Project-based Learning: Engaging Biomedical Engineering Sophomores Through a Collaborative Vein-finder Device Project with Nursing

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Abstract

A new design project in collaboration with the School of Nursing and Health Sciences has been employed as a way to incorporate additional project-based learning into a sophomore-level Biomedical Engineering Principles course. Project-based learning has been shown to improve student motivation and performance. It is often implemented in senior-level engineering courses; however, the main goal of this effort was to establish a project that would allow us to incorporate project-based learning earlier into our biomedical engineering curriculum. The challenge was selecting a project that had real-world applicability, integrated knowledge from several different engineering subjects, resulted in a functional device, and would be appropriate for sophomore-level biomedical engineering students. The vein finder device project met all of these requirements. Students worked in teams and applied various skills such as programming, circuit design, soldering, computer-aided design, and rapid prototyping to develop a functional, inexpensive vein finder device, which could be used by nursing students to learn how to locate suitable veins for intravenous insertion. Student feedback from course evaluations indicated that the design project was effective in increasing student motivation and learning. The study was concluded with preparation of a course assessment report.

Introduction

Project-based learning (PBL) has become an integral component of undergraduate engineering education[1-5]. It is based on the constructivist theory of learning, which focuses on active, self-directed learning[6]. In project-based learning, students often work in collaborative teams to develop a solution to a technical design problem that is relevant to their field of study. Project-based learning has been shown to improve student motivation, problem-solving skills, communication skills, teamwork skills, creativity, critical thinking, and student retention[5, 7]. Furthermore, a review of 225 studies that compared student performance in undergraduate STEM courses that utilized traditional learning approaches versus active learning approaches, such as project-based learning, found that active learning increased examination performance and the likelihood of students to pass a course[8].

It has been suggested that project-based learning is most effective when implemented throughout an undergraduate engineering curriculum[9]. In a program where project-based courses were offered at the beginning (First-Year Engineering Projects) and at the end (Senior Capstone Design) of an engineering curriculum, Kotys-Schwartz et al. found a decline in student confidence in professional and technical skills during their sophomore and junior years when they were not engaged in PBL[7]. In our biomedical engineering program, students are exposed to project-based learning in two senior-level courses: Integrated Engineering Design, which is a senior capstone course where students work on a design problem in interdisciplinary teams, and Design & Manufacturing of BME Devices and Systems, where students work in teams on the design of biomedical devices and systems. Providing students with more opportunities to engage in project-based learning earlier in the curriculum would allow students to start developing their professional, technical, and problem-solving skills at an earlier stage and to start putting their knowledge into practice.

One of the challenges of incorporating project-based learning early in an engineering curriculum is finding an appropriate project. The project must integrate knowledge, have real-world applicability, and be appropriate for the students' level of knowledge. Furthermore, proper scaffolding and guidance must be provided to support student learning. Previous studies have shown that student motivation and confidence can be negatively impacted without proper guidance in self-directed learning activities[10]. Considering these requirements, we have established a new vein finder device project for a sophomore-level engineering course. The project incorporates a broad range of skills and knowledge and addresses several ABET student outcomes, including the ability to design a system, component, or process to meet desired needs; the ability to communicate effectively; and the ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. The project is described in detail in the following sections.

Methods

Course Structure

The vein finder device project was implemented in a sophomore-level Biomedical Engineering Principles course. This course is required for biomedical engineering students in our General Engineering B.S. program. The course is designed to provide an overview of the biomedical engineering discipline and the major subdivisions within biomedical engineering. It also serves to introduce students to quantitative tools utilized throughout the biomedical engineering curriculum, such as MATLAB programming. The course is offered once per academic year, and on average, 25 students enroll in the course. The vein finder device project was incorporated into the course instruction for the first time in the Spring of 2017.

Project Conceptualization

The vein finder device project was established through a collaborative effort between our nursing and biomedical engineering programs. Vein finder devices use near-infrared (NIR) light to illuminate veins, which may not be visible to the naked eye[11-14]. These devices serve as an invaluable tool to locate a suitable vein for peripheral intravenous catheter (PIVC) insertion, which can be challenging in some patients due to age, skin color, obesity, or existing medical conditions[15]. Near-infrared vein finding technology can be especially valuable to nursing students who are learning how to select appropriate veins for IV insertion and are expected to perform PIVC insertion on real patients once becoming registered nurses[16]. Many of the commercially available vein finder devices are expensive, which restricts their use in nursing education[17]. As a result, the efficacy of developing a low-cost vein finder device for clinical simulation training of nursing students was explored through a collaboration between engineering and nursing.

A prototype of the vein finder device was initially developed through our senior capstone design course, Integrated Engineering Design, in the Spring of 2016. The Integrated Engineering Design team consisted of Biomedical Engineering, Industrial Engineering, and Manufacturing Engineering students. The team was advised by both engineering faculty and a Nursing and Health

Sciences faculty member. The team designed a low-cost device that used near-infrared (NIR) spectroscopy to visulaze veins[18]. Using visible light in the red to orange spectrum was also considered, but not chosen due to the quality of the results. The final design consisted of a Raspberry Pi controller, a bright high-contrast display, an NIR light source, an infrared camera along with a touch screen input device, all powered by a USB battery pack. The device was assembled in a 3D-printed housing (shown in Figures 1 & 2) with total parts costs of $168.84.

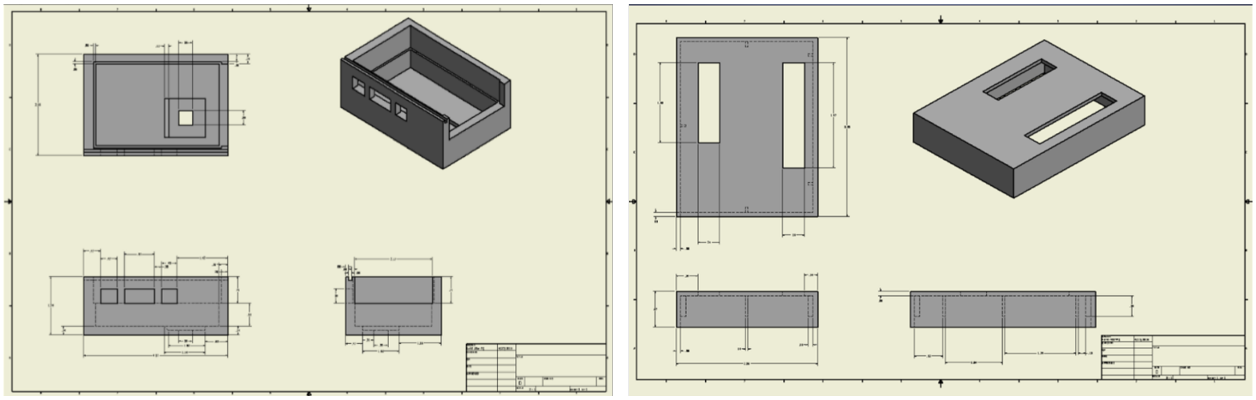


Figure 1. Housing Components: PCB Holder and Raspberry Pi Case Components[18].

Figure 2. Completed Integrated Engineering Design Prototype[18].

Project Implementation

The initial prototype developed through the senior capstone course served as a basis for the design project that was implemented in our sophomore-level Biomedical Engineering Principles course. Students were provided with the equipment and supplies that are listed in Figure 3. By requiring students to use the same components in their design, it provided some structure to the project, ensuring that it could be completed within the course of the semester and with the available materials. The total cost to implement the project in the course was around $200 (not including the cost of the soldering equipment and 3-D printing supplies). The project required students to engage in the engineering design process, from research and design conceptualization to prototype building, testing, and redesign.

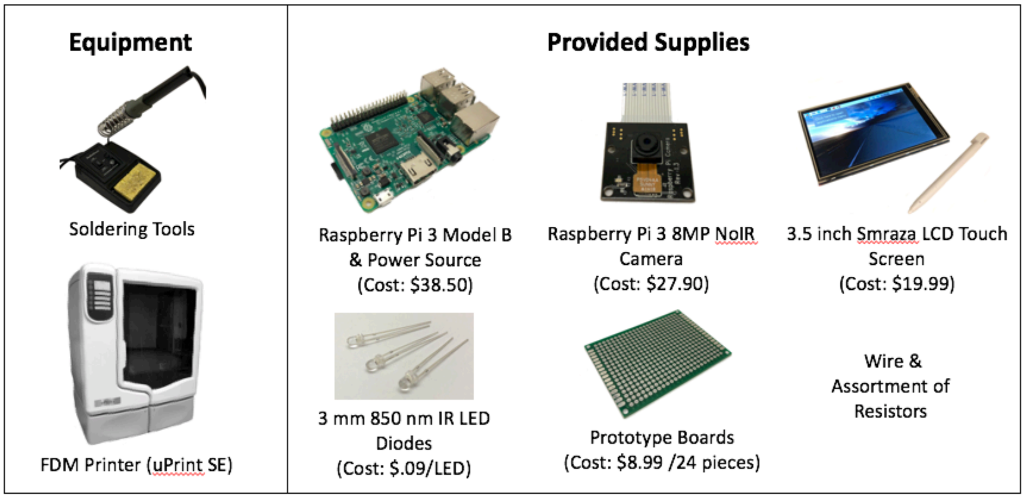


Figure 3. The equipment and supplies provided to students for the completion of the project are shown.

The main components of the vein finder device included a Raspberry Pi 3 Model B, 8 MP NoIR Camera, LCD Touch Screen, IR LED Diodes, and circuit board. Before beginning the project, students were shown how to assemble and operate the Raspberry Pi, NoIR Camera, and touch screen. The Raspberry Pi 3 Model B is a small single-board computer that can fit into the palm of a hand, so it is ideal for use in a hand-held device. It also has WiFi and Bluetooth capabilities. The NoIR Camera is a fixed focus, infrared camera that connects directly to the Raspberry Pi through a short ribbon cable. The camera is small, 25 mm x 23 mm x 9 mm in size, and contains an 8 megapixel image sensor. The camera is controlled through an RPI Cam Web Interface software (elinux.org/RPi-Cam-Web-Interface), which was installed on the Raspberry Pi. Using this web interface, live images from the camera can be displayed on the touch screen or be displayed remotely on any web browser. The camera settings (brightness, contrast, etc.) can also be adjusted through the web interface. The IR LEDs serve to illuminate the skin with NIR radiation. The LEDs can be powered through the Raspberry Pi or an external power supply. The optical absorbance of NIR radiation is much greater for deoxygenated blood compared to human skin and muscle; therefore, images captured with an IR camera will show significant contrast between subcutaneous veins and the surrounding muscle and skin, allowing veins to be visualized (as shown in Figure 4)[14, 15]. Optical filters and diffusers can also be integrated into the device to block wavelengths outside of the near-infrared range and to spread the light evenly across the skin. Optical filters are usually costly, but low-cost options, such as the plastic sheet inside floppy disks or negative films, can serve as an inexpensive IR filter, blocking wavelengths less than 600 nm. Inexpensive diffusers, such as tissue paper and frosted window films, can also serve to diffuse the light from the LEDs.

Students were provided with all of the necessary components to create a functional vein finder device; however, they were not provided with specific instructions on how to build a functional prototype. The functionality of the prototype was dependent on several factors. Visualization of veins requires proper illumination of the skin with the NIR LEDs. If the NIR radiation is not evenly distributed across the skin, the image quality will be poor. If an insufficient or excessive number of LEDs are used, the images may be underexposed or overexposed. Students must also carefully design the LED circuit based on the power requirements of the LEDs. The case design is another important component of the vein finder device. The case must properly house all of the device components and should allow for easy handling and operation of the device. This requires an ergonomic case design and consideration of how the device will be utilized. Given these requirements, the students were tasked to design and build a functional vein finder device prototype that met the following specifications:

1. Utilized the provided equipment and supplies.
2. Housed device components within a 3-D printed ergonomic case that is portable.
3. Incorporated a modular design that allowed the Raspberry Pi, NoIR camera, and touch screen to be easily removed from the case. This requirement was necessary so that a single Raspberry Pi, NoIR camera, and touch screen could be used for all project teams, reducing the cost to implement the project in the course.
4. Incorporated an LED circuit where the number and placement of LEDs was optimized to evenly illuminate the skin.
5. (Optional) Integrated inexpensive optical filters and diffusers to improve image quality.

In addition to these design requirements, students were also expected to create a design concept for a graphical user interface (GUI), which would allow a user to interact with the device, such as to control the camera settings and to capture images. The GUI was designed in MATLAB. Since creation of a graphical user interface on the Raspberry Pi requires knowledge of Python programming, which the students had not learned, the students were not required to implement their GUI design on their prototype. They were only required to create a representative GUI design concept.

Table 1. Overview of the tasks and skills utilized in the vein finder device project.

Project Tasks	**Skills Utilized**
Background Research	Literature survey; Patent search
Case Design	Computer-aided design (CAD software: Inventor, Solidworks); Rapid prototyping
LED Circuit Design	Design of circuits (Multisim software); Soldering
GUI Design	MATLAB programming
Presentation/Final Report	Oral and written communication skills
Overall Effort	Teamwork skills; Problem-solving skills; Critical thinking

Team Formation

The design project was completed in teams consisting of 5 – 6 students. The project required students to be proficient in computer-aided design, circuit design, soldering, development of GUIs in MATLAB, and rapid prototyping (Table 1). Since the students had varying levels of knowledge and technical skills, teams were carefully formed based on the results of a team formation survey. The survey asked students to rate their perceived skill level on various engineering tasks and to propose where they felt they could make the greatest contribution to the team. Based on these survey results, teams were formed such that each team had at least one member with a high level of proficiency on each technical skill that was required for the project.

Project Timeline
The project was implemented over a five-week period towards the end of the course. Specific project milestones and deliverables were defined as shown below:

- **Week 1:** Conduct background research (review of existing vein finder device technologies, determine FDA classification, etc.).
- **Week 2**: Design conceptualization.
- **Week 3**: Create circuit design using Multisim software. Create case design using CAD software. Designs were submitted to the instructor and feedback was given.
- **Week 4**: Build prototype. Create GUI design using MATLAB software.
- **Week 5:** Demo of final prototype and submission of final report.

Students were given some class time to work on their projects, but most of the work was conducted outside of class. At the conclusion of the projects, each project team shared their final prototype designs with the class and to a nursing faculty member. The prototypes were tested and evaluated for ease of use and vein visualization capability. Each project team was also required to submit a report that described their design concept and prototype.

Student and Team Evaluation
The team projects were assessed using a detailed rubric. Individual student contributions to the team effort were also assessed through a confidential Peer Evaluation Form that was completed at the conclusion of the project. The form asked each student to describe the specific contributions of each team member and to distribute $1000 among team members based on the level of each member's contribution. These scores were averaged for each student, and students received either all or some fraction of the total points earned by their team, proportional to their individual level of contribution to the team effort.

Project Assessment
The effectiveness of the project in enhancing student motivation and improving student learning outcomes was assessed through post-course evaluations and through surveys administered at the end of the semester. Two of the statements in the course evaluation pertained specifically to projects:

- Exams, assignments, or projects accurately reflected course content.
- Assignments or projects helped me learn the material.

The mean course evaluation score from the Spring of 2016 and from the Spring of 2017 were compared for these two statements to determine if implementation of the vein finder device project had an effect on perceived student learning. A two-sided t-test was used to compare the mean scores from the two years. Student feedback from the surveys was also valuable in evaluating student learning and potential areas of improvement. A few of the survey questions are listed below:

- What did you learn from doing this project?
- What did you enjoy the most about the project? What did you find to be the most challenging?
- Do you have any suggestions on how to improve this project in the future?

Results and Discussion

Student Learning Experiences

The vein finder device design project was successfully implemented in the Biomedical Engineering Principles course in the Spring of 2017. There was a total of four project teams in the class. For many of the students in the course, this was the first time that they had designed and built a prototype. Figure 4 shows an example of a vein finder device prototype that was created by one of the project teams. A representative image produced by the vein finder device is also shown, showing the contrast of the veins. All of the project groups had unique case designs and graphical user interface designs. The circuit designs were similar, with all groups utilizing a parallel circuit for the LEDs; however, the placement and number of LEDs differed between the groups. Only one group incorporated an optical diffuser (tissue paper) to diffuse the NIR radiation, which led to improvements in image quality.

The students learned to design and build a device at the systems level, integrating several components to produce a functional prototype. None of the groups were able to fully assemble all of the device components into their cases due to design elements that were overlooked, such as not leaving enough room for the wire connections between device components. The students did not have enough time to go through more than one design iteration. If more time had been given to complete the projects, the project teams would have been able to redesign their prototypes, correcting for some of the errors in their designs.

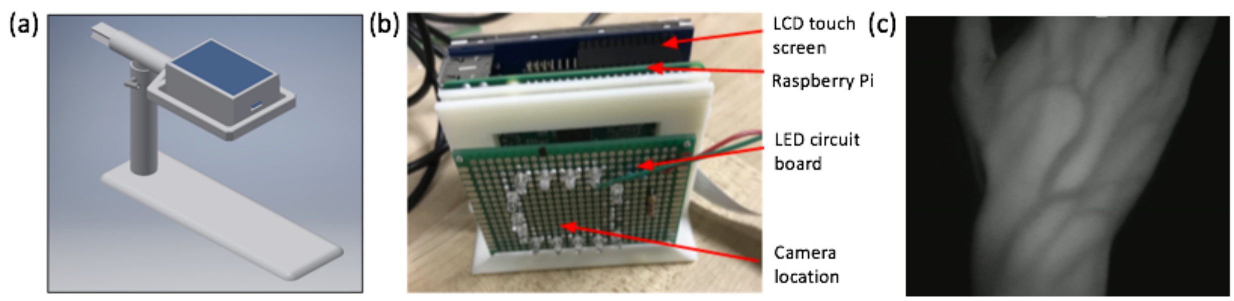
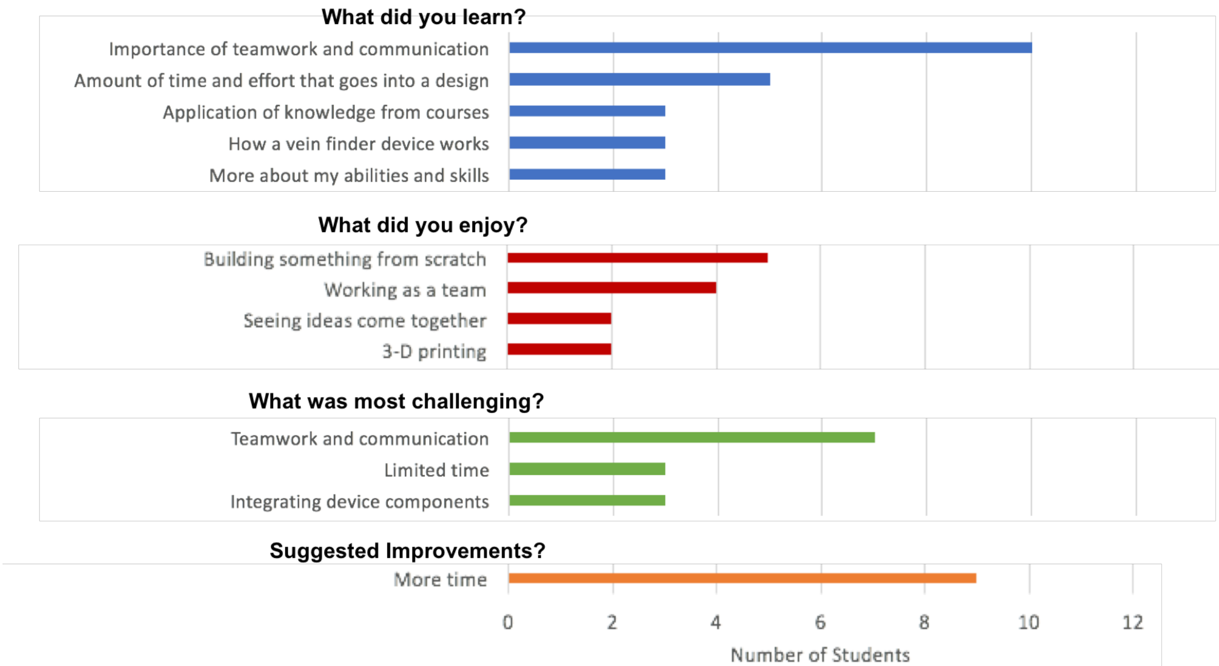


Figure 4. An example of a vein finder device design concept is shown. (a) A custom rig was designed to allow nurses to operate the device hands-free and to allow for proper positioning of the device above the arm[19]. (b) The internal components of the device are shown[19]. (c) A representative image produced by the vein finder device is shown.

The results from the student survey (Table 2) provide some insight into the student learning experiences. Teamwork and communication was a common theme in the answers to the survey questions. Many of the students stressed the importance of teamwork and communication between team members to achieve the project goals. Most of the groups had issues with one or more of the team members not contributing sufficiently to the team effort, which slowed their progress. Many of the students were surprised by how much time and effort went into the development of a functional prototype, and about half of the class suggested that more time would have been helpful to achieve their desired goals. Overall, the students enjoyed the open-endedness of the project, seeing their ideas come together to produce a functional device, and found the project to be a worthwhile learning experience. The real-world applicability really hit home for the students when they received feedback on their projects from the nursing faculty and saw the potential of their prototype to be used in clinical practice and in nursing education. Five of the students in the course expressed an interest in continuing to work on their designs after the conclusion of the course, and two students from the course have continued to work on their designs over the course of this past year. Below are a few comments from the student surveys:

- "Final vein finder project was a great experience in design & collaboration"
- "The project was a great idea! It gave us a little taste of what it would be like to start from ground zero on designing a new device"
- "I really liked the final project and how it incorporated the aspects of other engineering classes into it as well"

Table 2. Student survey results. The answers that appeared most often to the open-ended survey questions are shown below.



Course Evaluation

To quantitatively assess the effectiveness of the vein finder device project on student learning, mean scores from post-course evaluations administered in the Spring of 2016 and in the Spring of 2017 for the Biomedical Engineering Principles course were compared. A short-term design project was implemented in the course in the Spring of 2016. Students were tasked to design a graphical user interface for a medical device of their choice. This project was conducted in teams over a 2-week period. The graphical user interface was developed in MATLAB; however, students were not required to take their designs any further nor create a functional device prototype. The vein finder device project was implemented in 2017 as described in the previous sections, where students engaged in all aspects of the engineering design process from design conceptualization to prototype development and testing.

The mean scores from the course evaluations are shown in Table 3. The scores are compared for two assessment outcomes that pertain to course projects. As shown in the table, the mean scores increased for both of these outcomes; however, the difference in the scores was not found to be significantly different using a two-sided t-test. Since these outcomes measure the effect of all exams, assignments, and projects assigned in the course, it is difficult to draw conclusions concerning the effect of the vein finder device project alone. However, in general, the mean scores for the course were significantly higher than the departmental average in 2017, which was 4.37 for both outcomes, and the university-wide average in 2017, which was 4.38 for the first outcome and 4.27 for the second outcome. This suggests that students found the projects and assignments in the Biomedical Engineering Principles course to be appropriate and effective. Considering that the vein finder device project was a significant component of the course, it most likely had an effect on the course evaluation scores.

Table 3. Course evaluation results, comparing scores before (2016) and after (2017) implementation of the vein finder device project.

Course Evaluation Statement	Mean ± SD (Max value: 5) Spring 2016 (N = 28)	Spring 2017 (N = 20)	% Increase	P-Value
Exams, assignments, and projects accurately reflected the course content.	4.68 ± 0.61	4.90 ± 0.31	4.73%	0.1440
Assignments or projects helped me learn the material.	4.75 ± 0.52	4.90 ± 0.31	3.16%	0.2540

Suggested Changes

There are several changes that would be recommended for future implementation of the vein finder device project. Two reoccurring issues in all of the project groups were issues with teamwork and communication and the lack of time to complete the project. To address the first issue, it may be helpful to incorporate team building activities and to assign specific roles to each team member. For example, a team leader could help manage the team effort and work with team members to resolve communication issues. Several of the students suggested choosing their own group members; however, this is not recommended. This most likely would have resulted in some teams not having the required knowledge-base to complete the project. However, smaller team sizes (3 – 4 students per group) would have been beneficial to ensure that each student had a significant role in the device development process.

Five weeks was not enough time for the students to complete the project. Although the project milestones helped keep the students on track, more time was needed to build the prototypes and address issues with their initial design concepts. It is recommended that at least eight weeks are given to the students to work through the engineering design process. Requiring the students to submit weekly progress reports may also be helpful to keep the project groups on task and to provide feedback to the teams.

Students would have benefited from a more in-depth analysis of their design concepts. Although each project group came up with a practical design concept for their vein finder device, it was not clear how much time was spent conceptualizing and assessing their designs. Incorporating design thinking activities early in the design process would encourage students to explore a wider range of design concepts, consider the social implications of their design, and assess the technical challenges. Feedback from nursing faculty and students early in the engineering design process would also be valuable. Students were provided with feedback from nursing faculty at the conclusion of their projects; however, receiving feedback earlier in the design process would help the engineering students better understand the potential implications of their design.

Applicability to a Broader Audience
Although the vein finder device project was implemented in a sophomore-level biomedical engineering course, it has much broader applicability. It would be a suitable project for a number of engineering disciplines and subdisciplines, including mechanical engineering, manufacturing engineering, and mechatronics. To implement this project, students must have knowledge in computer-aided design and circuits. Prior knowledge of rapid prototyping is not required since students can be provided with the necessary instruction to operate a 3-D printer in a single class. Although it is helpful to have prior knowledge in anatomy and physiology, it is not necessary to complete the project. The programming component of the project (i.e., design of a graphical user interface) can also be removed from the project requirements since it is not integral to the functionality of the device. Alternatively, the project could be modified to incorporate a more significant programming component where students develop codes for the Raspberry Pi to improve the image quality (e.g., applying image enhancement algorithms) or to improve the user interface. An Arduino microcontroller could also be used in place of the Raspberry Pi and still achieve the desired learning outcomes.

Providing sufficient guidance to students was imperative for successful implementation of the design project in the sophomore-level course. Developing the initial prototype through the senior capstone design course allowed the project to be structured around that initial design concept. While a completely open-ended project is appropriate for senior-level engineering students, a guided inquiry-based approach is better suited for sophomore-level students, especially for students who do not have prior experience in device design. Even with this structured approach, a few students expressed that they wanted more explicit instructions and steps. Finding the right balance between open inquiry and guided inquiry can be a challenge. Scaffolding a design project around a prototype initially developed in a senior design course is a useful approach that can be applied to incorporate project-based learning in a wide range of courses.

Conclusions and Future Work

In an effort to incorporate more project-based learning into our biomedical engineering curriculum, the vein finder device project was established and successfully incorporated into our sophomore-level Biomedical Engineering Principles course. Overall, student feedback was positive, and students found the project to be a worthwhile learning experience. Given the success of the project, the project will be implemented again in the Biomedical Engineering Principles course in the Spring of 2018. Pre- and post-course surveys will be administered to obtain additional data on the impact of the project on student learning. Several changes will be made to the implementation of the project. The project will be started earlier in the semester to give students more time to develop their prototype designs and to allow them to go through several design iterations. Team building and design thinking activities will also be incorporated into the course instruction. The impact of these changes will be assessed through surveys and comparison of course outcomes before and after implementation of these changes. Additional projects from the senior capstone design course will also be explored for their potential use as future design projects.

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