Engaging Undergraduate Biomedical Engineering Students in Lab on a Chip Research through a Course-Based Project

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Abstract
A course-based project was developed and implemented to engage undergraduate biomedical engineering students in Lab on a Chip research. The research project was integrated within BME 432 – Lab on a Chip, which introduces students to the theory and application of microfluidic systems in medicine and biology. Once the project had been described to the students on the first day of the course, all subsequent lectures were designed to deliver content required for each stage of the device development process, including concept generation, design, fabrication, and testing. In order to assess the impact of the project on student interest and attitudes toward the Lab on a Chip research field, pre- and post-course surveys were developed and administered. The results from the surveys showed increased student-reported knowledge, confidence in developing devices, and level of interest in pursuing further studies, training, and careers in the area of Lab on a Chip. Additionally, student responses recorded at various time points throughout the course identified research skills that were developed as a result of the project.

Introduction
Recently, there has been significant interest in the enhancement of research skills for undergraduate biomedical engineering (BME) students. Such research skills are critical for students wishing to pursue graduate studies, academic careers, or industrial employment in research and development (R&D) positions. However, there are limited opportunities for research in undergraduate BME programs, and many of these experiences are extracurricular in nature or are only available to a small percentage of students. For example, students may complete research projects during the academic year on a volunteer basis, as a paid researcher, or to receive course credit. Unfortunately, for many students it can be difficult from a practical perspective to partake in such an assignment due to lack of time and space in their curriculum. Other students may apply to participate in summer-based research experience for undergraduates (REU) programs, but these are highly competitive and limited in capacity. As a result, alternative methods for cultivating research skills for a broader student audience are sought.

One potential solution to this issue is to integrate research projects within existing undergraduate courses. Such an approach would offer opportunities for practical skill development to a larger number of undergraduate students. Additionally, the projects could be designed to complement course material as well as the active research areas of faculty members. Such authentic learning experiences (i.e., projects pertaining to active faculty research areas as opposed to academic exercises) have been shown to enhance student learning and retention. Additionally, practical course-based research projects bearing relevance to ongoing faculty research can activate an...
otherwise untapped workforce while meeting learning objectives. In this work, a course-based project was developed and implemented to engage undergraduate BME students in Lab on a Chip (LOC) research.

**Course Background**

The research project was integrated within BME 432 – Lab on a Chip, an upper-level elective course at Western New England University that introduces students to the theory and application of microfluidic systems in medicine and biology. In the first iteration of the course-based learning model, a standard lecture and laboratory approach was utilized to follow a logical progression from core concepts to applications of this emerging technical field (Table 1). Once sufficient course material had been covered, a laboratory project was implemented that allowed students to design and fabricate a microfluidic mixer, which was one of the concepts introduced in the microfluidics section of the course. While the original laboratory project reinforced course content regarding microfluidics and fabrication, the students were given very little autonomy in the design process. Additionally, the project did not directly relate to the instructor’s active research projects, which made it academic in nature as opposed to an authentic research experience. Moreover, the project was implemented during blocks of class time towards the latter portion of the semester, which resulted in compartmentalization of the theory and application aspects of the course.

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In the present course-based learning model (Table 2), a research project was implemented that formed the basis for all learning in the course. The project, which was introduced on the first day of class, involved the development of a LOC device for a specific medical application that was identified by a clinical sponsor. Once the project had been described to the students, all subsequent lectures were tailored to deliver content required for each stage of device development: concept generation, design, fabrication, and testing. For example, after the completion of the concept generation lecture, the students worked in teams to develop a set of design concepts, which were later produced after the module on microfabrication. At the end of the course, the final fabricated device for each group was tested to determine its performance.
Table 2 – New Course Layout (bolded items represent the research project)

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<td>Course overview/Project intro</td>
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The research project that was realized in the new version of the course, which was implemented for the first time in Spring 2012, involved the development of a microfluidic device to measure hematocrit in a blood sample. Such hematocrit measurements are critical for diagnosing anemia, a disease that affects approximately 1.6 billion people worldwide. To achieve progress toward anemia diagnosis, the students were tasked with developing a microfluidic device capable of separating red blood cells (RBCs) from plasma. Design constraints included compatibility with a custom-built laboratory centrifuge and use of low-cost fabrication materials (e.g., polydimethylsiloxane, PDMS) suitable for disposable LOC applications.

The student population in the first offering of the new course format consisted of 9 BME students, including 4 seniors and 5 juniors. On the first day of the course, the students self-assembled into groups of 2-3, resulting in 4 total groups within the class that remained for the duration of the research project. After the project and its clinical relevance had been introduced, the students were provided preliminary lectures on the necessary microfluidic concepts to initiate the design process. Next, the groups held brainstorming sessions to develop 3-5 concepts per team. During such class periods designated for project work, the groups went to separate meeting rooms in the same area of the engineering building at Western New England University, which helped avoid cross-talk between groups that would have reduced the design concept diversity. The students then documented their concepts with sketches and short descriptive text, which were presented to the class and instructor in the form of a mini-design review. Next, the students performed concept selection by evaluating their group’s designs according to parameters such as projected performance, footprint, and interface requirements. Once each group had settled on a design concept, the students were given an introductory lecture in computer-aided design (CAD), which provided training for their subsequent design efforts. Each group then submitted a preliminary CAD file to the instructor, who reviewed it for technical
content and manufacturability. After revised CAD files were finalized, the designs were sent to a manufacturer (EC Shaw Co., Cincinnati, OH) for production of a polymer-metal mold. While the molds were being produced, students were provided lectures on microfabrication processes, including the specific elastomer casting method using PDMS that was subsequently implemented after receipt of the molds. Following the lecture on packaging and interconnections, the students sealed their microfluidic systems using adhesive tape after punching inlet/outlet holes in the PDMS layer. Functional tests were performed first using a colored dye to ensure that the device was properly sealed before final tests were conducted using bovine whole blood (Hemostat Laboratories, Dixon, CA). In each case, the completed devices were loaded onto a custom lab centrifuge that was operated between 1,000-10,000 RPM. The result from testing one of the designs produced by the class is displayed in Figure 1, showing separation of RBCs from plasma.

![Figure 1](image_url)

**Figure 1.** Images from testing the final design from one student group: (a) after loading blood sample; (b) after completion of centrifuge cycle (inset shows higher magnification view of separated blood sample in one of the four detection chambers).

After completion of preliminary testing, the students performed an after-action review to assess how the results from testing could be used to inform a next generation design, including a complete redesign or incremental changes. Due to time constraints in the course, the next generation design was discussed, but it was not implemented.

**Results and Discussion**

In order to assess the impact of the new course format on student interest and attitudes toward the LOC research field, pre- and post-course surveys were developed and administered. The surveys consisted of 5-choice Likert questions, which were analyzed using a one-tailed, paired t-
test with a significance level of 0.05. The results from the surveys are shown in Figure 2. Compared to the pre-course responses, student responses on the post-course survey showed increased student-reported knowledge regarding LOC technologies \( (p=6.05\times10^{-5}) \), confidence in their ability to develop LOC devices \( (p=1.21\times10^{-4}) \), level of interest in pursuing further studies/training in the area of LOC \( (p=0.048) \), and likelihood in pursuing a career in the area of LOC \( (p=0.004) \).

![Figure 2](image.png)

Figure 2. Results from student surveys (Likert scale 0-4) comparing responses on pre-course (left) and post-course (right) surveys regarding LOC: (a) student level of knowledge; (b) student confidence in their ability to develop solutions; (c) student level of interest in pursuing further studies/training; and (d) student likelihood in pursuing a career in this area. * indicates statistical significance.

Qualitative information was also used to assess the impact of the course on the students along several dimensions. This feedback was obtained from student answers to free response questions on the pre- and post-course surveys, as well as surveys administered at various time points throughout the course. For example, in order to identify the research skills that were developed as a result of the project, students were surveyed at multiple time points throughout the course, as well as on the post-course survey. In each case, the students were prompted to comment on their development in the course since the previous survey. Examples of skills identified by the students are shown below (divided into in-class and post-course survey responses):

**In-class surveys**

- *I know more as to the applications of lab-on-a-chip and the processes involved in designing and fabricating.*
- *Learned about the design process and fabrication techniques, advantages and disadvantages of miniaturization.*
• It is interesting to learn how factors that you usually don’t take into account for large scale fluidic devices can have a huge effect in microfluidic devices.
• I have learned to cast PDMS mold of our LOC device which we drew in CAD software. I have learned many of the aspects of microfluidic devices including their valves, pump options and different design conditions.
• I think lab-on-a-chip will have a large impact on the future of medicine. I liked that the class would split time between design and lecture and hands on.
• I’ve learned a lot about the materials and processes that are used to create lab-on-a-chip devices as well as the micro-components of typical lab-on-a-chip devices.
• The factors that need to be taken into account when packaging the device (environment, interconnects, etc.).
• Learned about problems and solutions with fabricating and testing these devices through project testing.
• I have become more knowledgeable about the processes used in fabrication.
• I have learned the fabrication process in much more depth.

Post-course
• I have learned a great amount of information about LOC devices since the beginning of the semester. In addition, I now have the ability to develop my own LOC device in the lab.
• I believe this course has been very beneficial in developing my knowledge in one specific area in my career field. I feel as though I could approach a BME related problem with the LOC fundamentals I have learned in this class.
• The design project was a great tie into how what we have been learning is actually used.
• Learned about specific applications especially through writing the research paper and presentations. The end of the course really brought everything together.
• I have learned a lot about microfluidics. I think microfluidics have the ability to make a large impact on medicine. Because of this class I am considering a future in microfluidics.
• I have learned many different theories, designs, and processes of microfluidic systems. I have also had the chance to learn about current applications of microfluidic systems.
• Learned a lot about microfluidics and fluid dynamics. Better grip on the importance of micro- and nano- scaling.

The students were also prompted on the post-course survey to describe the things they liked about the class. Results from student responses included:
• The whole aspect as an entire unit; how current technology can be miniaturized to make performing many tasks easier and more cost effective.
• The lab part. It was interesting to have hands on approach with developing a lab-on-a-chip device.
• I really liked the project. I enjoyed designing a device knowing there was a purpose for it. I also like the discussions that broke up the lectures.

• The design project got me involved and excited about the material I was learning.

• The design project was good. Presentations were interesting to listen to. Applications really pulled everything together to see the big picture.

• The project.

• I enjoyed the design project because we were able to create LOC devices.

• I liked the project! It was fun and very useful in developing my LOC knowledge.

The results of the quantitative and qualitative analyses from surveys show the course had a significant impact on the students, including increased interest in LOC as both a research field and a potential career option. Additionally, the project was identified as a catalyst for learning in the course. A variety of skills were identified by the students, most of which were specific to the design project. Interestingly, one student highlighted that they felt confident in solving other BME problems as a result of the training received in the course.

Another dimension that was investigated was the impact of the new format on student learning in the course. A question that was common to the final exams in both the original and present course offerings was analyzed to determine whether there was a difference in student performance. The question contained multiple parts, addressed concepts related to fabrication and microfluidic design, and consisted of quantitative analyses as well as short answer questions. The average score on the question under the previous course format was 41±7.4 points out of a maximum of 50 (82%, N=11). The average score on the same question in the new course format was 44±4.9 points (88%, N=9). The scores were compared using a one-tailed, unpaired t-test with significance level of 0.05. The result of this study yielded p=0.14, which was not statistically significant. While this result indicates there was not a significant improvement in student performance on the exam question in the new course format, the average score increased by over half a letter grade (B- to B+) in the new course format.

The results from the research project itself were also positive. All four of the groups successfully designed, fabricated, and tested their concept, thus satisfying the academic goal of reinforcing the lecture content with hands-on learning. Additionally, the designs produced by two of the groups showed significant promise and were selected to move on in the research program of the course instructor, which involves the development of low-cost diagnostic tools for use in resource-poor environments. Thus the research project not only provided benefit to the students, but also to the research agenda of the faculty member. As mentioned previously, it is likely that the direct connection between the research project and the faculty member’s active research area added to the authenticity of the project, which may have enhanced the impact measured by the pre- and post-course surveys.
The students were assessed on their performance in the project along the dimensions of attendance (35%), participation (35%), and on time-submission of various assignments (30%). The project was worth 5% of the total course grade. The weighting of the project and its various dimensions was selected to balance the need for accountability while also recognizing that the score represented group work. An important aspect of the described approach to integrating research projects within the classroom involves the increased number of students that are exposed to research methods. In this case, the course involved 4 seniors and 5 juniors, which represented 47% of their combined graduating classes. For comparison, a typical cohort from our institution has 20% of students participating in summer REUs.

One potential limitation to course-based research projects involves the issue of scalability. For example, the project described in this work was implemented with a class of 9 students, which is a relatively small number that reflects the size of our program and the elective status of the course. In larger class sizes, such as those found in required courses, there may be challenges in implementing similar research projects. One factor that may aid the scalability is the use of groups to complete the research project. In the described effort, 4 groups were formed with 2-3 students in each group. If the class size was increased to 30 students, it is anticipated that 6 groups of 5 students could be formed, which would not significantly impact the day-to-day implementation of the project. For class sizes over 30 students, the additional number of groups and/or students per group would eventually have a negative impact on student engagement and learning. Similarly, the cost of the project should also be examined when considering scalability. Since the project utilized existing laboratory instrumentation (e.g., light microscopy) and research tools of the course instructor (e.g., custom centrifuge), the costs were primarily related to consumables and contract manufacturing, which resulted in a project cost under $200. One solution to the increased costs associated with larger class sizes would be to fabricate only the top few designs produced by the class. This could be achieved during the preliminary design review phase, and would result in reduced costs from fabrication and testing. An alternative approach might involve dividing the design into modules requiring optimization. For example, microfluidic sample loading could be addressed by several groups, while other groups focused on blood sample separation and methods for recording results from separated samples. For this modular approach, each group would be working on a different component of the system, but the ability of the subsystems to work together would require input from the class as a whole.

Due to time limitations, the research project implemented in this work only consisted of design, fabrication, testing, and analysis of a microfluidic system. In future iterations of the course, it may be possible to incorporate computational modeling of the microfluidic designs so that students can compare the predictions from simulation with experimental results. This would further reinforce course content while also introducing students to the use of simulation tools.
As a result of the success of the new course format, which was implemented for the first time in Spring 2012, it is expected that subsequent offerings will maintain the course-based research project approach. In future course offerings, different research topics may be explored in order to maintain the connection between the course material and active faculty research projects. Additionally, the course could be modified so that students do not generate competing designs for the same project, but rather attempt to design solutions to different research problems. This would allow the student teams to be co-located during the design phase since inter-group communication would not stifle creativity as it would on a single project. Additionally, it would allow students to develop solutions to a wider range of research problems, which could continue to impact both the students and the faculty members at our institution.

References