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Work in Progress. Building a Learning Continuum: Forging Connections Across a Bioengineering Curriculum for Improved Student Learning

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WIP: Building a Learning Continuum: Forging Connections Across a Bioengineering Curriculum for Improved Student Learning

Abstract:
It is becoming increasingly clear that higher education must adapt to address the needs and learning styles of a new generation of students and to provide students with the mindset and skillset to create personal, economic, and societal value through a lifetime of meaningful work. Here, we describe our global strategy to create a learning continuum, so students retain fundamental principles and have context to strengthen their knowledge as they progress. We have utilized a three-phase process involving curriculum evaluation, faculty recruitment, and module development and implementation, while planning for a fourth phase, assessment. We have evaluated the undergraduate, Bioengineering curriculum in its entirety, identifying the areas where the three concepts from the Kern Entrepreneurial Engineering Network (KEEN) (www.engineeringunleashed.com) – curiosity, connections, creating value – could be implemented in a more comprehensive manner across the Bioengineering curriculum, and mapping topics across the 4-year curriculum, in integrated core classes, as well as through track/concentration-specific courses and technical electives. In addition, we initiated a "customer discovery" process, through which the key stakeholders, the Bioengineering students and faculty members, were surveyed to provide input about course topics for which achievement of student learning objectives was particularly challenging. The results of this survey presented us with the opportunity to target curriculum development for specific topics in multiple courses, across the curriculum with the goal of students gaining a more complete understanding of the material. Our efforts have seen not only an expansion in the number of Bioengineering faculty members engaged in continuous curriculum improvement, but increased faculty interaction during curriculum development, resulting in the potential for strengthening a number of content themes presented with increasing depth across multiple courses, from years one to four. Collectively, we are developing modules through which faculty can create content and contextual connections in earlier courses and give students the tools to think progressively about topics as they follow the curriculum. We have adopted a set of specific behaviors, previously cited by the faculty at Ohio Northern University, to provide faculty of examples of what to assess as curricular innovation is incorporated into their courses. Additionally, these extended student outcomes have been mapped to ABET outcomes. To date, project-based learning (PBL) activities have been implemented or are planned in most of the second and third year Bioengineering integrated core classes, as well as several of the track-specific courses and upper level elective courses. As we move forward, establishing an effective assessment mechanism to measure student outcomes will be a key component of our continuous curriculum improvement plan.

Introduction:

The concept of "Vertically Integrated Projects" and "Connected Curriculum" in university settings is not new. The concepts were originally conceived at Georgia Institute of Technology and the University College of London, respectively [1]. The practice of connecting projects across years, classes, and student cohorts, and further linking these projects to research interests of the faculty, is a model of education that could benefit members of a university system at all levels [2-3].

Programs such as the KEEN network [4] have provided both the resources necessary to rethink traditional curricula in engineering. Likewise, pedagogical training has reduced the activation energy required to engage in active learning strategies, specifically open-ended, project based learning [5]. This educational model has been cited as one method to increase student motivation, curiosity, and ultimately understanding of how engineering truly fits into the world [6-7]. As the interrelatedness of courses in Bioengineering and the relationship to "real-world" engineering are often cited as areas for curriculum improvement, we elected to integrate content across two skill-building courses through a multi-semester project in the sophomore year. We hypothesize that having students directly apply knowledge to a physical project across multiple courses, where the project grows in scope and complexity, will enforce the learning of key theoretical and technical skills [8]. In addition, application of concepts and use of a problem-solving approach will aid in the development of a mindset to solve problems that do not have a singular correct solution.

Program, Curriculum, and Assignment Structure:

Lehigh University offers a semi-traditional undergraduate Bioengineering (BIOE) program with no affiliation to a medical school. The BIOE program has three academic tracks: Biomechanics/Biomaterials, Biopharmaceutical Engineering, and Bioelectronics/Biophotonics. Students take common first-year courses (Physics, Chemistry, Biology, Calculus, Computer Programming); beginning in the second year, students take track-neutral BIOE courses (Fundamentals of Bioengineering, Engineering Physiology), additional science/math courses (Organic Chemistry, Genetics, Linear Methods) and courses related to the specific track. Courses often are augmented with laboratories; each BIOE student also has a defining track-specific laboratory experience. However, a missing element in the curriculum is the purposeful translation of knowledge across courses and semesters. Thus, as part of the university's interaction with the KEEN network, we created a concept map (Table 1) to identify areas where integrated projects would provide maximum impact in knowledge translation. To include student input, we examined exit interview data, course evaluations, and worked with a senior BIOE student to identify opportunities for integration. Through this process, we chose to focus on cardiovascular circulation and physiology. These generally familiar topics are presented in track neutral sophomore year courses, Fundamentals of Bioengineering (fall) and Engineering Physiology (spring). Associated concepts appear throughout the advanced BIOE curriculum, including Biological Fluid Mechanics, Regulatory Affairs, and Bioengineering Ethics. Future modules will connect content throughout these advanced classes.

Table 1. Abbreviated Concept Map to Identify Opportunities for Integrated Concepts. The yellow shading indicates areas where integrated projects could be implemented in the "cardiovascular" project theme.

Freshman			Sophomore			Junior		
Engineering Computations	BioE Seminar	BioE Seminar	Introduction to Bioengineering	Engineering Physiology	Engineering Mechanics	Fluid Mechanics	Ethics	Regulatory Affairs
Algorithm Design	MicroElectro-Mechanical Systems	Biopharmaceutical Engineering	Bioengineering Principles	Homeostasis	Forces, Moments	Conservation relations & Navier-Stokes	Rhetorical and Logical Reasoning	FDA Overview
Matlab Data Analysis	Biomaterials & Device Design	Biomaterials & Tissue Engineering	Physiological Communication	Action Potentials	Free Body Diagrams	Bernoulli's Equation, Integral momentum balance	Responsible Bioengineering Design & Development	Medical Product Disasters
Engineering system control	Stem Cells	Cell Signalling	Engineering Balances	Synapse, Central Nervous System	Particle Equilibrium	Applications: Hemodynamics	Humans and Animals in Research	Drug Development & Approval
Breadboard circuits: Interfacing w/ microcontrollers	Biomanufacturing	Drug Delivery	Circulation	Sensory Physiology (vision, hearing ,etc.)	Rigid Body Analysis	Diffusion and Flux	Human Augmentation (Steroids, Neural Enhancement, Genetic Modification	Drug Manufacture
Teamwork	Neural Engineering	Biomedical Microdevices	Biomaterials	Muscles and control (Skeletal)	Trusses and Frames	Steady and Unsteady Diffusion in 1D	Clinical Trial Design	Device Development & Approval
	Environmental Biotechnology	Bioengineering: A Physician's Perspective	Biomechanics	Muscles (Smooth/Cardiac)	Internal Forces	Electrolyte Transport 1D diffusion	Privacy vs New Technology	Device Manufacture, Safety & Surveillance
			Biomedical Devices	Cardiovascular Physiology (Biomechanics)		Applications: Heart valve design	Responsible Conduct of Research	

Project Descriptions:
The project descriptions below were developed by an undergraduate BIOE student who worked closely with KEEN faculty to ideate, develop, and identify assessment strategies.

Module 1:
Design and fabrication of an artificial heart valve. Level: sophomore (fall). Students are grouped to form a hypothetical medical device company, pitching to become the new provider of an artificial heart valve to cardiovascular surgeons at a hypothetical hospital. The hospital is concerned about design issues, as well as the legal and financial impacts of moving to a new heart valve provider, thus, has requested a proposal for the new valve design from each company, as well as a physical model. In this five-week project, student teams work to deliver a product design proposal, and a physical 3D printed heart valve prototype. Our aim is that this earlier exposure to these topics will positively impact achievement of all ABET student outcomes (1-7), and in particular will improve their ability to apply engineering design (ABET Student Outcome 2).

Module 2:
Artificial heart valve lab. Level: sophomore (spring). In this two week module, student teams use the 3D-printed heart valve prototypes from Module 1 to test the valve's functionality and efficiency, using team-determined experimental parameters representing normal and pathological physiological flow conditions, to determine whether their design meets the requirements. Through this project, students are introduced to experimental design, practice programming skills with Arduino and Matlab, become proficient with flow measurement techniques and equipment and data acquisition and analysis. Activities support ABET student outcomes 1, 2, 5, 6, and 7.

Results and Discussion:
At this time, two modules have been implemented in their respective courses, with Module 1 run twice (Fall 2018, Fall 2019) and the second trial of Module 2 in progress currently (Spring 2020). A third module (not reported here) is being implemented in the Fluid Mechanics class and will be the subject of future work. Thus, we will report here only on data collected for Module 1. Our hypothesis is that connected curriculum modules will help students build curiosity about our changing world, think critically about design ramifications and accepted solutions, integrate information from many sources to gain insight, connect content from multiple courses to solve a problem and become aware of the need to assess and manage risk. Additionally, it is expected that students will become more adept at identifying resources and become more effective problem solvers through collaborative open-ended projects, allowing them to teach and learn from peers. To tap into student motivation, project(s) are designed to allow for creative freedom, while being sufficiently self-contained to avoid overly complicating the grading structure for the instructors.

Module 1 has been implemented twice, however, we did not collect data in the initial offering. Anecdotal evidence (as qualitatively assessed by student questions, perceived excitement of students, and overall increase in dialogue between faculty and students) pointed towards a successful pilot of Module 1, thus prompting more formal assessment of the student mindset and motivation related to these projects. We have begun this process through a survey (which will be adapted for Module 2 and future modules) of the Fall 2019 cohort who worked on the design and fabrication of an artificial heart valve (Figure 1 shows a student work artifact). The purpose of the initial indirect assessment is to evaluate the impact that the module had on the key KEEN concepts - curiosity, connections and creating value - as one of our main goals is to increase student motivation and curiosity, enroute to improving student understanding of key engineering concepts and acquisition of technical skills.

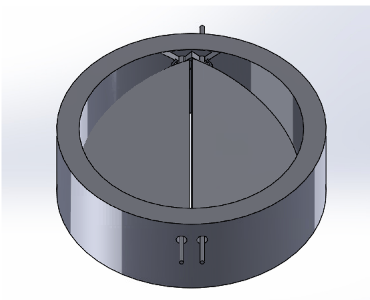

Figure 1. Student heart valve design.

After the second iteration of Module 1, students were asked about their initial interests in the project and their personal motivational style. Students were generally interested in the topic, and found some parts more interesting than others. Students were apt to focus on areas of interest, and were in general, more curious about the parts of the assignment to which they felt most connected.

Students were also asked about the process and their development throughout the learning and implementation of Module 1. As shown in Figure 2, students reported overcoming roadblocks, integrating new information, and learning from "just-in-time" opportunities (including Solidworks, cardiac physiology, etc.). In addition, students reported being satisfied with their experiences in applying new technical and engineering skills to Module 1.

A goal of Module 1 was to demonstrate to students how course content and technical skills relate to medical devices. Thus, students were asked a series of questions related to their overall understanding and state of curiosity after completing the project. From the data compiled in Figure 3, the project (Module 1) enhanced understanding of how fields are related and why biomedical technology evolves. Also, students were positive about the learning outcomes of the assignment related to traditional homework. Students also reported a greater understanding of "How" biomedical technology evolves, although the outcomes for this question were lower than the question related to "Why" biomedical technology evolves. This is an area that could be enhanced through additional just-in-time modules, and reinforced by discussions at the conclusion of subsequent connected modules, where design function and efficiency are tested experimentally (Module 2), or through simulations (future modules).

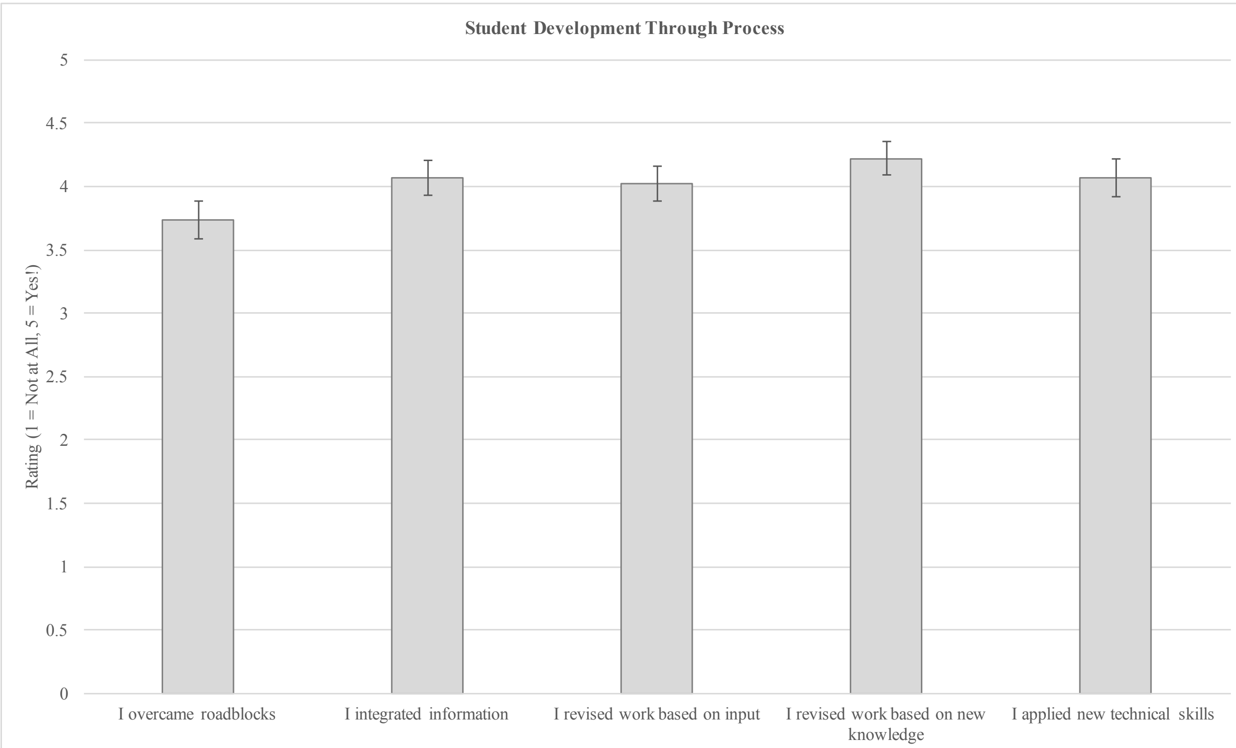

Figure 2. Students were asked about their educational development and processes during the project. Response count = 46.

Future Work:

Moving forward, additional themes will be targeted for vertically integrated projects and connected activities to provide a richer student learning experience. Longitudinal assessment of student motivation, curiosity, and ability to connect concepts will be included in the next phase of this integration process. In addition, academic work that is not directly related to the project will be the subject of future assessment to determine whether students are able to translate the skillsets, mindsets, and knowledge gained in these modules to other coursework, including Senior Capstone Design. To measure these outcomes, we have adopted a set of specific behaviors, KEEN expanded outcomes [9], originally developed by the faculty at Ohio Northern University, to guide our assessment strategy. These extended KEEN student outcomes to assess curiosity, connections, value creation, communication, collaboration and character have been mapped to ABET student outcomes, as well as to the National Academy of Engineering (NAE) Grand Challenges Scholar Program [10] to extend assessment applications. In future studies, we will present on these integration efforts, as well as the tools used in assessment and mapping of KEEN related outcomes.

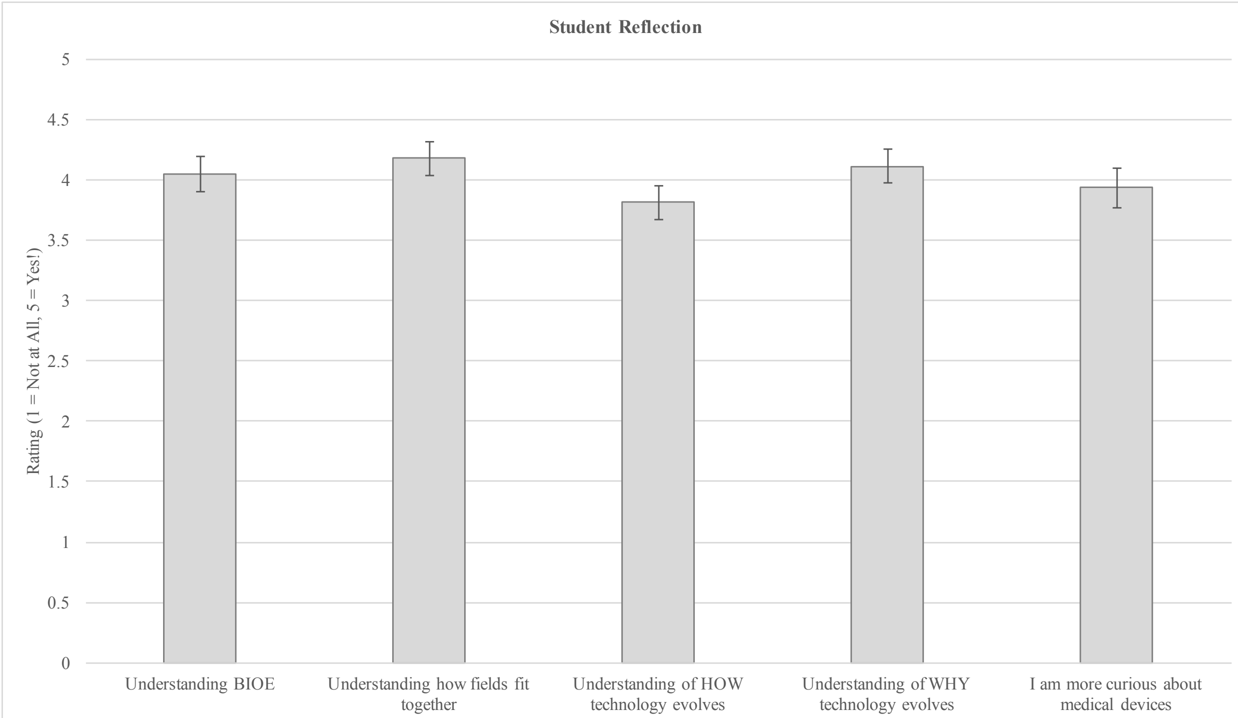

Figure 3. Students were asked to reflect on the efficacy of the assignment to achieve the educational goals. First four questions were prefaced with “Project aided in”.

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