, reviewing others' evidence, documented general assistance to the class
Medium	Standard operating procedures, non-refereed conferences, providing expertise to other research groups in a lab
High	Invited outreach activities, refereed conferences, refereed journal manuscripts, scholarships, fellowships, awards, invention disclosures, business pitches, business plan competitions

Table 1: Examples of deliverables at each level of external value

Application in a Cardiovascular Engineering Course

Structure of the Course

A 3-credit Cardiovascular Engineering course has used a form of this assessment style for the last four years, and student data was collected during the most recent iteration of the course. Students learn five main cardiovascular engineering concepts (functional block diagram of the cardiovascular system, resistance and compliance concepts, pressure/volume loops and time domain, ECG, and arterial systems) and are expected to demonstrate their competency in each of these areas. These objectives fall under the category of Discipline Specific Knowledge 0 (DSK0), the only required objective. Students watch videos outside of class about each of the topics and are expected to come to class ready to participate in worksheets and discussion. Beyond DSK0, students are allowed to write their own objectives and edit them as the course goes on. Class time is dedicated to both digging deeper into DSK0 concepts and having students present learning updates where they share their objectives with the class and instructors and get feedback [18, 19]. If students show competency in each of the five areas of DSK0, they are at a grade level of a C. If students apply the knowledge to a project, they are at a B grade level. Finally, if students achieve high external value with their project, they will receive the grade of an A.

Choosing a Team and Topic

As students decide on learning objectives, most of the learning is based around an innovation project that teams choose. At the beginning of the semester, students look at cardiovascular-related funding opportunity announcements from agencies like National Science Foundation and National Institute of Health to determine projects of interest. From there, students pitch project ideas and form teams based around the projects [20]. Students are not evaluated based on their ability to solve the problem presented in the funding opportunity announcement, but rather on their ability to demonstrate how they applied their learning to their innovation project and share it with a broader audience.

Logging Learning Objectives

Students use an online portal to log learning objectives and corresponding deliverables, allowing them to track progress on each objective in real time [21]. Each student has multiple learning objectives, and each learning objective may have one or more deliverables. Learning objectives are categorized with Bloom's Taxonomy and the Learning Objective codes in Appendix A. Deliverables are categorized with the level of external value, expected completion dates, and current progress level (not started, in progress, and completed).

Methods

Participants

28 students chose to share their learning objectives during the span of the course. Of those 28 students, 22 were male and 6 were female, and the mean age of the group was 26.5. There were 13 undergraduate seniors, 3 Masters, and 11 PhD students (1 student did not provide a response to this question). A variety of majors and programs were also represented in the sample. The class is offered by the department of Electrical and Computer Engineering, but other departments allow their students to take the class for technical elective credit. 9 students were in Biomedical Engineering, 9 in Electrical Engineering, 5 in Mechanical Engineering, 4 in Computer Engineering and 1 in Health, Nutrition, and Exercise Science. This offering of the course was different from other years in part because students from a partner university and distance students were allowed to enroll. 20 of the students in the study were from the local university, 5 were from a partner university, and 3 were distance students.

Learning Objective Collection

Throughout the semester, all students logged their progress in an online portal where they could add, categorize, update, and delete learning objectives and deliverables. Whenever a student made an addition, change, or deletion, the event was logged in a searchable database [22]. Therefore, in addition to being able to analyze the end state for each student, we could also analyze the steps that it took to get there. Trace data were collected because self-reported data about metacognition is often inaccurate. Although this method loses some student perspective, it does gain temporal accuracy by being able to reference the log data directly [23].

Assessment Reliability

In order to measure the reliability of the assessment process, all six authors graded the level of external value of each of the students in the class. Two of the raters consistently attended class, and all six have either taken or taught the class in the past. The raters discussed the grading criteria, but did not discuss individual instances until after the individual ratings had been completed. The interrater reliability was calculated by taking Fleiss' Kappa, which measures agreement while factoring out agreement due to chance.

Post-Survey

During the last two weeks of the semester, students were asked to fill out an online survey about the class. 24 students responded to the survey, and it should be noted that the students that completed the survey are not necessarily the same students that agreed to share their learning objectives. 26 questions were asked, 5 of which were most pertinent to the research questions of this paper and will be discussed here. Other questions were focused on topics such as the team formation process, team composition, and use of various software in the class. Those questions will be published in other papers exploring these specific topics. The 5 questions were:

- Note something that this class has inspired you to do better or differently.
- Describe new competencies you have learned/developed (skills, tools, methods, software).
- Describe qualities you have discovered about yourself (characteristics, traits, features)

through the class.

- I would recommend this class to another student. (5-point Likert scale)
- How would you describe the class to a peer? Pick all that apply. (15 words were listed)

The first three questions were adapted from Jaeger [24]. The goal of these questions was to assess student perceptions about skills they have gained without priming them by asking about specific skills. The goal of the last two questions was to assess student sentiment about the class.

Results

Learning Objective Collection Results

Of the 28 students that shared their learning objectives, 18 clearly achieved high external value, 8 were borderline, and 2 did not provide any evidence at all. Learning objectives for two example students are included below. Student A is an example of a student that clearly achieved high external value. Student B is an example of a student that attempted an innovation project but was not quite up to the level of high external value.

Learning Objective	Deliverables	Linked Evidence
Learn the fundamentals of the cardiovascular system (DSK0: Fundamental Cardio Concepts, Understand, Conceptual)	Create a functional block diagram	Virtual copy of notes
	Understand R&C relationship and pressure volume loops	Virtual copy of notes
	Understand ECG concepts	Virtual copy of notes
	Understand the arterial system	Virtual copy of notes
Develop a measurable relationship between ECG, cough frequency, and respiratory rate (DSK3: Learning outside of student's College, Create, Procedural)	Compile resources that discuss the relationship between variables	List of 12 peer-reviewed journal articles
	View resources given by other teammates to develop understanding of biosensors	Link to a shared folder with papers from other group members
	Determine limits of variables	A summary slideshow with information compiled in literature review and applied to project
Collaborate with team to complete project (RM6: Team conduct, Evaluate, Metacognitive)	Create Gantt chart to map out project timeline	Link to Gantt chart document
	Create google drive to compile all documents/progress of project	Link to shared drive
Develop the multi parameter biosensor into plan for a prototype (ES5: Product evaluation, Create, Procedural)	Create layout of expected device	Block diagram of the device
	Create a 3D model of the expected device	Screenshots of model
	Begin a material analysis for future material selection in prototype stage	Document with advantages and disadvantages of various materials for each design component
Communicate technical knowledge that relates to the group project (PC7: Outreach communication, Create, Metacognitive)	Create a poster that communicates overall idea of project	Copy of poster
	Obtain feedback from class for revisions of symposium poster	Copy of the poster with new revisions
	Present poster at graduate symposium	Photo of group at the symposium

Table 2: Student A's learning objectives and deliverables

Student A had five main objectives, each with clear deliverables and linked evidence. They are shown in Table 2. The student's project was to work with their team to build a prototype of a multi-parameter biosensor. In addition to learning the main fundamentals of the cardiovascular system (DSK0), they also determined that they needed to better understand how ECG, cough frequency, and respiratory rate relate to each other (DSK3). They showed that they learned these topics by summarizing what was read in a variety of publications. In addition to gaining information, they also worked on team conduct, evaluating a product, and outreach communication. They demonstrated external value by presenting at a poster session and getting review, sharing their work with a wider audience, and winning an award for their work. Many of student A's objectives are at the metacognition and/or creation level.

Learning Objective	Deliverables	Linked Evidence
Class Learning (DSK0: Fundamental Cardio Concepts, Understand, Factual)	Make connection of in class learning	Summary of notes
	In-class worksheets	Virtual copy of worksheets completed in class
Website (DSK2: Learning in student's College, Evaluate, Conceptual)	Create a template	Link to the website
	Website content review	Link to a form where website users can submit feedback
	Design critique	No evidence linked; marked as still in progress
Code documentation (DSK3: Learning outside of student's college, Understand, Procedural)	Make READme documentation	Link to code repository with READme file
	LO contribution	Document explaining how work was split between group members
Cardiovascular genetics (DSK3: Learning outside of student's College, Understand, Factual)	Find/read an educational journal	Link to 13 online sources
	Create intro to genomics video	Link to video
	Add information to website	Link to website that student created about cardiovascular genetics
Distance collaboration tools (DSK3: Learning outside of student's College, Understand, Procedural)	Use Google Drive for working collaboration	Link to shared drive
	Discord	Copies of meeting minutes (meetings were held using the program, Discord)

Table 3: Student B's Learning Objectives and Deliverables

Student B also listed 5 objectives with evidence, but the external value of the work is less clear. Their learning objectives and deliverables are shown in Table 3. Some possible ways for the student to improve would have been to find a clearer need to fulfill, rather than making a website that might not be helpful or easy to find. Also note that the Bloom's categorization levels do not have anything at the creation or metacognitive level.

Assessment Reliability Results

After all six raters scored all students, Fleiss' Kappa was calculated to determine interrater reliability. One rater had a misunderstanding about some of the students' deliverables, so some of that rater's scores were adjusted before large group discussion began. Kappa was 0.412 before this adjustment, and was 0.505 after the adjustment. A score close to 0 is considered no better agreement that if the raters had randomly scored the subjects; a score close to 1 is considered almost perfect agreement. Although there is no officially agreed upon benchmark for Fleiss' Kappa, 0.4-0.6 is considered moderate agreement, meaning there is still room for improvement in increasing reliability. Suggestions for improving interrater reliability are included in the Discussion section under *Takeaways for evaluators*.

Survey Results

For the three open response questions, six gained skills were identified from the emergent coding. The categories and the number of students who mentioned each skill are shown in Figure 2. The most commonly mentioned skill gained was communication. Student responses that were coded in the communication category ranged from improving presentation skills to better communicating projects to non-engineers to technical writing. A large number of students also had responses mentioning teamwork, leadership, and teaching others. In addition, some students mentioned gained technical skills, including five responses about software and programming, two about cardiovascular engineering, two about web design, and one about electronics skills.

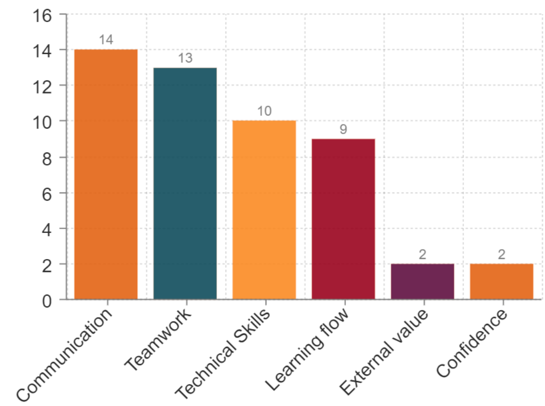

Figure 2: Top skills gained identified by students

The next category was learning flow, or the ability to direct your own goals and learning. Nine students included a response with this theme; they mentioned that they learned how to set goals, go out and find new information, and assess themselves. Two students mentioned the idea of external value or being able to identify and solve a problem that meets a clear need, and two other students mentioned improvements to their confidence.

Figure 3 shows how students responded to the prompt, "I would recommend this class to another student," and Figure 4 shows the top words chosen to describe the class to a peer. Top words included time-consuming, satisfying, beneficial, frustrating, and motivating.

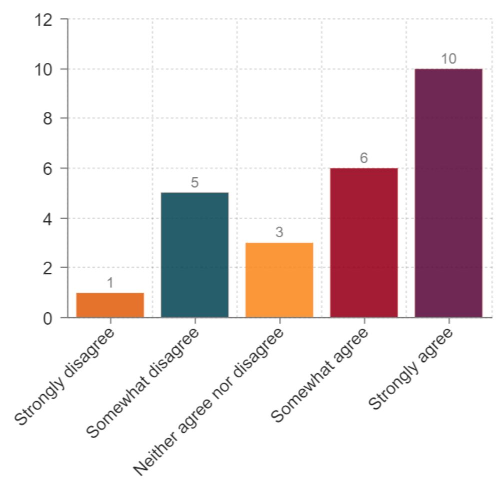

Figure 3: Responses to the question: "I would recommend this class to a friend."

Discussion

Takeaways for educators

This unique form of assessment puts students in the driver's seat, allowing them to focus on learning both content and skills that are called for by ABET and engineering employers and institutions. The assessment strategy requires students to identify and solve complex problems

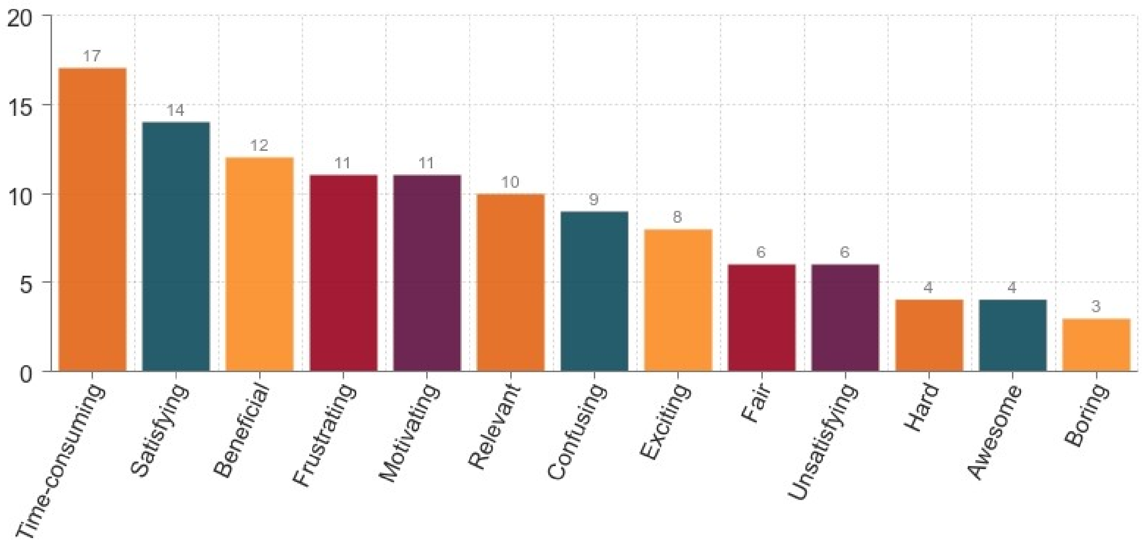

Figure 4: Top words chosen to describe the class to a peer

(ABET Desired Student Outcome 1), develop a solution (ABET Desired Student Outcome 2), and run experiments and collect data (ABET Desired Student Outcome 6). Students recognize that they are working to improve communication, leadership, and their ability to acquire new knowledge (ABET Student Outcomes 3, 5, and 7, respectively). Many students met and exceeded expectations by publishing, presenting, and submitting invention disclosures while gaining knowledge about cardiovascular engineering. However, to help more students succeed and decrease confusion, more time should have been spent at the beginning of the semester defining terms and how students will be assessed. For example, when an instructor says ”research paper”, they often think of a peer-reviewed publication; a student, on the other hand, might think of writing a summary of existing information. Spending time defining some of these outcomes at the beginning of the semester will help students plan accordingly and rise to the challenge at hand. Another way to better support struggling students is to encourage more entrepreneurial thinking. Who is their customer/audience, and what are their wants/needs? By focusing on these ideas, students can better understand the idea of external value and find more ways to add external value to their work. Finally, reviews should occur early and often. By communicating what students are doing well and what they can improve upon, they begin to feel more comfortable with the control they have.

Takeaways for evaluators

For those that are evaluating students at the end of the semester, it is important to make sure both the students and instructors know how you plan to evaluate different cases. For example, what will you do if there is missing evidence? Will you allow students to provide it after the due date? For this class, students were allowed to clarify the level of external value of a deliverable by providing more information, but they were not allowed to add more evidence after the due date passed. On a similar note, what happens if DSK0 is not included and the fundamental cardiovascular engineering elements are not demonstrated? In this class, students were dropped a letter grade, but that does bring up more questions about how to ensure that all students are meeting the main content-oriented learning objectives of the class. Finally, most disagreement in evaluators was about the difference between a B and a C. To get a B, students were supposed to apply their knowledge to an innovation project, but what happens if their project isn't innovative. How can we recognize the effort they put in, but also encourage them to focus more on the innovation? These questions need to be answered by any instructional team that is considering implementing this assessment technique.

Conclusion

A form of assessment that focused on giving students the opportunity to guide their own learning was presented. In the case study of 28 students, about 2/3 agreed that they would recommend the class to a friend, and about 2/3 achieved high external value through the form of a patent, publication, or peer-reviewed poster presentation. Future work includes collecting data from future iterations of the course, expanding data collection to other universities that will be implementing this system, and utilizing educational data mining techniques to explore patterns in successful/unsuccessful learning objectives. Although more work needs to be done to understand the best ways to support students while also giving them academic freedom, this work is a step in the right direction to empower students to innovate and grow as engineers.

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Appendix A

Category	Code	Objective
Discipline-Specific Knowledge	DSK0	Fundamental Cardiovascular Concepts
	DSK1	Learning in student's major/program
	DSK2	Learning in student's College
	DSK3	Learning outside of student's College
	DSK4	Freeform learning
Fundamentals of Research	FR1	Research method
	FR2	Literature review
	FR3	Experimental design
	FR4	Experimental equipment
	FR5	Intellectual merit
	FR6	Broader impact
	FR7	IRB/IACUC
	FR8	Lab safety
Mechanisms of Research	MR1	Statistics
	MR2	Experimental controls
	MR3	Data collection
	MR4	Data analysis
	MR5	Drawing conclusions
	MR6	Knowing nature of results
Professional Communication	PC1	Conference abstract
	PC2	Conference poster
	PC3	Conference presentation
	PC4	Proposal presentation
	PC5	Journal manuscript
	PC6	Standard operating procedure
	PC7	Outreach communication
	PC8	Invention disclosure
Research Mindset	RM1	Personal statement
	RM2	Receiving critique
	RM3	Providing critique
	RM4	Metacognition
	RM5	Establishing learning requirements
	RM6	Team conduct
	RM7	Mindset
Entrepreneurial Skills	ES1	Business model
	ES2	Customer communication
	ES3	Customer segment
	ES4	Value proposition
	ES5	Product evaluation

Table A.1: List of all categories that students could choose from to classify their learning objectives