AC 2007-1855: BIOMEDICAL ENGINEERING PROJECTS: INTEGRATING OUTREACH INTO ENGINEERING EDUCATION

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Biomedical Engineering Projects: Integrating Outreach into Engineering Education

Abstract

As the second course in a two semester sequence in transport phenomena, Biotransport focuses on passive biological transport, including mass and fluid transfer both in the body and in artificial organs. In the presentation of biological transport, it is essential that students recognize the limitations in solving problems with fundamental equations and the importance of assumptions when investigating realistic problems. A non-traditional laboratory component was developed to address these issues and it involved a semester-long group project to create an experiment based on teachings in the first transport course. The objective of the project was to apply the basic principles learned in the first course to biological situations and to present a laboratory using these concepts to a specified audience (e.g., first semester transport students). The project allowed students to develop experimental protocols, troubleshoot problems with design and set-up, begin to understand their strengths and weaknesses in a team environment, and conceptualize transport phenomena as applied to biological situations. This laboratory component brought the challenge of choosing assumptions directly to the students and allowed them to see first hand the problems in setting up and solving for biological situations.

Over the past two years, the project description has been modified to address an outreach audience of middle or high school students. This subtle change in the project description has completely altered the outcome of the projects, with the projects containing more complicated analyses that are evaluated more accurately (e.g., delivery of "mouthwash" from Listerine Strips using finite element modeling and partial differential equation solvers) while maintaining the simplicity that middle or high school students would understand. Although the primary goal for the class learning is the theoretical evaluation of the experiment with minimal error, the teams must also develop a video demonstration for their target audience. In the video, the teams explain, in layman terms, both background and the phenomena for their demonstration. The video not only encourages further creativity in leading the demonstration, but also allows the students to improve their communication skills. Feedback through evaluation forms is primarily positive, with many of the undergraduate students enjoying the creativity that is required for the project, along with a more thorough understanding of how to evaluate real systems.

For the past two years, the department has used some of these outreach projects for Upward Bound (high school level) students who are visiting during the summer. Typically, students who had developed the projects have assisted in running the demonstration and found that their understanding of the material increases even further when they have a live audience. Overall, these projects have provided a novel mechanism for students to apply their knowledge in a creative fashion while also demonstrating the limitations of assumptions in real situations.

Introduction

Biomedical Engineering, by nature, attracts undergraduate students who are interested and excited about serving medicine with their engineering knowledge. However, as educators, we continue to see that many students do not understand what biomedical engineering is and how it may be different from biology or other engineering disciplines. At Saint Louis University, the curriculum is designed for students to take a set of general engineering courses followed by upper level biomedically-related engineering courses. In an attempt to further establish and reinforce that connection between engineering and biomedicine, the two-course sequence in transport phenomena has utilized student-developed laboratories as integral parts of the courses. Students in Biotransport (upper level course) have developed laboratories for introductory students and these laboratories have been used in the first, general transport phenomena course[1]. This project was a unique opportunity to address ABET Criterion 3b[2] ("an ability to design and conduct experiments, as well as to analyze and interpret data") prior to capstone courses and outside of a research opportunity. While this project has been successful, an integral part of the experience at Saint Louis University is service to others. Therefore, the project was changed from development of a laboratory for introductory students to the development of a demonstration as outreach for pre-college students.

In general, it is important that engineering programs attract and retain a diverse student population. At Saint Louis University and elsewhere, two obstacles have been noted in attracting future students: (1) many students are not prepared for the rigors of engineering and (2) students don't see role models like themselves in engineering. A variety of K-12 programs[3-5] have been set up to address these issues, however local outreach efforts, such as demonstrations for middle school students performed by undergraduate students, may be able to address both of these issues on a small scale. If these demonstrations are performed at the middle school level, students can more easily recognize their needed coursework and take these courses in high school. These middle schools students also better identify with local undergraduates than with college faculty or teachers. Another issue at the K-12 level is the aptitude and comfort-level of the teachers to present engineering materials[6]. As the developed demonstrations are also on video, they may give teachers who are not comfortable with engineering material the opportunity to present the material to the students.

This paper discusses the implementation of the project, along with the feedback from students who have developed (and run) the demonstrations. The primary objectives of the project are for Biotransport students to apply their knowledge and creativity to topics in biotransport and stimulate their interest in outreach and service to others. Each group chooses the intended audience for their end-product so that they can better format their presentation. Feedback is through group evaluations and course evaluations, along with personal notes from students who have run their demonstration for Upward Bound students.

Project Description

The project description is handed out with the syllabus, describing the project goals, and deadlines for the semester. As learning to work in a team environment is critical to the success of students after their undergraduate education[4], these projects are completed by assigned teams.

During this first class, the teams have their first meeting to set up a common weekly meeting time and brainstorm ideas for the project. Additionally, they chose a time to meet with a teaching assistant (TA) every other week. This meeting with the TA gives the teams a chance to ask questions or troubleshoot problems on a regular basis. The project logistically has two components: (1) a demonstration for high school or middle school students and (2) the design and analysis of an experiment using engineering knowledge. Biotransport students must analyze their designed demonstrations both experimentally and theoretically, using engineering and science techniques learned in courses. At the same time, they must design the demonstration for an audience that has minimal science and engineering background. These two components require the teams to actively utilize knowledge from previous courses and to creatively apply this knowledge to engage younger students in their demonstration.

The project description (from 2006) reads:

> Design and implement an experiment as outreach for future BME students that allows them to explore aspects of Transport Phenomena in Biomedical Engineering. The topic must be in the realm of mass transfer and must be described with a biological/biomedical basis. Because this project is designed as outreach, you should think about what the students (high school or upper middle school) will get out of it (what will they learn about BME), what would they do during the experiment/demonstration (~1/2 hr long), and what would they see. In addition, you will need to evaluate your experiment/demonstration as a Biotransport student and solve all relevant equations, analyze the results and discuss the outcomes.
>
> Your team is responsible for the design of an experiment, including the equations and mathematics behind the experiment, a sample apparatus (if necessary), a description of the set-up for a TA/moderator, parameters for the experiment and a sample laboratory write-up/handout. Additionally, you will need to video-record a model presentation. Be sure to have a hypothesis or purpose to the experiment, background on what the students will learn and why it is important (in other words, what will they learn?). You may also design 'props' that will be used in conjunction with your experiment to describe what/why/how.

Teams are organized to have students swap roles (Leader, Secretary, Resource) during the semester at specified dates. The role swapping did not alter the team's projects or goals, just the primary role that the individual would perform in meetings. No team had more than four people. They must write personal role reviews after they complete each role, describing how well they performed as part of the team in their role. Teams have access to a wet laboratory with basic biological and chemical equipment and have a budget of $50 per team, which must be tracked, justified, and approved prior to reimbursement. Additionally, teams have access to video equipment and editing software through the university and/or the department.

Students presented their final projects in both oral format to the class and in paper format. The oral presentation was 15 min and focused on the engineering background and analysis. The final report consisted of:

- Cover page with title of project, group member names & date
- Introduction of project – relevance of project to transport & biology; intended audience (high school, middle school) of the project
- Project design – apparatus description and set-up
- Typical results – what should the raw data look like (i.e. give data)? Analyze the data using statistical methods.
- Discussion of project – how many redesigns did it take? what will the problems be in doing this experiment? did it work? does it take a few times to work? are there secrets to get it to work? modeling of the experiment as comparison to the data…
- Appendix 1: Sample hand-out – what you would hand out to students who were going to do this experiment; it should include a brief introduction, set-up description, how to do the experiment, what data to take, questions for pre-lab, discussion topics during/after experiment, and questions for post-lab if applicable (include error analysis in post-lab questions) – the exact nature of this Appendix will depend on your specific presentation
- Appendix 2: TA Lab – similar to sample hand-out but with all the answers, tricks to getting the apparatus to work, sample data, presentation information, etc… If someone was going to do your project as outreach, what should they know.

Students evaluated the projects during their course evaluation. In addition, each student performed self evaluations during the semester and a team evaluation (which included a self evaluation) at the end of the semester. As each project was presented during class, the students were able to peer review the other projects through feedback forms, which were typed and given to each group before the final paper was due.

Projects

Biotransport has utilized this project description for approximately 6 years, with the topic for the project and the target audience changing. As described above, for the past 2 years, all projects were targeted as outreach for middle and high school students. The differences between the project descriptions for the past two years were related to the assignments: (1) the students from 2005 were not required to make a video demonstration, but it was an option for extra credit and (2) students from 2006 were required to do both self assessments and enhanced team assessments. For extra credit, 5 out of 6 groups made the video demonstration. The projects described here are from the 2006 Biotransport Class at Saint Louis University. For this semester, four teams of four people were set up alphabetically. Each team had to specify the target audience (e.g., grade level) for the demonstration, as well as develop a theoretical mass transfer analysis that described their demonstration. Their projects are described below utilizing the team's description when available.

Project 1: Glomerular function; a tangential flow filtration model: "The Kidney—You Mean, The Bean?"

The purpose of *Glomerular function, a tangential flow filtration model* is to physically demonstrate glomerular filtration of smaller solutes (ie. NaCl) in comparison with larger solutes (ie. protein, specifically lactalbumin and lactoglobulin). The corresponding demonstration is potentially geared towards educating high school seniors about the fundamentals and significance of physiological transport and therefore introducing them to their options in biomedical engineering. An apparatus was made to represent the kidney with Millipore© filters (.2 μm in diameter) equilibrated to the glomerular capillary membrane. The filter separated the central chamber of the apparatus into two portions, representing the systemic circulation and the excretory circulation beginning at the Bowman's capsule, respectively. It was hypothesized that the physical model would strongly resemble the theoretically expected data for this system. Protein concentrations on both sides of the apparatus were determined using a Pierce Protein Assay; NaCl concentrations were determined by determining the resulting volumes and salt masses in the outlet beakers on either side of the apparatus. Predictions of the apparatus' performance were made using theoretical equations developed based on mass transfer relationships. Experimental results were compared to the theoretical models (generated in both Femlab and Matlab) resulting in percent error of <15% (variable depending upon which theoretical model it was compared to). As a result, the project proved successful and its structure and simplicity would make the respective demonstration effective not only in a high school setting but also in a college engineering classroom.

Project 2: Digestion Takes Guts

The experimental set up represents certain structures in the body that are involved in the diffusion of nutrients across the small intestine wall and into the blood. The nutrients in the lumen of the small intestine are modeled by an acid (citric acid) and a base (sodium hydroxide). The citric acid and sodium hydroxide dissociate into their respective ions in the aqueous solutions used just as nutrients are broken down into smaller molecules inside the lumen of the small intestine. The dialysis tubing serves as a short section of the small intestine, which is a tube-like structure. The pores in the cellulose membrane of the dialysis tubing represent the tight junctions and enterocyte membrane pores. The deionized water in the surrounding beaker represents the surrounding blood through which nutrients are able to be transported throughout the body. The change in blood pH that can occur due to the acidity and basicity of the nutrients absorbed, or the change that would occur without mechanisms in the blood to maintain a stable pH, is measured as the change in pH of the surrounding beaker. While blood samples could be taken in the body to determine blood pH or concentration values, the pH of the fluid in the surrounding beaker was measured directly (with a pH meter) and converted to concentration. (Target Audience = High School)

Project 3: Drug delivery at the Gastro-Intestinal tract

Drugs are widely used as a treatment for many illnesses and diseases. In order to understand how certain drugs induce changes in the body, we must understand the mechanism through which the drug reaches various regions within the body. The most common form of drug administration is a pill, which enters the body through the gastrointestinal tract. This project aims to create a model of the mass transfer of a drug from the small intestine to the blood stream that can be used to teach middle school children about drug delivery. The experimental setup involved a concentrated solution of either NaCl or Kool-Aid flowing through a dialysis tube or suitable surrogate, allowing solute diffusion through the membrane and into surrounding fluid. The resulting concentration profiles, representing those of a drug in the blood stream, were compared against two mathematical models. The results versus model provide below 17% error for the salt case, and 74% error for the Kool-Aid case. The setup provides a teaching aid that is both simple to use and suitable for middle school children, and should effectively convey information about drug delivery to this target group.

Project 4: Diffusion & Dissolution of Pullulan in Listerine® Breath Strips

The intended audience for the presentation portion of our project is 8th grade middle school students, specifically in science courses. The students will be exposed to the basic concept of diffusion and dissolution, observe the different factors that affect diffusion and dissolution, and actively participate in an experiment involving these two mechanisms of mass transfer. The students will also be taught basic anatomy of the mouth, the biology of an enzyme, and the structure of a pullulan molecule. The project is relevant to both biology and transport, and the students will experience a rudimentary portion of both.

The four projects used similar methods of comparing their results to theoretical equations. Each project had a unique component of the analysis that had to be overcome to fully describe their experiment. For example, Project 2 readily collected data, but when comparing it to theoretical results, had significant error. After some searching, the team realized that the dialysis membrane they utilized would not withstand all of the pH environments that they had exposed it to. Therefore, they were able to complete an additional test that demonstrated the changing pore sizes due to the acidic environment could cause the discrepancy in their results. So, they were able to still utilize acids and bases in their demonstration, which can easily show color change, allowing the audience to better participate, while still theoretically modeling their experiment.

The video demonstrations serve two purposes: (1) it provides our future students the chance to see what the original designers intended to demonstrate and (2) it provides future audiences the chance to see what our students will demonstrate. The videos will soon be available as DVDs to local school teachers with funding provided through an award to the author.

Assessment

Project assessment was conducted using traditional methods, such as course (both 2005 and 2006 data) and team evaluations (2006 data) and self assessments (2006). While students also did peer evaluations on other's projects, this data is not included except as anecdotal. The students were told at the beginning of the semester that a goal was to utilize their projects in outreach, including their video demonstrations. They were also told that their projects and assessments were being used as information for a paper.

Course Evaluations

Questions were added to the typical course evaluation at the end of the semester, evaluating the project. The added questions and results are listed in Table 1, with the results being the percentage of students who responded with agree or strongly agree (2006, n=15; 2005, n=14; 2004, n=14). The results from 2004 are included as a comparison from a year when the project was not directed as outreach, but was designed for introductory transport students. The majority of the students agreed or strongly agreed that the outreach project was useful in their overall learning in the course and that the skills learned would be useful for the future. An interesting point in these evaluations is that the idea of designing an outreach project did not substantially alter the project's overall usefulness from the student perspective, with numbers from 2005 and 2004 being similar. When the project was specifically mentioned, comments in the course evaluations confirmed the numbers. Students enjoyed the projects and learned a lot from them, but sometimes thought they were time consuming, especially in the end of the semester, right before it was due.

Table 1: Assessment through course evaluation questions, with percentage of student responses that were either agree or strongly agree. For both 2005 and 2006, the project was outreach oriented and 2004, the students designed introductory college-level projects. NA = not asked. Number of students for each year was: 2006, n=15; 2005, n=14; 2004, n=14.

Question	**2006**	**2005**	**2004**
The project added to my understanding of transport phenomena.	80%	93%	100%
The design of an experiment for transport students helped me integrate the knowledge I've learned in this sequence of courses.	73%	93%	93%
The meetings with the TAs for the project were helpful to keep the group on track.	33%	86%	93%
The meetings with the TAs for the project were helpful to develop ideas.	40%	93%	100%
The meetings with the TAs for the project were helpful to troubleshoot.	40%	93%	93%
Designing an experiment gave me skills that will be useful in my future classes.	67%	100%	100%
The group environment of the project helped me to evaluate my strengths and weaknesses in a team.	80%	93%	100%
The project helped me conceptualize how transport phenomena is applied to biological and biomedical situations.	87%	93%	100%
The group project helped me to understand how to apply fundamental equations of transport to more realistic situations.	87%	100%	100%
The group project helped me to understand how to apply assumptions to realistic situations, and the consequences of those assumptions.	87%	100%	100%
The project helped me to integrate mathematical concepts and scientific principles in fluid and mass transfer into biomedical systems.	80%	NA	93%
Overall, I felt the project was an integral part of my learning in this course.	73%	NA	93%

Students from 2006 were also sent questionnaires about the outreach component of the project. Those that responded were enthusiastic about the outreach component and considered it not only critical to their final outcome, but also thought it was important to them as individuals. The question "Did you feel that the project demonstration was an important piece of the project because it may be used for outreach? (or would you have done the same amount of work if it was not)" was particularly interesting because it demonstrates whether the students become more invested in their work if they see it has an impact. While each student had a slightly different explanation, the resounding answer was yes, it was important.

The largest differences in the results from 2005 and 2006 relate to the usefulness of the meetings with the TA. The results from 2006 are the lowest since the meetings were instituted and were likely due to the assistant for the year rather than the actual idea of the meetings. Because of these evaluations, TA meetings will be more closely monitored in the upcoming course, with teams having the option of meeting with the professor or the TA.

Team Evaluations

While a team evaluation has been completed each year, 2006 was the first year there was a specific form with questions about contribution for each member (Table 2). All students are required to complete the forms and distribute percent contributions for each team member. While the percentages are not displayed here, the honesty displayed in assigning percentages to both themselves and their team members was notable. The students recognized their faults and the roles they, as well as their team members, played in completing the project. Although the forms were confidential and filled out individually, the team members were fairly consistent with their grading of themselves and each other, including both those students who excelled and those who did not. Ultimately, these evaluations allowed the students to identify their strengths and weaknesses in the team, as well as identify their overall contribution to the project.

Table 2: Team/peer evaluation form. Percent effort for each row should add to 100%, but as each team member may be assigned different tasks, some people may have 0% for a certain category.

	Team Member 1	Team Member 2	Team Member 3	Team Member 4
Name:				
Intellectual Contribution: understanding the project, doing the work				
Emotional Contributions: enthusiasm, creative efforts and problem-solving insight				
Communication contributions: writing reports/updates, making video demonstration, making presentation				
Managerial contributions: keeping team on task when needed, meeting deadlines, keeping track of resources				
Time contributions: use of time in and out of meetings, didn't waste time socializing during meetings				
Outcome contributions: writing computer code, collecting data, analyzing data				
Ratings: Rate each team member of a scale of 1 to 10				
Overall: If you were to do another team project, would you work with this person again (yes/no)? Explain.				

Self Evaluations

Self evaluations were performed after each role change during the semester. These evaluations were also new for 2006, and asked for the student to:

- Evaluate the role and their performance in the role
- State their strengths and weaknesses in the role
- Determine how they could do a better job if they were in that role again.

While the evaluations were required, they were not graded on their comments. These reviews were very interesting and demonstrated that many students could critically evaluate their performance. Below is a sample of student's comments on their performance in the various roles:

Leader

Person 1: I was the leader in this past rotation of the project and feel that my reign was smooth sailing. At our meetings I worked to keep everyone focused on what we needed to get accomplished that meeting or that week. When someone took on an assignment, I followed up with them to see if there was progress or if they needed additional information. At this stage of the project, this role was fairly easy since we're really moving forward on our design. Everyone came to the meetings with a pretty clear idea of what we needed to do and the motivation to work on it making my job fairly easy. The only blotch on my record was failing to call when I was quite sick and couldn't come to the meeting. Our attendance policy states that we need to notify the group, and I just forgot. I would grade myself a B- on my role as not quite a solid "good," but more like a "not half bad."

Person 2: This portion of the semester I had the role of leader. I feel I did a good job for the most part. I am comfortable taking control of a group and people tend to listen to me when I do. I have found that I am also pretty good at keeping the group in order, focused, and on some sort of schedule or plan. I believe that I also did a fairly good job of representing the group in situations such as discussions with professors. My personality is very well suited to that of a leader. I did have a few problems being the group leader. My main problem was one of insecurity. I did not know if I was being to bossy or overbearing, but I also did not want the group to get behind. The other problem I had was related to the fact that the project was just beginning. During the first few meetings, we did not know what type of project we wanted to do. It was a bit difficult to direct a group that had no obvious goals. Both problems seem somewhat trivial and were easily overcome. Overall, I really liked being the leader. I like having the security of knowing things will get done. I love being in control of situations. Because of this, I really enjoy organizing ideas, planning meetings, and delegating jobs. I foresee this being my favorite of the roles.

Secretary

Person 1: As secretary, keeping the lab journal up to date has been my responsibility for the last several weeks. In recent weeks it's been especially important that we keep good notes since we have been running tests on the components of our model system. I've recorded all the data from the urea and protein tests and have kept a careful list of what we need to do next and the obstacles we still need to solve. The objective of this position is fairly simple, and I executed it well. I submitted our progress report on time and kept notes from the beginning to the end of each meeting. I give myself an A for this role with possible few points taken off for sloppy handwrititng.

Person 2: During this quarter of the semester, I had the role of secretary. I was not comfortable with this position at all. I generally like to hold discussions and not necessarily take notes on them. I am incredibly disorganized and should not be trusted with such a responsibility. I do not like to write down ideas, take notes, make schedules, and keep track of everything. When doing this, I am too focused on writing to contribute to the discussion. I am very glad this portion of the semester is over. Were I to do this job again, I suppose I would try to keep better organized. I would like to have a distinct pattern to the notes I took. For example, I would like to have at least labeled dates in lab notebook. It may have helped to have a checklist of all the things I needed to do. My only strength for this role is that I am very good at always being available and on time. I do not think I did a very good job with this role. The group had to consistently remind me to write down important ideas. I frequently forgot to add important details or points of the discussion. I did not realize how deficient in information the notes was until it was time to write the project update. I also had to be reminded to take attendance. Were I to grade myself on the position, I would give myself a D. I hated this role.

Resource/Researcher

Person 1: I feel I did a good job as a researcher in this early stage of the project as I amassed information on all of our ideas to help the group make decisions. As a general group member, I don't feel I contributed very much to the brainstorming process; I only felt like I was being productive when I had someone else's idea as a guide. To a degree, this bothers me because I could contribute if I just took the time to brainstorm on my own. Instead, I got comfortable in the role of researcher and preferred the semi-mindless grunt work to taking a thoughtful approach to the problem we had to tackle. As the project moves forward, I hope to contribute more to our meetings and put more effort into developing my own ideas to present to the group.

Person 2: This portion of the semester, I had the role of resource person. I am pretty comfortable with doing this role. I can listen pretty well to requests, follow instructions, and get assigned tasks done. I help whenever help is needed. Currently I am focused on writing the paper and helping XXX with the video presentation. I do not really know how to work the spectrophotometer or Femlab, so I am not very helpful there. Because we split it all up, towards the end, it didn't seem like there was need for a resource person. Everyone just did their own job while the leader organized weekly meetings and secretary took notes on those meetings. I was just there to help out. I think I did a good job. I was usually available to help out if necessary, with the exception of the finer details of the spectrophotometer or Femlab. I would give myself a B+ or an A- on the role. I could have been more helpful and more organized but otherwise, I did my fair part.

Demonstrating the Projects - Outreach

Several students have been involved in utilizing their demonstrations for a high school level summer program at Saint Louis University. The students were in the department for four days, and saw two or three of the demonstrations. While the high school students did not fill out formal evaluations, the students spoke with the presenters and feedback was generally good and gave the high school students a better understanding of biotransport. Some of the topics were more complex than others, allowing the presenters to even further integrate their knowledge by breaking the topics down for the high school level. The presenters were asked to fill out a short questionnaire (Table 3) about their experience of presenting their project for outreach. While there were only a small number of student presenters (n=2), the feedback was good. They both cited how the high school student questions allowed them to reflect on their knowledge. Additionally, both students cited methods of improving their projects as demonstrations, including using more games and focusing less on equations or actual lecture. The results from this questionnaire will be distributed to students in future courses, to allow them to see other's reflections on their projects.

Table 3: Questionnaire for students who presented their project to high school students during a short summer program.
1. Did an actual demonstration of your project to high school students cement the basic biomedical transport ideas that you were trying to convey when you developed your project? Why/Why not? 2. Was it beneficial to have the delay between completing the project and the demonstration? Please comment. 3. What would you change about your demonstration now that you have demonstrated it to students? 4. Were the students interested in the same things that you thought they would be when making the project? Please comment. 5. Did the demonstration of your project enhance your own knowledge about transport? For example, did you get any questions that you had to figure out how to explain a complicated transport concept to students without all of your experience? 6. Did you feel that the students left the demonstration with a better understanding of biomedical engineering transport than prior to the experience? Why/why not? 7. Any further comments or suggestions?

As the summer program was headed by the department chair, his comments were:

> One component of the Mission of the University centers on community building and outreach programs. The BME Department has participated in the Upward Bound program here at Saint Louis University for several years now. Aimed at high school students from all cultural backgrounds, the program has proven to be a strong influence on promoting the opportunities of higher education. We have designed our segment of the program around creating hands-on activities that students will find engaging, informative, and fun. The most successful experiences have been the experiments developed in the Biotransport class for middle and high school audiences. From snot rockets to Listerine strips, all of the labs have been well planned and well received by these young students.

Conclusions

This paper describes the implementation of an outreach project for an upper level biomedical engineering course. Although the outcome of this project is a demonstration for middle school or high school audiences, the work required for the project is advanced and has aided in the students understanding of biotransport according to course evaluations. Additionally, the project has allowed students to begin to understand their role on a team, assessing their strengths and weaknesses within the team structure. As students present their projects for outreach, they are also able to further strengthen their knowledge and directly interest students in the field of biomedical engineering. The next step for this work is to allow teachers to access the video demonstrations for their use in the classroom. At the same time, those students interested in outreach will be available to run the demonstration. During these demonstrations, additional data will be collected directed at assessing the usefulness of the demonstrations for the middle and high school students.

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