2006-1968: TEACHING BASIC CARDIO-VASCULAR MECHANICS WITH LEGO MODELS: A HIGH SCHOOL CASE STUDY

Reginald Hobbs, Tufts University

Reginald is currently a graduate student at Tufts University in a M.S./Ph.D. program in Science Education. He previously earned his M. Ed. in Secondary Education from Harvard University and his B.A. in Biology from Carleton College. Reginald is also currently a research assistant at TERC where he is involved in looking at improving the performance of historically under-achieving groups in the field of science.

Nataliia Perova, Tufts University

Nataliia is currently a graduate students at Tufts University majoring in Mathematics, Science, Technology and Engineering education. She previously earned her M.S. in Electrical Engineering from Tufts University in 2005 and B.S. in Electrical Engineering from Suffolk University. Nataliia is currently a research assistant at the Center for Engineering Outreach where she is involved in using engineering approaches to teach high school students science and mathematics.

Igor Verner, Technion-Israel Institute of Technology

Igor M. Verner received the M.S. degree in Mathematics from the Urals State University and the Ph.D. in computer aided design systems in manufacturing from the Urals Technical University, Ekaterinburg, Russia. He is a Senior Lecturer and a coordinator of teacher-training programs at the Department of Education in Technology and Science, Technion – Israel Institute of Technology. His research interests include learning through designing building and operating robots, and education design experiments.

Chris Rogers, Tufts University

Chris got his PhD, M.S. and B.S. at Stanford University. He is a Professor of Mechanical Engineering at Tufts University and Director of the Center for Engineering Outreach. His research interests include: particle-laden flows, telerobotics and controls, slurry flows in chemical-mechanical planarization, the engineering of musical instruments, measuring flame shapes of couch fires, and in elementary school engineering education. He has a strong commitment to teaching and was awarded the Carnegie Professor of the Year in Massachusetts in 1998. He has worked with LEGO to develop ROBOLAB, a robotic approach to learning science and math.

Teaching Basic Cardio-Vascular Mechanics With LEGO Models:
A High School Case Study

Abstract

This interdisciplinary instructional unit will teach participants the basics of the cardio-vascular system through fluid mechanics. It will explore the human circulatory system, while involving the concept of pressure. Students will explore the cardio-vascular system through both computer simulation and hands on modeling activities using a LEGO pneumatics construction kit and modifying it for desired outcomes. The LEGO pneumatics model serves as an instructional tool for high school students in their study of the cardio-vascular system. This model is used to explain different components of the system and the effect of blood flow through the heart. One of the ways to analyze the workings of the system is through the readings offered by the pressure sensors. Students can interpret the data in real time using Vernier probes and software. Graphic interpretations will demonstrate relationships between the various components of the system and help students to develop scientific thinking through analysis of physical phenomena. The success of the unit will be measured by looking at the experiences of students with the material and their interest in the field of engineering. Pre and post written questionnaires and observations were used to determine how this module impacted students' engagement, motivation, and interest in the cardio-vascular system, engineering, and physics. The following paper accounts and demonstrates the positive impact teaching science through an interdisciplinary approach involving the engineering design process has on students, motivation, engagement, and interest.

Introduction

Currently in most high schools physics, anatomy, and engineering are taught as three separate classes. Three years of science is required for graduation from most public high schools, while most college bound students take four full years of science.[1] Engineering courses are offered, but in most high schools are not required for graduation.

The state of Massachusetts in their educational frameworks currently requires the teaching of the concept of pressure in any introductory engineering course, specifically in a unit involving energy and power technology. The cardio-vascular system according to state frameworks is taught in grades 6-8: Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other[2] and in grades 9-10 with vertebrate anatomy and physiology: explain generally how the circulatory system (heart, arteries, veins, capillaries, blood) transports nutrients and oxygen to cells and removes cell waste.[3]

We are currently engaged in work to develop an interdisciplinary classroom module to teach the cardiovascular system through the concepts of pressure and engineering design. We use LEGO models, and Vernier probes/software for real-time data analysis. Based upon the initial module we hope to design and implement additional modules to teach other human body systems and through them the underlying physics concepts (e.g. the muscular-skeletal system using Newton's 2nd law and the concept of torque). Overall, we hope to develop an entire interdisciplinary curriculum that combines physics and human anatomy and physiology using LEGO models, Vernier probes, with various pieces of the engineering design process. As science and engineering educators we are concerned with how the module and its instructional technologies are useful in the classroom and impact students' motivation and learning, as well as how a user of these technological systems will be able to make connections to the theoretical and conceptual frameworks of science.

Since the topics of anatomy, physics, and engineering are all taught as separate subjects, in most secondary schools in the United States our interdisciplinary module would improve the curriculum by connecting these various disciplines. In this module we aim to teach high school students the concepts of pressure, while focusing on how blood flows through the cardio-vascular system. LEGO (model design) and Vernier Probes (simulations) help the teacher facilitate the learning process by using engineering components to present an alternative method of teaching science. Our module includes components of the physics curriculum (pressure), the biology curriculum (cardio-vascular system), and engineering curriculum (design process). The current version of this module would fit into the anatomy and physiology curriculum during a study of the cardio-vascular system. Our initial case study was piloted as an after-school program at a suburban public high-school. It is anticipated that results from the case study will show an increased motivation and engagement in physics, engineering design, and biology based upon the module and the hands-on approach used.

Literature Review

Prior educational research,[4] substantiates our use of the interdisciplinary module setting. This module is part of a larger education design experiment where we are creating, testing, and revising the learning environment while examining how to best implement and evaluate the educational effectiveness of the interdisciplinary module.[5] This will allow the module to evolve based upon feedback and research results from our initial case study. Also, by having a brief module we are able to use action research methodologies.[6] The reflection aspect of action research is used to review the previous action and plan the next one.[7-8] By conducting and modifying the module in brief time periods we can learn the most effective way to emphasize and enhance learning about anatomy, engineering, and physics in an interdisciplinary learning experience.

The goal of our research is to determine where this interdisciplinary instructional unit can be integrated into the curriculum. In any change of the curriculum it is important to use what is known about individual differences of the students to determine for whom any particular instructional method is appropriate and for whom it is not appropriate.[6]

Our interdisciplinary module should be effective in improving the learning, interest, engagement and motivation of students based upon theories about learning such as situated cognition, multiple intelligences, and constructivism. Situated cognition promotes transfer of knowledge to day-to-day real life situations. It enriches the learning process by providing practical experiences of real situations[9]. This module takes the concept of pressure and deals with it in a way that is real and directly related to every student's life. This module provides a situated learning experience that enhances the learning process through social interaction, authentic activity, and participation within a larger community. With situated learning, students are better able to construct meaning in practical ways so that knowledge can be applied outside of school settings.

Howard Gardner developed the idea of multiple intelligences: several different kinds of intelligence exist in humans, each relating to a different area of human life and activity.[10] Any learning environment can be organized to draw on most of Gardner's multiple intelligences by including a variety of learning activities, such as lectures rich with visual information, discussions that promote student–student interactions, group projects that allow for creative elements and laboratory investigations that engage learners in the physical doing of science.[11] This module with its hands-on application, discussions based upon observation, and group building fits the learning environment described by Tanner and Allen (2004). Our interdisciplinary module and its modeling of a real-practical problem also follows the framework of Robert Sternberg who modified the focus of learning from formal evaluation to studying and solving real practical problems.[12]

Finally, our module fits into basic constructivist educational theory that considers learning as an active process of recreating knowledge and hands-on learning activities must be the basis of all formal educational situations.[13] Based on this theory it is important for students to make their own inferences, discoveries and conclusions in dealing with new concepts. Our educational module uses a hands-on activity as one of the learning approaches. This learning method is based on the constructionism theory developed by Papert. This theory was built upon Piaget's constructivist theory. It is based on the principle that learning happens especially well when people are engaged in constructing a product.[13]

This instructional unit uses a real time data acquisition system and displays data in real time. It helps students to analyze their results in the testing phase of their model. Research has found that real-time data displayed in graphical representation facilitates specific connections between the experiment and data.[14] As research indicates, using real time data collection and analysis helps engage students in the learning process and makes science for them more exciting because students are active participants in the discovery and in creatively building and testing their models.[15] However, this research is only true when the students understand the significance and relevance of the data. It is the role of the teacher to foster this understanding of the data, so that the students can benefit from the real time data collection and analysis.

Methods

To determine how the interdisciplinary module on the cardio-vascular system influenced motivation, interest, and engagement in physics, human anatomy, and engineering design a one-time 2.5-hour after school program available to high school students was designed, developed, and implemented.

Participants

This case study was conducted with a group of 23 students in grades nine through twelve in a suburban northeastern city. Thirteen of the participants were male and ten were female. The students were all members of the FIRST robotics club at the local public high school. The module was presented during a 2.5 hour after-school program. Parents provided written consent in response to explanatory letters that were sent home with the children; children provided written consent at the time of the program.

Module Description

The module was made up of several standard educational activities, including lecture, group work, experimentation, discussion, and problem-solving. The goal of the module was to expose the students to the cardio-vascular system and then explore the concepts through lecture, demonstration, and hands-on investigation.

Students learned through lecture the basic parts of the heart as well as the circulatory system and the concept of pressure. The lecture included a short video presentation that detailed blood pressure and how the heart functions. Students made initial connections between pressure and the circulatory system by exploring and taking their own heart rate as well as seeing the effect exercise has on heart rate. Students engaged into the discussion of how pressure is related to the cardio-vascular system in humans and in other animals. Students watched the LEGO model run for several minutes and analyzed the data from the Vernier pressure sensor displayed on the screen in real-time. After the demonstration, the teacher initiated a discussion about behavior of fluids in the model. Next, students learned how to program the LEGO bricks using ROBOLAB software through lecture and demonstration. After seeing the model and learning about ROBOLAB students were divided into seven groups, five groups had three members and two groups had four members. The groups were randomly assigned. Each group had a hands-on experience by modeling the heart using LEGO pneumatic kits. For their first task, groups were expected to build a model that would replicate a heart and was able to pump a liquid. The second task for each group was to program their model to act like the heart filling with blood and then pushing blood into the body, thus replicating the human heart rate and the difference between systolic and diastolic blood pressure. Groups tested their final product at a central apparatus using graphical representation of the data in real time. During the hands-on cardio-vascular modeling part of the activity students used the engineering design process. They built their models through problem identification, discussed different solutions to the design problem, built and tested their models. Discussion of their results helped each group verify or contradict their ideas about their model and the scientific concepts.

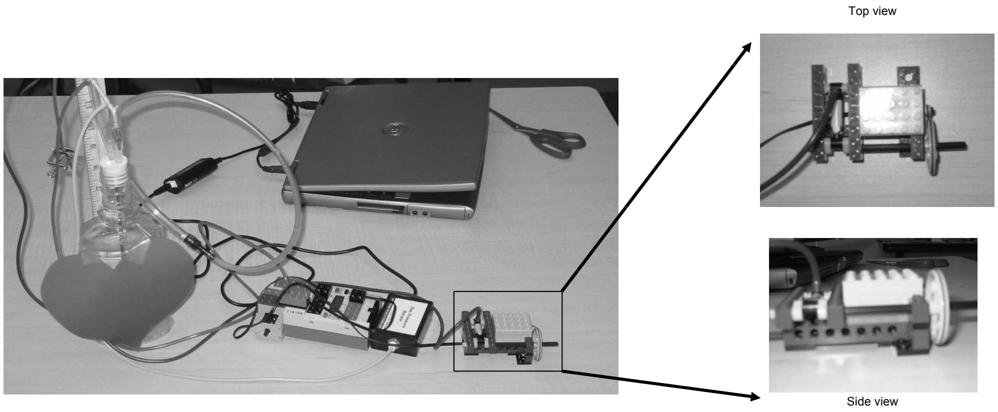

Figure 1. A sample model of the heart is shown. The picture on the right shows the entire set-up complete with ROBOLAB interface, and Vernier Probes. The two pictures on the right show the sample heart model designed from a LEGO pneumatics kit. The heart was built using a LEGO motor that turned a flywheel, which was attached to and moved a piston. The movement of the piston forced air into the system, which resulted in the pumping of liquid.

LEGO and Vernier Equipment

Students used LEGO Pneumatic kits to build their models. They used LEGO parts included in the kit to model the cardio-vascular system and programmed RCX microcomputer using ROBOLAB, a programming language based on LabView. Students also used Vernier Technology and software to collect, graphically display and analyze data in real time.

Data Collection

A classroom observation log was kept by the researchers during the module. The log focused on noting instances of student engagement. At the start of the module, students were asked to fill out a pre-questionnaire to determine their initial notions and conceptions about anatomy, physics, and hands-on learning. At the conclusion of the program, students were asked to fill out a post-questionnaire evaluating their experience and the effectiveness of the program. The pre and post-questionnaires were coded by researchers that were blind to the experiment. Of the 23 participants, two did not completely fill out the pre-questionnaire. Five participants were not able to complete the entire program and did not fill out a post-questionnaire.

Results

All groups were able to complete the first task of constructing a model that was able to pump blood. Only one of the seven groups was able to use ROBOLAB and program their model to replicate a human heart rate.

The results to the pre-questionnaire and the post-questionnaire are shown in the figures below. There were 18 completed pre-/post- questionnaires. The answers to some of the questions were missing and were taken into account when calculating the statistics.

Additionally, it is important to note that because the workshop was offered as an after school program, after completing the activity students were answering the post-questionnaire more hastily and some of the students who completed the pre-survey did not fill out the post-surveys.

Pre-Questionnaire

TABLE 1. Multiple–choice results collected from questionnaires given before the workshop. The results indicate the percent value. The selection of the student is indicated in the parenthesis and is based on the following scale:
For Questions 1-3: (1) Not at all (2) A little (3) Partially (4) Somewhat (5) Definitely

Question	**Number of students completed this question**	**Results**
1. Do you think that use of technology in the classroom is helpful for your understanding of a science subject?	17	47 (5) 29 (4) 12 (3) 12 (2)
2. To what extend do hands-on activities interest you?	18	56 (5) 44 (4)
3. Do you think that learning math and science in high school is important for your future career?	18	89 (5) 11 (4)

Post-Questionnaire

TABLE 2. Multiple–choice results collected from questionnaires given after the workshop. The results indicate the percent value. The answer selection of the student is indicated in the parenthesis and is based on the following scale:
For Questions 1-2: (1) Explanation (2) Demonstration (3) Hands-on Activity
For Questions 3-6: (1) Not at all (2) A little (3) Partially (4) Somewhat (5) Definitely

Question	**Number of students completed this question**	**Results**
1. What part of the instructional unit helped you the most to understand the concept of cardio-vascular system?	18	61 (1) 33 (2) 6 (3)
2. What part of the instructional unit helped you the most to understand the concept of pressure?	18	67 (1) 17 (2) 17 (3)
3. To what extend do hands-on activities interest and motivate you?	18	50 (5) 28 (4) 22 (3)
4. How useful was the graphical data representation for your understanding of what was happening with the model?	17	12 (5) 47 (4) 24 (3) 18 (2)
5. To what extend is this type of activity needed in the curriculum?	18	28 (5) 28 (4) 33 (3) 11 (2)
6. Would you recommend your friend to study this activity?	18	28 (5) 33 (4) 33 (3) 6 (2)

Discussion

The students who participated in our workshop showed an interest in the topics presented and excitement about using alternative ways to study them. Students were particularly interested in using LEGO Mindstorms Pneumatic kits to help them build and model the cardio-vascular system which they could test with Vernier Pressure Probes and real-time data display.

Instructional Technologies in the Science Classroom

When students were asked whether the use of technology was helpful in their understanding of a science subject based upon their experience in the module (refer to Figure 2 below), 43 percent of students thought the use of technology in the science classroom was definitely helpful for understanding the concepts presented, 31 percent thought that it was somewhat beneficial. The remaining 26 percent felt the technology was only partially or slightly useful in learning. These results suggest that students, when exposed to various instructional technologies in their classes, feel that the technologies are helpful to learning. The variation in the results also indicates that the effectiveness of the instructional technologies on motivation, engagement, and interest depends on the learning style of the specific student.

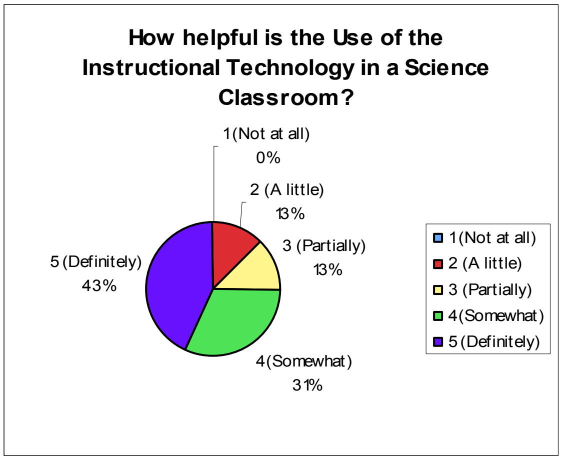

Figure 2: Results from the pre-questionnaire: Do you think that the use of technology in the classroom is helpful for your understanding of a science subject? These responses are based on the following scale: (1) Not at all (2) A little (3) Partially (4) Somewhat (5) Definitely

Teaching Methodologies for Specific Science Concepts

During the module, students were asked to evaluate what teaching method helped them understand the basics of the cardio-vascular system (see Figure 3 below). A majority of the students (61 percent) felt that the teacher-centered explanation with video evidence helped them most understand this topic. Similar results were also true for the concept of pressure (see Figure 4 below) where 67 percent of students felt that a teacher's explanation was most helpful in understanding the concept. While noting the value of the use of technology and hands on activities, the students pointed to the importance of theoretical explanation for understanding science concepts, specifically the cardio-vascular system and the concept of pressure.

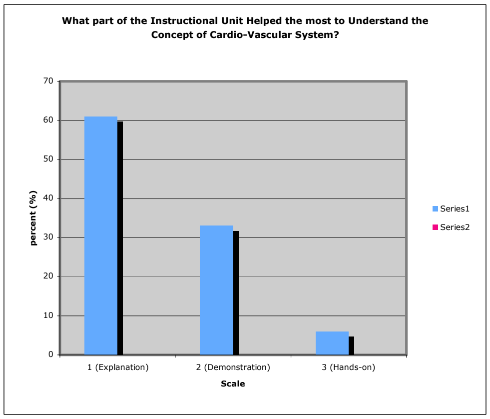

Figure 3: Results from the Post-Questionnaire: What part of the instructional unit helped you the most to understand the concept of cardio-vascular system? These results are based on the following scale:
(1) Explanation (2) Demonstration (3) Hands-on Activity

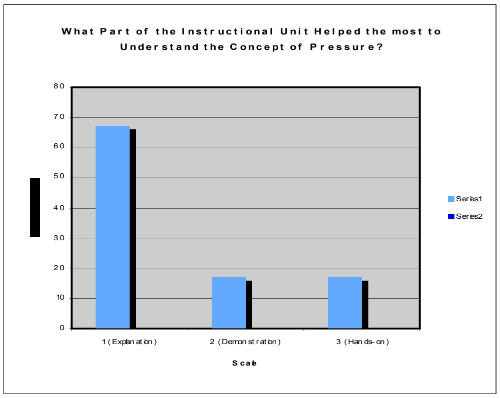

Figure 4: Results from the Post-Questionnaire: What part of the instructional unit helped you the most to understand the concept of pressure? These results are based on the following scale:
(1) Explanation (2) Demonstration (3) Hands-on Activity

Students in their pre-questionnaire responses indicated the interest in hands-on activities (see Figure 5 below). Fifty-six percent of the students were definitely interested in hands-on activities and 44 percent were somewhat interested. Such a positive response to this question can be explained by the already existing interest in designing and building robots. Students were eager to learn how they can apply their knowledge to new problems and what LEGO robotics can offer them.

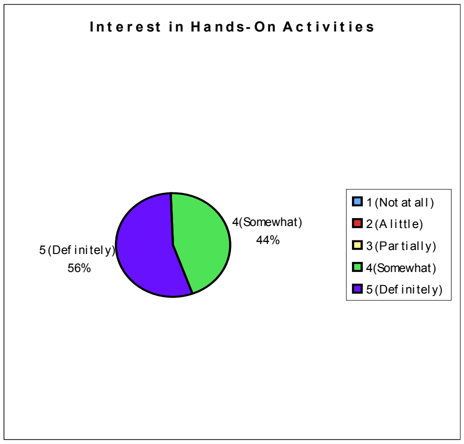

Figure 5: Results from the pre-questionnaire: To what extend do hands-on activities interest you? These results are based on the following scale: (1) Not at all (2) A little (3) Partially (4) Somewhat (5) Definitely

Students' original expectations from the workshop partially determined their opinions about hands-on activities presented in the post-questionnaire (see Figure 6). Half of the students said that they were definitely interested and motivated by the hands-on activities, 28 percent said that they were somewhat interested and 22 percent selected partial interest. The change in the interest level points out the necessity of identifying student's expectations and their knowledge in a subject prior to developing curriculum. This particular group of students had an experience in building and designing sophisticated robots and their expectations of the workshop hands-on activity were high. However, the module was able to maintain the engagement and motivation. This particular group of students had an experience in building and designing sophisticated robots and their expectations of the workshop hands-on activity were high.

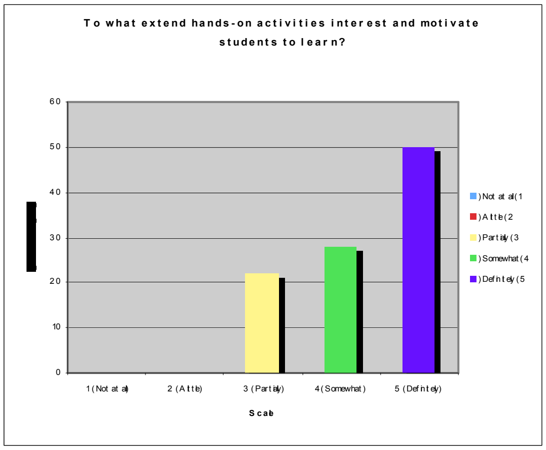

Figure 6: Results from the Post-Questionnaire: To what extend do hands-on activities interest and motivate you? These results are based on the following scale: (1) Not at all (2) A little (3) Partially (4) Somewhat (5) Definitely

Importance of Science in Future Careers

It is important to note that a large number of the participants intend to pursue an advanced degree in science or engineering field. In response to the question (see Figure 7 below) whether they think that learning math and science in high school is important for their future career, 89 percent of the students believed that it will be definitely important and 11 percent felt it somewhat important. Below are some student reflections that indicate the importance of teaching math and science in an engaging way:

> "In today's world and for the future, no matter what someone decides to major in, they will need to have some background in math and sciences because pretty soon we won't just be using it in the classroom or workplace but also in everyday life."
> "Because math is necessary in so many careers, and science is coming up so much that it's both necessary in order to form an opinion and to keep up with the world."
> "I am enthralled by the problems posed by science and mathematics. I believe without them, I'd be a largely different person."
> "Learning mathematics and science is extremely important in our modern day. To get ahead you must have a general understanding of these topics."
> " I like them and by learning them I learn how to problem solve, look at all aspects of the problem, figure stuff out on my own."

These student responses show that an interdisciplinary approach to teaching science exposes students to situations and experiences that engage and interest them. The last response is especially interesting in a sense of applying an engineering approach to problem solving. This observation will be discussed later in the section.

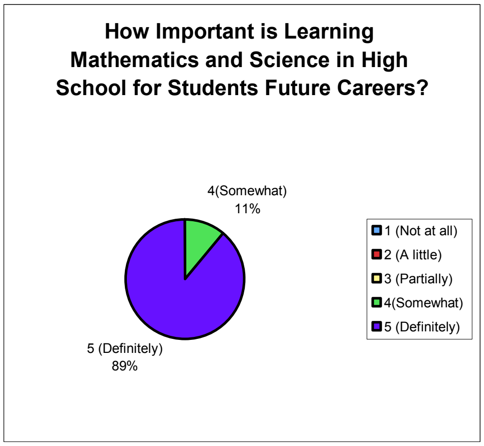

Figure 7: Results from the Pre-Questionnaire: Do you think that learning math and science in high school is important for your future career? These results are based on the following scale: (1) Not at all (2) A little (3) Partially (4) Somewhat (5) Definitely

Need for Interdisciplinary Science Modules

This case study showed that the presented cardio-vascular module interested students to actively participate in the process. Taking into the account the fact that majority of the participants had a prior knowledge and experience in building robots for the FIRST robotics competition, which created a higher expectations from the hands on part of the activity, students still found that a multidisciplinary approach creates different ways of presenting the information and appeals to different learning styles. In response to the question (see Figure 8) To what extent is this type of activity needed in the curriculum, 28 percent of the students thought that this type of activity is definitely needed in the curriculum and 28 percent said that it is somewhat needed in the curriculum. One explanation is presented below:

> The concept of joint sciences, perhaps even taught simultaneously, is very helpful to understanding even both of them. The hands-on activity is not as helpful to me as the explanation, but would be very helpful to some. I already know the basic concepts then the demonstration would teach others.

This response shows that although this student considers him/herself on a high level they still understand the need and importance of such an approach. It is worth noting that the high school where this workshop was conducted is putting significant resources into teaching science through applications. The response to this question indicates that the students already came into the workshop with the knowledge of the concepts and could not learn as much from it as someone with less knowledge and experience in the subject. This information helps interpret the data for 11 percent of the responses where students said that this type of activity is needed only a little. The response suggests that either these students came with an existing knowledge and did not learn anything new or that they did not have this knowledge and the activity did not help them to acquire the understanding of the concept. These results show that there are different learning styles and that the use of varied interdisciplinary science modules in the classroom is a successful way to maintain student motivation and engagement.

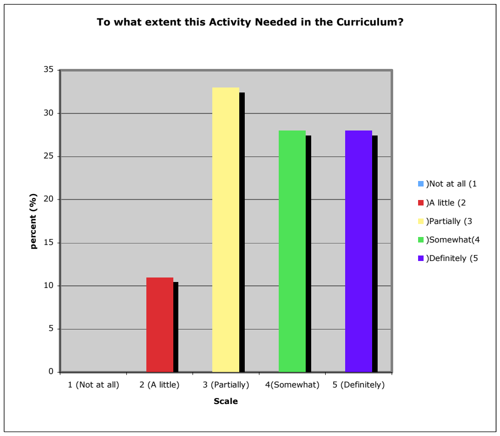

Figure 8: Results from the Post-Questionnaire: To what extend is this type of activity needed in the curriculum? These results are based on the following scale: (1) Not at all (2) A little (3) Partially (4) Somewhat (5) Definitely

Twenty-eight percent of the participants would definitely recommend that their friend participate in this activity, while 33 percent somewhat recommend it (Figure 9). These results from the questionnaire as well as from observations indicate that students found this workshop engaging. They were actively involved in all three parts of the activity: explanation, demonstration of the cardio-vascular model that was built using LEGO Pneumatic kit and analyzed with Vernier pressure probe and real time data display, and they actively participated in the hands-on part of the workshop.

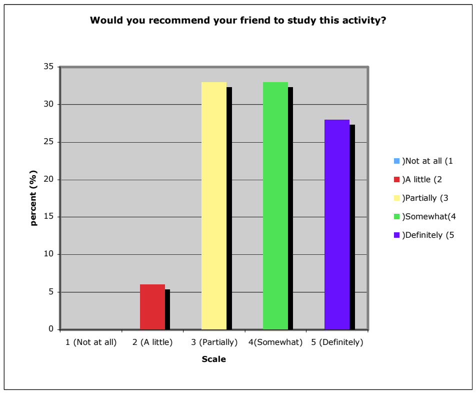

Figure 9: Results from the Post-Questionnaire: Would you recommend your friend to study this activity? These results are based on the following scale: (1) Not at all (2) A little (3) Partially (4) Somewhat (5) Definitely

Instructional Strategies in Science Classrooms

This interdisciplinary unit was taught through several instructional strategies, and gave students an opportunity to see the connections between disciplines of mathematics, science and engineering. Our approach used different types of technologies to help students model and analyze the cardio-vascular system while developing a theoretical explanation and real-world example for the concept of pressure. This module actively engaged the students and was an overall positive experience for them.

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Students expressed their opinions about what makes it interesting for them to learn science. For approximately ¼ of students use of visual aid in the science classroom is very important:

> "Visuals. Especially in physics, diagrams and such help make difficult concepts easier to understand."
> "The labs. Learning something from a badly written book or confusing teacher isn't as effective as an interactive 3d model, so you can actually see how something works."

Forty-four percent of the students felt that connections to real life situations were necessary components to learning in the science classroom:

> "Hands on science is the most interesting part of a class. Labs add an aspect that book work alone cannot. When a principle is demonstrated through a lab I feel that it has a much bigger impact and that I tend to remember it longer/better."
> "Seeing applications to real life and building a final product is entertaining, looks cool, or makes some task easier."

Thirty-five percent of students' responses reflected the need for teamwork, open group discussions, sharing of knowledge and also competition in the science classroom:

> "In a classroom you can use the knowledge of other students to gain more knowledge. You also learn to see things differently."
> "You can have discussions or group activities. You are able to learn with people who are at the same level. They can help you understand things wit their different perspectives.
> "Competition makes everything interesting."

> “I enjoy learning how and why things work. I also enjoy problem solving. Many examples of approaches also make it more interesting.”

Despite the fact that many new instructional technologies capture the attention of the students and have a positive influence on their interest and motivation, our study showed that other components, such as teamwork and open debates are important and can not be ignored.

These components are integral parts of developing student interest in science and technical fields. The process that students describe as important for them to make science more interesting, is similar to the design process used in engineering described in the Engineering with LEGO Bricks and RoboLab[15]. It combines the identification of the problem, brainstorming and exploration of alternative solutions, designing, building and testing and communication and dissemination of the solution. Student comments point to the idea that one way to make science and mathematics more interesting and engaging is by teaching these disciplines through an interdisciplinary approach that includes the engineering design process.

Conclusion

This paper presents preliminary results from a workshop on teaching high school students the cardio-vascular system through an interdisciplinary approach and its’ impact on students’ motivation, curiosity, and learning. Modern educational technology enables teachers to extend the conventional studies of biological systems and human anatomy in schools by hands-on experimentation with physical models. Our physical model of a cardio-vascular system can help students to understand its structure and function as well as the concept of pressure. The physical model is constructed as a system based on a LEGO Mindstorms Pneumatic kit and Vernier Pressure Probe. These are both affordable tools which are widely used for science-technology education in schools and can enhance the learning experience.

Pilot teaching of our instructional module indicated that students showed an interest in the interdisciplinary approach, the students in this workshop indicated that this type of module is definitely needed in the high school science curriculum. Student responses indicated that integration of the theoretical explanation, classroom discussions, use of instructional technology and teamwork can have a powerful impact on students understanding, motivation and active engagement in the process of learning science. In view of these positive results we plan to expand this module into a unit that explores in more detail the human cardio-vascular system. Initial steps already underway include presenting the module to students from a broader demographic as well as lengthening the duration and exploring the science concepts in more detail. The module also serves as the first step in creating a new interdisciplinary curriculum that will teach students human anatomy and physiology through the use of the interdisciplinary approach, instructional technology, and incorporation of the principles of the engineering design process.

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