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A Learning Module Involving Point-of-Care Testing and Team-Based Design Implemented in an Upper Level Biomedical Engineering Elective Course

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Abstract

A learning module was developed and implemented in an upper level biomedical engineering course to provide students experience with practical aspects of point-of-care testing (POCT) through a team-based design project. The module, which included lectures and project work, involved the development of a container that could protect a POCT device from extreme temperatures when used outside of a hospital setting (e.g., by medical responders during disaster relief). In order to assess the impact of the new learning module on student interests, attitudes, and skills regarding the POCT field, a set of pre- and post-course surveys was developed and administered. The results from the surveys showed increased student-reported knowledge, confidence, and level of interest in the area of POCT following the completion of the module. Additional qualitative data obtained from free-response questions on the surveys also indicated that the module impacted overall student development in the course. The results of this work could be used as a model for faculty wishing to expose their students to emerging areas of biomedical engineering through project-based learning.

Introduction

Recently, there has been significant interest within the medical community for the development of devices to enable point-of-care testing (POCT).[1,2] These technologies allow clinical measurements to be made wherever the patient is located, such as inside ambulances and homes as well as in the field during disaster relief.[2,3] Examples of POCT devices include blood glucose monitors, immunochemical fecal occult blood tests, urine dipsticks, and many others.[1] These POCT systems offer a number of benefits over traditional centralized testing methods, including providing rapid results in remote and low-resource areas when swift treatment decisions are required for effective therapy.

Due to this growing interest, there is a need for biomedical engineers (BMEs) that have experience with POCT, including the inherent challenges involved with their development and implementation. For example, one of the major applications of POCT devices involves their use outside of a traditional hospital setting, which causes the device and associated peripherals to be exposed to uncontrolled environmental conditions.[4] Unfortunately, many POCT devices and reagents have storage and operating specifications that require them to be maintained at or near room temperature.[1] Thus, existing POCT devices may need to be retrofitted with heating/cooling systems to enable their use in a wide range of environmental conditions, or completely redesigned to increase their robustness.

As an emerging area within BME, there are limited opportunities for students to learn about POCT along with its associated benefits and challenges. In this work, a learning module was developed and implemented in an upper level biomedical engineering course to provide students experience with practical aspects of POCT through a team-based design project.

Course Background

The learning module was integrated within BME 434 – Biosensors, BioMEMS, and Nanomedicine, which introduces students to the use of micro- and nanotechnologies in biomedical and life sciences. The typical topics covered in this elective course, which is available to 3rd and 4th year engineering students at Western New England University, include microfabrication, sensors, actuators, drug delivery, clinical laboratory medicine, lab on a chip, genomics/proteomics, emerging bioMEMS technologies (including POCT), and nanomedicine. In the previous course offering, a lecture was provided that introduced the topic of POCT to students, including the use of miniaturized components to enable the creation of portable instruments. In the revised course format, a team-based design project was also implemented to provide students with practical training regarding the use of POCT devices in harsh environmental conditions. The project, which was introduced on the first day of the class and subsequently worked on throughout the semester, involved the development of a container that could protect a POCT device from extreme temperatures when used outside of a hospital setting (e.g., by medical responders during disaster relief).

As mentioned above, the use of POCT devices under harsh environmental conditions present during recent disaster relief scenarios (e.g., Hurricane Katrina) has illustrated several challenges for engineers and medical responders.[3] For example, high environmental temperatures can lead to equipment failures as well as the degradation of reagents and samples collected from patients. In this project, the students were challenged to develop a system for keeping liquid samples and reagents cool when exposed to elevated temperatures during transport and use in a harsh POCT environment. Another target for the system was to monitor the acceleration experienced by the samples, which is an additional factor that can lead to damage and degradation (e.g., broken vial containing samples or reagents).

Once the project was initiated, the class was divided into teams of 3-4 students, and each team was assigned one of the project subsystems, as shown in Table 1. Prior to team formation, the students were asked to rank the subsystems according to their preference, and teams were established by the course instructor to match student interests (the majority of students received their first choice, and all students received at least their second choice).

Table 1 – Project Subsystems

Group	Subsystem
1	Thermostat
2	Peltier coolers
3	Accelerometers
4	Power supply

Throughout the semester, the groups worked on their subsystems by completing tasks related to background research, design, ordering parts, assembly, and testing (Table 2). For the Peltier cooler, accelerometer, and power supply teams, the majority of their work involved specifying performance parameters, investigating commercially available components, and writing/implementing test protocols to verify performance. The thermostat group developed their own device using a thermistor, analog circuit, and LabVIEW interface. While each group worked independently, significant inter-group communication was required since each subsystem was dependent upon the others to create the final integrated device. To facilitate this communication, periodic design reviews were held so that groups could communicate information regarding specifications that were common to multiple groups. The only design constraint given to all teams involved the target POCT device to be protected from a harsh environment (portable glucose meter), which had a specified temperature range of 15-40°C. This also necessitated a physical constraint of the container housing the system to be approximately the size of a shoebox.

Table 2 – Project Timeline

Week	Topic
1-2	Research
3-4	Design
5-6	Ordering parts, experimental design
7-12	Assembly and testing
13-15	Report and presentations

After this initial set of constraints was provided, the teams then developed their own specifications according to the component needs of their subsystem. For example, the Peltier cooler group developed specifications for power consumption, heat transfer, and operating time required on the basis of regional weather profiles describing conditions of various locations across the country. The accelerometer group investigated the range of acceleration values likely to be experienced by the system, as well as power consumption and number of axes for measurement. The thermostat team looked at response time and data acquisition, while the power supply group continuously evaluated portable battery options to meet the power specifications provided by the other three groups. All groups were given a target budget of $50 per team; the students were informed that this budget was flexible so long as they could argue effectively in a design review that the added cost was necessary to achieve a particular specification. In total, all or significant portions of twelve 50-minute class periods were devoted to the project, which represents approximately a quarter of the 45 available lecture meetings during the semester.

Student performance on the project was assessed along several dimensions. Attendance was monitored and recorded for each class session involving the design project. The students also produced a final report documenting their design and results. Finally, an in-class presentation was developed and implemented to communicate the progress made in each project subsystem. The project was worth 25% of the total course grade; this number was selected to match the relative percentage of the course devoted to the project.

Survey Methodology

In order to assess the impact of the new learning module on the students, a set of pre- and post-course surveys was developed and administered (see Appendix). Prior to their use, the surveys were approved by the Institutional Review Board (IRB) at Western New England University. The primary goal of the surveys was to measure student interest and attitudes toward the POCT field. The surveys consisted of 5-choice Likert questions that were designed to obtain student feedback on their current knowledge of POCT, confidence in their ability to develop POCT devices, level of interest in pursuing further studies/training/careers in the area of POCT, and the suitability of POCT devices for solving problems in medicine and biology. Students also completed a Likert-scale skills inventory that prompted them to rate their current level of knowledge and confidence in their ability to develop and/or utilize the various components/subsystems of the design project, including thermostats, Peltier coolers, accelerometers, and powers supplies. Similar to the attitudes and interests questions, the skills inventory was also completed pre- and post-course. Both sets of Likert-scale questions were analyzed using one-tailed, paired t-tests with a significance level of 0.05.

In addition to the analysis of the Likert-scale questions directly related to the module, qualitative information was obtained through the use of free-response questions on the post-course surveys. These questions prompted students to comment about their overall development in the course, rather than focusing on the module directly. The intent of these questions was to determine if the students would highlight the project as an important component of their learning in the course, even if unprompted. As a final measure, student performance in the course was compared to the previous course offering to determine if student learning was impacted by the module. A question on the final exam that involved POCT and was common to both course offerings was studied, as was overall student performance in the course.

The student population in the present course offering (Fall 2012) consisted of 14 BME students, including 8 third-year and 6 fourth-year students. There were 7 males and 7 females. 11 of the students were enrolled in the course as part of a sequence of four related elective courses they were taking toward their degree requirements. The remaining 3 students were taking the course as an elective outside of their four-course sequence. Of the 14 students in the course, 12 completed both the pre- and post-course surveys (N = 12).

Results

The results from the analysis of the Likert-scale surveys investigating student attitudes and interests toward POCT are shown in Figure 1. Compared to the pre-course responses, student responses on the post-course surveys showed increased knowledge regarding POCT ($p=4.1x10^{-5}$), confidence in their ability to develop POCT devices ($p=3.2x10^{-6}$), level of interest in pursuing further studies/training in the area of POCT (p=0.0027), likelihood in pursuing a career in the area of POCT (p=0.0064), and suitability of POCT devices for solving problems in medicine and biology (p=0.014).

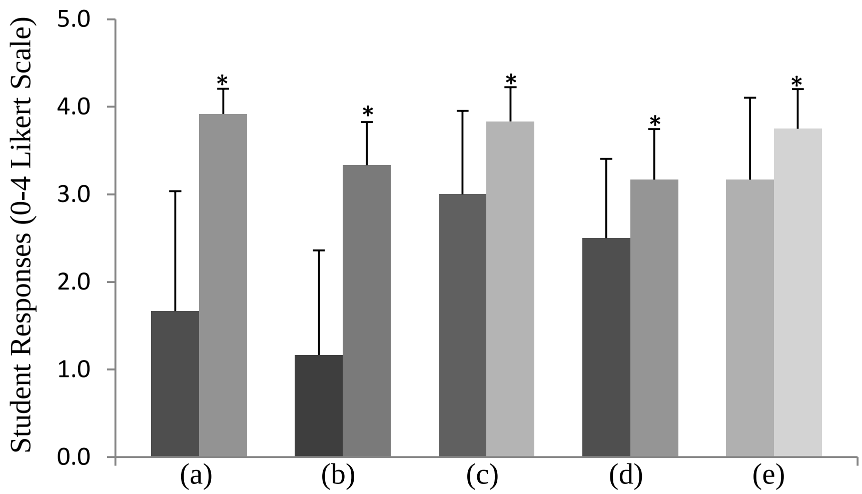


Figure 1. Results from student surveys (Likert scale 0-4) comparing responses on pre-course (left) and post-course (right) surveys regarding POCT: (a) student level of knowledge; (b) student confidence in their ability to develop devices; (c) student level of interest in pursuing further studies/training; (d) student likelihood in pursuing a career in this area; (e) student rating of the suitability of POCT devices for solving problems in medicine and biology. * indicates statistical significance.

The results from analysis of the Likert-scale skills inventories are displayed in Figures 2 and 3. As shown in Figure 2, the post-course inventories showed increased student-reported knowledge of the project components such as thermostats (p=0.0016), Peltier coolers ($p=1.8x10^{-8}$), and accelerometers ($p=2.6x10^{-6}$). Similarly, students reported increased confidence in their ability to develop and/or utilize thermostats ($p=2.0x10^{-4}$), Peltier coolers ($p=3.2x10^{-7}$), and accelerometers ($p=3.0x10^{-5}$) in their designs at the end of the course (Figure 3). Small, but statistically insignificant, increases were measured for student knowledge (p=0.11) and confidence (p=0.054) in using power supplies on the post-course skills inventories.

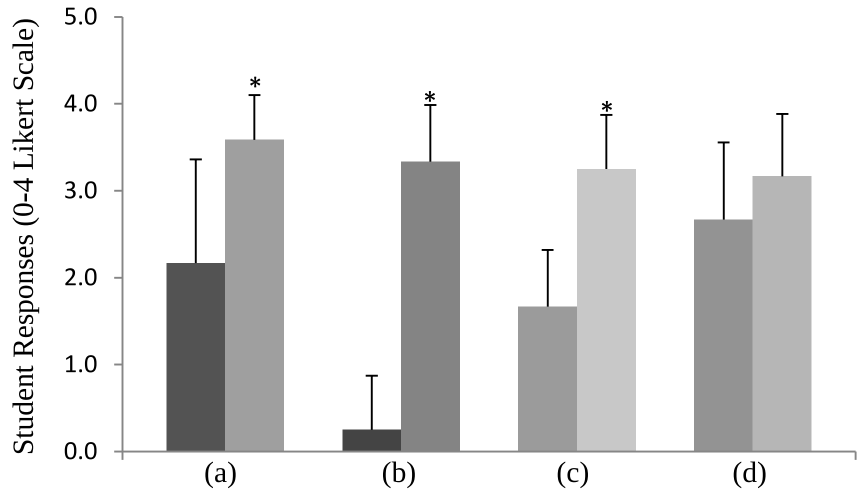


Figure 2. Results from skills inventories (Likert scale 0-4) comparing student responses on pre-course (left) and post-course (right) surveys regarding *level of knowledge* of: (a) thermostats, (b) Peltier coolers, (c) accelerometers, and (d) power supplies. * indicates statistical significance.

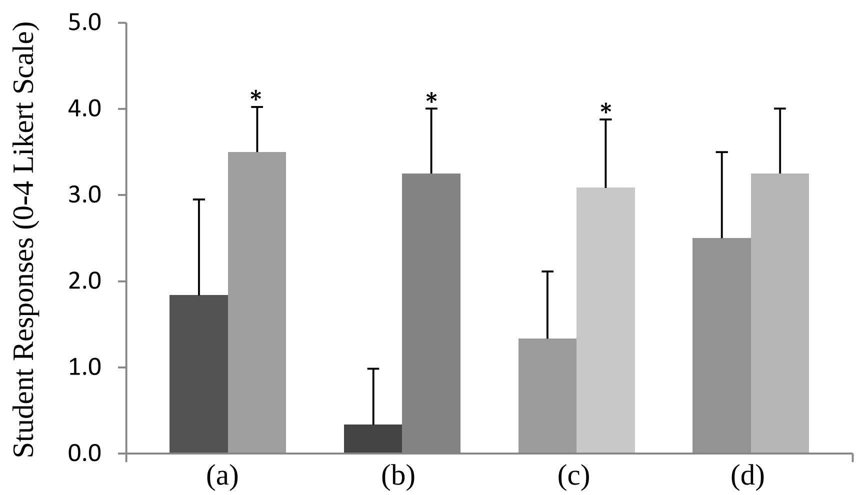


Figure 3. Results from skills inventories (Likert scale 0-4) comparing student responses on pre-course (left) and post-course (right) surveys regarding *level of confidence* in ability to develop and/or utilize: (a) thermostats, (b) Peltier coolers, (c) accelerometers, and (d) power supplies in their designs. * indicates statistical significance.

The results from the qualitative free-response questions on the post-course surveys, including the question prompts and student responses, are shown below.

Please comment on your overall development in this course (e.g., what you have learned, skills you have developed, etc.) since the beginning of the semester:

- I feel like I have learned more practical and useful skills and knowledge in this course than any other I have taken so far. I now know how to design and fabricate useful and needed devices.
- In this course, I hope [sic] learned about various biomems devices and sensors how they are applied to clinically relevant diseases and their advantages over traditional medical devices. The project was a great lesson in troubleshooting as this is what a good majority of time was spent doing.
- The details of fabricating and testing procedures that can be done selecting the right components for a particular sensor.
- I have gained much knowledge about point of care devices and testing and the use of biosensors and biomems. Now, I am considering a career in micro and nano biotechnology.
- Technical writing skills, experimental setup and testing, fabrication techniques, structure of nano and micro scale devices, etc.
- I learned more about silicon than I ever thought I would know.
- I have learned about different fabrication methods that are used to produce micro/nano devices [sic] I've learned how micro/nano devices are developed from larger technology.
- I have learned a lot about micro and nano technologies and micro fabrication methods.
- One of my favorite classes I have taken thus far. I am happy with the amount of information I learned. I am excited to learn more about this field.
- How to develop/alter protocols for testing. How to protect POCT devices.
- I have learned a great deal of things referring to nano and micro devices. I especially learned a great deal on fabrication techniques.

Please comment on the things you liked about this course, if any, and why you liked them:

- The project allowed me to use what I learned in class. The flow of the class – very organized and structured most of the topics, they were all very relevant.
- Lectures online, project.
- I enjoyed every aspect of this course.
- The lectures were always interesting and useful. Notes posted on Kodiak so no time is taken in class to be distracted from listening.
- I liked how the project was used to assist the learning of the materials. A problem was time constraints but overall it was a learning experience.
- More information on the fabrication of the films using soft polymers.
- The group project was interesting and informative. It was nice to apply what we learned to a real life device that we designed.

- The vast amount of information that I learned or was at least introduced to will be valuable to my future studies and work. The fabrication part of the course was my favorite – valuable knowledge that is useful beyond this course.
- One thing I found particularly interesting is the wide variety of things that can be learned with a blood sample. The simplicity of the structure and fabrication of a mems device.
- I enjoyed writing the term paper, as it allowed me to think creatively while applying many things I've learned over the past 4 years. Lectures were always interesting and well organized, making homework and studying easy.
- Project–however if there was more time allotted, I feel more would have been accomplished.
- I liked everything about this course. I found the information extremely interesting and the project fun and helpful. This was my favorite course this semester.

Please comment on portions of the course, if any, that could be improved or changed:

- Project time.
- The course was great, but the project would be greatly improved by better lab equipment and computers that can handle LabVIEW.
- Larger time slot for design project, like a lab block.
- More time for project work.
- More time for the project would have been nice; overall and during class time.
- Improve the time constraints of the 1 hour design studio.
- Time block of the design project.
- The design project portion was a little frustrating, but it wasn't the fault of the instructor.
- Just in class lab time.
- More time for project.
- I can't really thing [sic] of anything.

The average student score for the project was 96 ± 2%. The results of student performance on the POCT-related question on the final exam from the previous course offering (2010, N = 4) was 7 ± 0.5 points out of 8. For the present course offering (2012, N = 14), the student performance was 7 ± 1 points out of 8. The average total score in the course was 91 ± 4% for 2010 and 89 ± 7% for 2012.

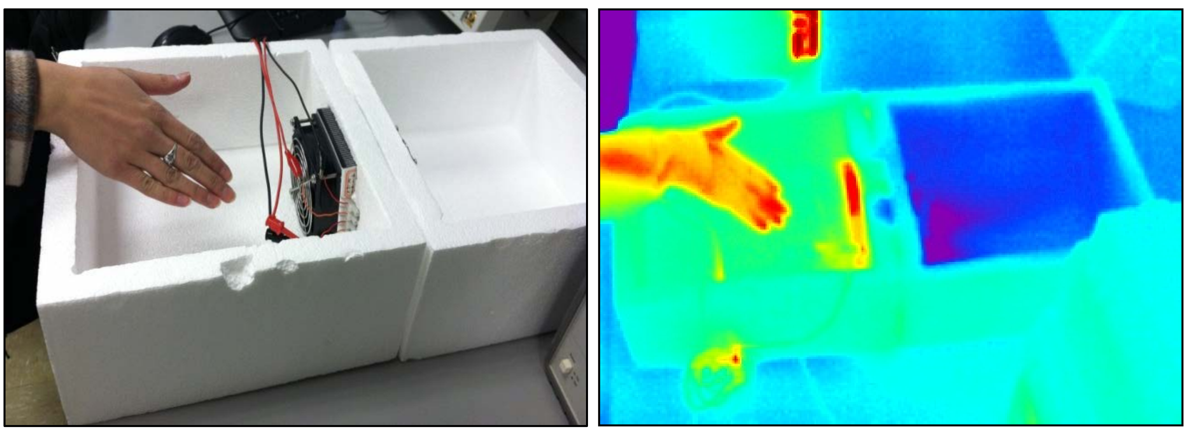
Discussion

The results from the quantitative Likert-scale questions on the pre/post surveys indicate that the learning module had a positive impact on student attitudes and interests toward POCT. Likewise, the skills inventories suggest that students were more knowledgeable and more confident in working with specific components related to the design project. One exception to these results was the power supply: student responses on the pre/post skills inventories were statistically insignificant regarding this component. This result is not unexpected; out of all of the components used in the design project, the power supply had the weakest connection to the rest of the course content, whereas Peltier coolers and accelerometers were directly addressed with lecture content. Additionally, pre-course survey results indicate the students had some background with power supplies whereas they had essentially no prior exposure to Peltier coolers. Thus, the large changes in survey responses regarding Peltier coolers resulted in the smallest p-values in this study. It should also be noted that the pre/post course measurement methodology used in this work makes it difficult to determine the specific aspect of the course and project that had the biggest impact on students. In the future, surveying the students at several time points throughout the course may help further elucidate the relative impacts of the project and lecture content on the students.

The results from the qualitative analysis are also informative. The question prompts were written in general terms (i.e., comment on overall development in the course) as opposed to specifically requesting feedback on the learning module/project. However, several students commented on the project regarding its impact on their learning or as something they liked about the course. One constructive criticism from the student feedback involved the need for more time on the project, which was mentioned by several students. For future iterations of the course, attempts will be made to either devote more time to the project, which may be difficult due to time constraints in the course, or make more efficient use of the designated time by providing the students with more structure. Another approach would be to switch the course from a 50-minute, three times per week model to an 80-minute, twice a week course offering. This would enable longer blocks of time to be devoted to project work, which could also increase efficiency.

The results from the comparison of student performance in the present course offering to the previous course offering showed that the module had no direct impact on student performance on a related final exam question or the overall course grade. While the first result is not ideal, it is not unexpected due to the small student populations in both course offerings and the lack of time available for asking an in-depth POCT question on the final exam that could have more clearly demonstrated a difference between the two groups. The second result, however, is quite important because overall student performance in the course was not significantly affected by the inclusion of a project that required significant class time. This is key because one of the major challenges that engineering educators face when considering the inclusion of a project-based learning approach to their courses is the tradeoff of reduced time for instruction and lecture.[5,6] The results from this work suggest projects may be included that provide students exposure to emerging fields within biomedical engineering without adversely affecting overall student performance in the course. Additionally, the assessment of student performance on the project itself indicated the students did excellent work, and the average project score was higher than the average overall score in the course.

The design project itself generated interesting and promising results for enhancing the use of POCT in disaster settings (an on-going effort in the course instructor's research program). All four groups made significant progress throughout the semester, and were ready for a system integration test when the course ended. Due to time constraints, the system integration testing was not completed; however, the project was continued by a 4th-year BME student (not enrolled in the course) for her senior design project in the following semester.[7] Figure 4 shows one of the experimental setups generated by the Peltier cooler subsystem team. This test was designed to study the heating and cooling performance of their Peltier cooler, which was integrated in the walls of two separate Styrofoam containers. The thermal image (Figure 4b) shows the heating of the container on the left and cooling of the container on the right. As discussed above, devoting more class time for the project (increasing from 25% to 35-40% of total class time) would likely result in the groups completing the full integration test by the end of the course. However, this increase in allocated time would come at the cost of instructional time devoted to other course material. This shift could be balanced through the use of a flipped classroom approach that maximizes in-class time for projects by using video lectures to communicate content to students outside of class time.[8,9]



(a) (b)

Figure 4. Experimental setup produced by Peltier cooler subsystem team to study the heating/cooling performance of their component: (a) photograph of Peltier cooler integrated into walls of two Styrofoam containers; (b) thermal image of the system in operation.

One unexpected challenge that arose during the project involved the students' lack of experience with purchasing components for a technical design. Typically, the students attempted to maximize their purchasing power by selecting the most readily available and lowest cost components they could find. However, in some instances students did not verify whether datasheets were available for their targets prior to purchasing, and thus ended up with a component that was difficult to implement due to lack of technical information. This proved to be a valuable learning experience for affected groups, who ended up purchasing suitable replacement parts at an added cost to their group's budget.

Due to the success of the new learning module, which was implemented for the first time in Fall 2012, it is expected that subsequent course offerings will maintain the team-based design project approach for introducing POCT to students. For example, in the Fall 2014 course offering, the students again worked to develop a container to protect a POCT device. However, rather than each group developing a different subsystem, the groups were given the task of optimizing the Peltier cooler subsystem, and the groups competed versus each other to achieve the best performance. Additionally, the project topic could be modified in future course offerings to provide training in different aspects of POCT device development, such as the redesign of an existing POCT device to improve its robustness. However, it should be noted that one potential limitation to this learning module involves scalability. The design project has costs associated with the subsystem components that are purchased, thus for large class sizes the budget may become unsustainable. For such scenarios, a virtual design may be substituted; however, it is anticipated that the impact on students will be reduced.

References

[1] C. M. Curtis, R. F. Louie, J. H. Vy, W. J. Ferguson, M. Lam, A. -T. Truong, M. J. Rust, and G. J. Kost, "Innovations in point-of-care testing for enhanced United States disaster caches," *American Journal of Disaster Medicine*, vol. 8, no. 3, pp. 181-204, Summer 2013.

[2] W. Karlen, Ed., *Mobile Point-of-Care Monitors and Diagnostic Device Design*, Boca Raton, FL: CRC Press, 2015.

[3] G. J. Kost, N. K. Tran, M. Tuntideelert, S. Kulrattanamaneeporn, and N. Peungposop, "Katrina, the tsunami, and point-of-care testing: Optimizing rapid response diagnosis in disasters," *American Journal of Clinical Pathology*, vol. 126, no. 4, pp. 513-520, 2006.

[4] M. J. Rust, N. A. Carlson, and J. H. Nichols, "A thermo-modulating container for transport and storage of glucose meters in a cold weather environment," *Point of Care*, vol. 11, no. 3, pp. 157-160, September 2012.

[5] S. K. Esche and H. A. Hadim, "Introduction of project-based learning into mechanical engineering courses," *Proceedings of the 2002 ASEE Annual Conference & Exposition*, Montreal, Canada, June 16-19, 2002.

[6] D. Malicky, M. Huang, and S. Lord, "Problem, project, inquiry, or subject-based pedagogies: What to do?" *Proceedings of the 2006 ASEE Annual Conference & Exposition*, Chicago, IL, June 18-21, 2006.

[7] C. A. Gamache, M. J. Rust, and G. J. Kost, "Thermo-modulating container for protecting point-of-care devices from extreme temperatures during disaster relief," *Proceedings of the 39th Annual Northeast Bioengineering Conference*, Syracuse, NY, April 5-7, 2013.

[8] A. Saterbak, M. Oden, A. L. Muscarello, and M. Wettergreen, "Teaching freshman design using a flipped classroom model," *Proceedings of the 121st ASEE Annual Conference & Exposition*, Indianapolis, IN, June 15-18, 2014.

[9] J. -M. I. Maarek, "Flipping the biomedical engineering classroom: Implementation and assessment in medical electronics course," *Proceedings of the 121st ASEE Annual Conference & Exposition*, Indianapolis, IN, June 15-18, 2014.

Appendix

Pre/Post Course Survey

Please answer the following questions by filling in the bubble below your selection or, where appropriate, providing a short answer. You are not obligated to answer any or all of the questions, and may stop the survey at any time.

Please rate your current level of knowledge regarding the topic of Point-of-Care Testing:

Very knowledgeable				Not knowledgeable
4	3	2	1	0
○	○	○	○	○

How confident are you in your ability to develop Point-of-Care Testing devices?

Very confident				Not confident
4	3	2	1	0
○	○	○	○	○

Please rate your current level of interest in pursuing further studies/training (outside of this course) in the area of Point-of-Care Testing:

Very interested				Not interested
4	3	2	1	0
○	○	○	○	○

How likely are you to pursue a career in the area of Point-of-Care Testing?

Very likely				Not likely
4	3	2	1	0
○	○	○	○	○

Please rate the suitability of Point-of-Care Testing devices for solving problems in medicine and biology:

Very suitable				Not suitable
4	3	2	1	0
○	○	○	○	○

Please comment on your overall development in this course (e.g., what you have learned, skills you have developed, etc.) since the beginning of the semester.

Please comment on the things you liked about this course, if any, and why you liked them:

Please comment on portions of the course, if any, that could be improved or changed:

Pre/Post Skills Inventory

Please rate your current level of knowledge regarding <u>thermostats</u>.

Very knowledgeable				Not knowledgeable
4	3	2	1	0
○	○	○	○	○

How confident are you in your ability to develop and/or utilize <u>thermostats</u> in your designs?

Very confident				Not confident
4	3	2	1	0
○	○	○	○	○

Please rate your current level of knowledge regarding <u>Peltier coolers</u>.

Very knowledgeable				Not knowledgeable
4	3	2	1	0
○	○	○	○	○

How confident are you in your ability to develop and/or utilize <u>Peltier coolers</u> in your designs?

Very confident				Not confident
4	3	2	1	0
○	○	○	○	○

Please rate your current level of knowledge regarding <u>accelerometers</u>.

Very knowledgeable				Not knowledgeable
4	3	2	1	0
○	○	○	○	○

How confident are you in your ability to develop and/or utilize <u>accelerometers</u> in your designs?

Very confident				Not confident
4	3	2	1	0
○	○	○	○	○

Please rate your current level of knowledge regarding <u>power supplies</u>.

Very knowledgeable				Not knowledgeable
4	3	2	1	0
○	○	○	○	○

How confident are you in your ability to develop and/or utilize <u>power supplies</u> in your designs?

Very confident				Not confident
4	3	2	1	0
○	○	○	○	○