College and nonprofit industry partnership: coupling undergraduate projects with K-12 outreach program to enhance engineering education

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Ms. Wenger is active in a variety of professional informal education organizations and is co-founder and chairperson of the Mid-Atlantic YouthALIVE! Regional Network. She has co-authored two publications focused on family learning. Ms. Wenger is deeply commitment to diversity issues and broadening access to science for underserved audiences. She is also passionate about professional development of youth and staff working in science centers and museums.

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College and nonprofit industry partnership: coupling undergraduate projects with K-12 outreach programs to enhance engineering education

Abstract

The objective of this project is to improve undergraduate engineering education through the development of biologically-inspired educational tools, expose middle and high school students to exciting facets of engineering through the lens of biology, and enhance the educational programs at New Jersey Academy of Aquatic Sciences (NJAAS). To achieve this, a junior-level undergraduate course was developed and taught at Drexel University's Mechanical Engineering department. The course was closely coupled with the educational programs at NJAAS. The university and academy collaborated to simultaneously enrich the education of middle school, high school and undergraduate students through development and use of biologically-inspired educational devices. The experience of all students was recorded through surveys, observations and interviews. The partnership was assessed through surveys and interviews with the academy staff and observations and surveys of undergraduate students. The results suggested that the course, coupled with a real world partnership outside the university, improved the experience of undergraduate students by making it more engaging and practical and helped the undergraduate students develop a broader skill set. The results also suggested an increase in the interest of middle and high school students in learning about engineering through the use of biologically-inspired devices. The partnership also improved the educational programs at the academy through the use of biologically-inspired educational tools and enabled NJAAS to expand their curriculum to teach engineering topics. The collaboration helped increase engagement of undergraduate students in a university course, improved retention of undergraduate students in the field, developed a broader skill set for undergraduate students, and enhanced education for middle and high school students in Philadelphia and Camden school district.

Introduction

In 2007, the National Science Board (NSB) identified challenges that should be addressed to improve engineering education in order to meet the needs of the engineering workforce[1]. First, in addition to providing good analytical skills, engineering education should help students develop a broader skill set including good systems thinking, business aspects of engineering and knowledge to apply engineering to non-traditional problems. Second, engineering must be made into an attractive major for women, underrepresented minorities, and all creative students, so that the field recruits the best and the brightest of the entire student population. Third, the retention of engineering students who begin engineering studies must be improved. In addition to the NSB challenges, it has been identified that the undergraduate STEM enrollment and retention has declined over the last decade and one of the reasons for the reduction has been the students' perception of engineering as hostile and non engaging[2]. Therefore, the enrollment and retention of engineering students must be improved by, for example, engaging students in hands-on engineering and by exposing them to the business and social aspects of engineering.

In order to address the challenges identified by the NSB, three primary objectives were laid out for this project. First, enhance engineering education for undergraduate students through the development of a hands-on, project-based course in which they are exposed to real world applications and customers. Second, expose middle and high school students from traditionally underrepresented groups in Camden school district to non-traditional engineering through the lens of biology. Third, provide the New Jersey Academy of Aquatic Sciences (NJAAS) with devices that can enhance their educational programs.

In this paper, the development and assessment of an engineering design course that is strategically coupled with the educational programs of a nonprofit academy is discussed. The Laboratory of Biological Systems Analysis (LBSA), at Drexel University's Mechanical Engineering department, and NJAAS have collaborated for three years through the development of biologically-inspired educational devices. By incorporating the development of these devices into an undergraduate engineering course, the engineering students are exposed to a real world customer and a real world challenge that is outside their traditional comfort zone. Simultaneously, the middle and high school students' classroom experience at the NJAAS is improved by providing them with the interactive educational device produced during the engineering course. The undergraduate students enrolled in the course go through a formal design process and simultaneously put the knowledge to practical use by designing a biologically-inspired educational device and manufacturing a functional prototype. Some students continue to work on their devices after the competition of the course. These devices are used at the non-profit academy to teach middle- and high- school students about biology in an engaging and interactive way. They also enable the academy to expand their curricula to teach engineering and design in addition to biology. The undergraduate students collaborate with the academy staff and audience during the development of the educational devices. Collaboration with educators outside of the engineering realm and younger students encourages the undergraduate engineering students to synthesize their knowledge more broadly than they typically do during regular classroom examinations.

The intent of this project is to form a rewarding partnership between academia and nonprofit industry, while simultaneously benefiting the educational objectives of both parties. Several partnerships have been described between academia and industry such as software[3], defense, automation, and aerospace industry[4]. In order to graduate well-versed engineers, academic institutions have partnered up with industries to form advisory boards that provide feedback towards an academic program's direction[3]. Such partnerships have an instant advantage for academia but industry sees less near-term benefits. Through the partnership described herein, the academia and the industry are able to benefit almost simultaneously. Other forms of partnerships described in literature include student co-op, short-term projects and faculty internship programs. Through a college-industry partnership, students gain the experience of a realistic work environment, faculty become more aware of the needs of the industry, and industry become more aware of the constraints of academia to prepare students for the "real world"[3]. A typical goal of an industry and academic institutions' partnership is to increase the capabilities of students to solve practical problems similar to the real world problems. Similar to efforts made by others, this project also provides undergraduate engineering students at the Drexel University with a course that exposes them to real world applications and customers. It must be kept in mind that the industries who have partnered with academia have expressed that they should be actively involved in university's activities[5] for the benefit of both parties. Therefore, an iterative dialogue between the industry and LBSA and students at Drexel University is emphasized throughout the project.

The remainder of the paper is divided in four sections. The first section describes the university course taught to undergraduate students in the Mechanical Engineering department by the principal investigator of LBSA. The second section describes the role of the nonprofit academy, NJAAS, in making the undergraduate course engaging and how the course benefits the academy's educational programs. The third section describes the outcomes from the partnership and the university course for undergraduate students, middle- and high-school students and NJAAS. The fourth section describes upcoming efforts to analyze the partnership and middle school, high school and undergraduate engineering experience at a greater level.

Development of Undergraduate Course in Product Development

An undergraduate course was developed to teach product development by having students develop biologically-inspired educational devices for secondary school students. Good product development requires skills in business, communication, creative thinking, idea generation, systems design and analysis, and manufacturing[6]. Skills in these areas are important for engineering based problem-solving, and are critical for engineers to be successful in many industrial settings. In our study, design topics are introduced to students in lectures taught by faculty from Drexel University's product design and mechanical engineering programs. Students put the lectures into practice by developing functional prototypes of educational tools that can be used by educators at NJAAS to teach biology and engineering to students enrolled in NJAAS's afterschool program. To help ensure the devices address the needs of teachers, the educators from the NJAAS and from other local schools meet with the undergraduate students and discuss needs and requirements for an educational device. The development of a product that can be used to teach both biology and engineering exposes the students to a problem that is beyond the scope of a single individual and that encourages them to apply their engineering skills to solving an unfamiliar, interdisciplinary challenge.

The devices are developed by teams of four to six students over the course of a ten week quarter. Ideally, students with strength in particular aspects of the design process (e.g., machining, computer-aided design, customer interviews, etcetera) are distributed among different teams. The course is offered twice each academic year, and enrollment ranges from approximately 170 to

200 students annually. Design and development is done in the Mechanical Engineering department's undergraduate laboratory, which is equipped with computer-aided design (CAD) and analysis programs, and in the instructor's research laboratory (LBSA), which houses rapid prototyping, modeling, and assembly facilities. Each team is given a budget of $220 budget for the parts required for the prototype development. The course is divided into three phases – concept development (four weeks), system design (three weeks), and testing and refinement (3 weeks) – and culminates with the testing and presentation of a functional, proof of concept prototype. Teams who do particularly well, or who are especially enthused by the project, are invited to develop a fully functional system using a funded, ten-week independent study.

Phase 1 – Concept Development

In the Concept Development phase, the students are told to envision that they are part of an educational robotics company and are given a vision statement which states: "*Develop a medium-end, educational device that is useful for teaching and integrating principles of biology and engineering sciences (mathematics, physics, and analysis). The principles should be taught by actively demonstrating the function, performance, and mechanics of a biological system or phenomenon. Students who use the product will learn by interacting and experimenting with the device.*" The first task for the undergraduate students is to extract stakeholder need statements for the device as described by Ulrich and Eppinger[6]. During the process of collecting and documenting the need statements, the students visit high schools, museums, and local middle schools to engage with the primary stakeholders of the product, middle- and high-school students, and educators in the schools and museums. In addition to understanding the educational needs of the device, the undergraduate students interview machinists and business people to understand manufacturing and cost constraints. After identifying a comprehensive list of need statements, the students spend a week translating the need statements, which are in the language of a customer, to target specifications which are in the language of an engineer[6]. Some examples of the translation are presented in Table 1 below. In the third step of this phase the students generate numerous concepts that satisfy the needs and specifications they identified (Fig 1, 5a). A concept is an approximate description of the technology, working principles, and form of the product[6]. A concept is a brief description of how the product satisfies its end users and is usually in the form of a 2D or 3D sketch with some written description[6]. In the final step of this phase they objectively compare the generated concepts through a decision matrix method[6]. The teams choose a winning concept and present a formal proposal through an oral presentation to the faculty, the class and teaching assistants.

Phase 2 – System Design

In the System Design phase, the undergraduate students use computer aided engineering (Creo Parametric 2.0, PTC, Massachusetts, USA and ANSYS, Pennsylvania, USA) to create a high-level design for a final product that satisfies all the crucial specifications, and a detailed design for a prototype that satisfies crucial functions (Fig 2, 5b). 3D solid models are developed, using

Need Statement		Target Specification		
Raw Data/Customer Statement	**Interpreted Need**	**Metric**	**Ideal Value**	**Nominal Value**
Easy for teacher to set up	Require minimum tools for set up	Number of tools needed to set up device	0	1
	Quick set up	Time required to set up device	<10 minutes	<15 minutes
Must be interactive	Have multiple inputs	Number of inputs	>= 3	>=2
	Have measurable outputs	Number of outputs	>=2	>=1
	Have manual engagement from user	Number of handles, knobs or buttons	>=2	>=1

Table 1: Conversion of need statements, which are in the language of a customer, to target specifications, which are in the language of an engineer. Process similar to the one explained by Ulrich and Eppinger[6].

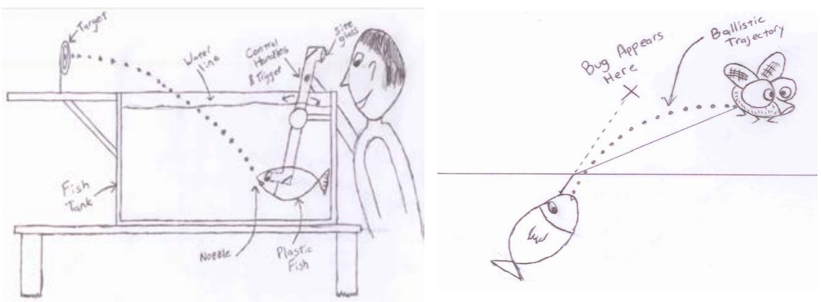

Fig 1: Concept Description. How a model of an archerfish will be used in a classroom to teach about predatory adaptation.

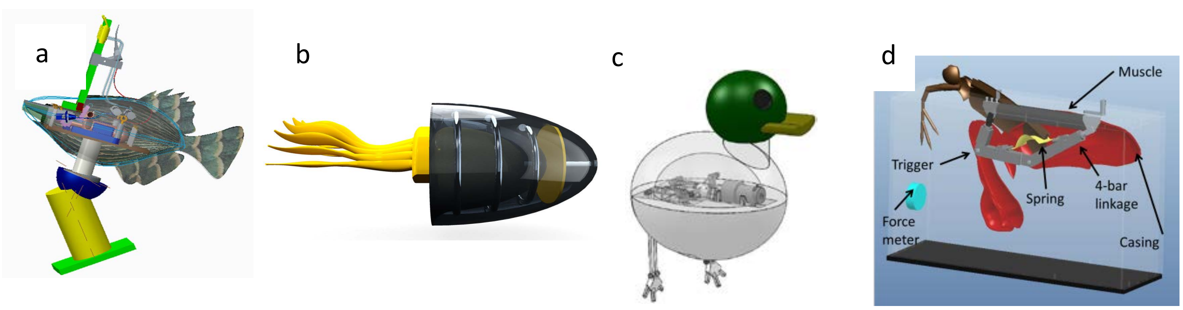

Fig 2: CAD of final designs of educational devices to teach biology and engineering to secondary school students at _ Academy.
(a) Model of an archerfish to teach predatory adaptation. The device shows how the fish uses its gills and bladder to store water and uses its muscles to squirt water out of the mouth to knock down bugs outside water.
(b) Model of a squid to teach jet propulsion. The device shows how the squid takes in water from its environment and uses its muscles to produce jets to propel under water
(c) Model of a duck to teach duck locomotion. The device teaches how toes movement and webbing on duck feet affect the swimming speed of duck in water.
(d) Model of a mantis shrimp to teach the interaction of muscles and saddle spring to produce large forces to hunt.

Creo, and used to demonstrate how the device will be constructed, assembled and used by the end users. These models are also used to demonstrate the architecture of the device and the engineering used to design it. During this phase the students are also introduced to advanced CAD tools like mechanisms and finite element analysis (FEA) so they can critically analyze their designs on CAD and make good engineering decisions, (like choosing the correct material, thickness etc.), before they begin constructing a prototype (Fig 3). The students identify elements of the final device that are crucial for its functionality and using a CAD model, they present how the crucial functionality will be assessed using a prototype (Fig 5c). At the end of this phase, the teams give a formal design proposal through an oral presentation to the faculty, the class, teaching assistants and real customers from NJAAS.

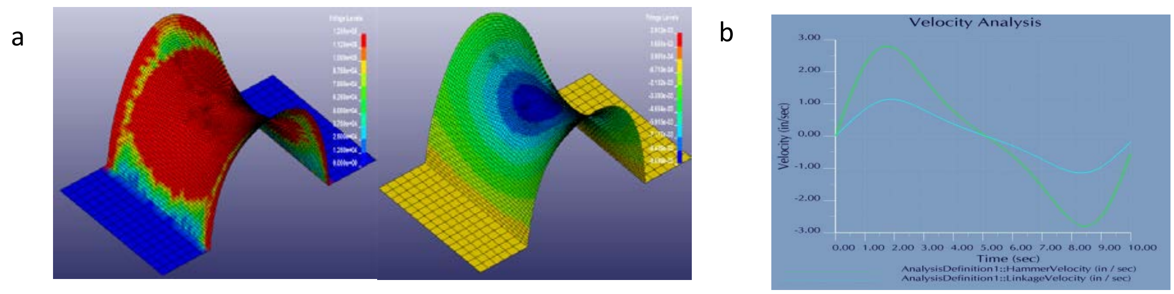

Fig 3: Mechanism and FEA example for analysis
(a) Finite Element Analysis (FEA) to determine the right thickness and right compressions of a given material to produce desired forces to replicate the appendage of a mantis shrimp
(b) Creo Mechanism analysis to show the magnification of speed before and after attaching a saddle spring in the model of mantis shrimp

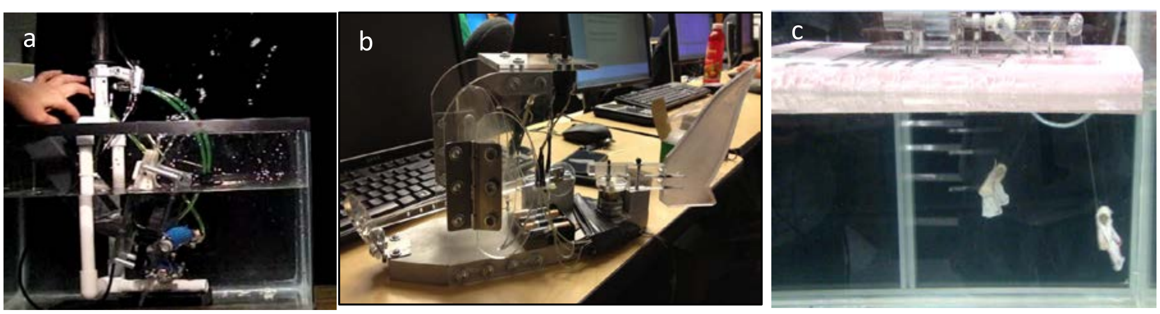

Fig 4: Prototypes developed by design teams at the end of nine week course.
(a) Functioning prototype to teach predatory adaptation of an archerfish
(b) Functioning prototype to teach the metabolic rate of a goldfish
(c) Functioning prototype to teach about duck locomotion

Phase 3 – Testing and Refinement

The goal of the Testing and Refinement phase is for the students to construct a functional prototype for their device ((Fig 4, 5d) and test the prototype against the critical needs and specifications. Because of the time constraint, the students are not able to develop the final device, but instead their goal is to develop a prototype that demonstrates the crucial functionality of their educational device. Crucial functionality includes all the needs and specifications the teams identified in phase one. These functionalities are sufficient to prove that the device can be a successful educational tool for the customers at the nonprofit academy as well as other high schools and museums. The teams show how the prototype allows them and their audience to assess the goodness of the educational device and how well the device meets the mission statement provided to the teams in phase one. At the end of this phase, the teams give a formal prototype demonstration through an oral presentation to the faculty, the class, teaching assistants and real customers from NJAAS. During this presentation, the students give a demonstration of their prototypes and how the prototype can be used to assess the goodness of their final devices.

The students who are enthused about their projects and who present a prototype that meets the needs of the NJAAS educators, return to the instructor's lab and complete their projects. The students sign up for independent study and work very closely with the NJAAS educators and a graduate student from the instructor's lab (Fig 5e,f).

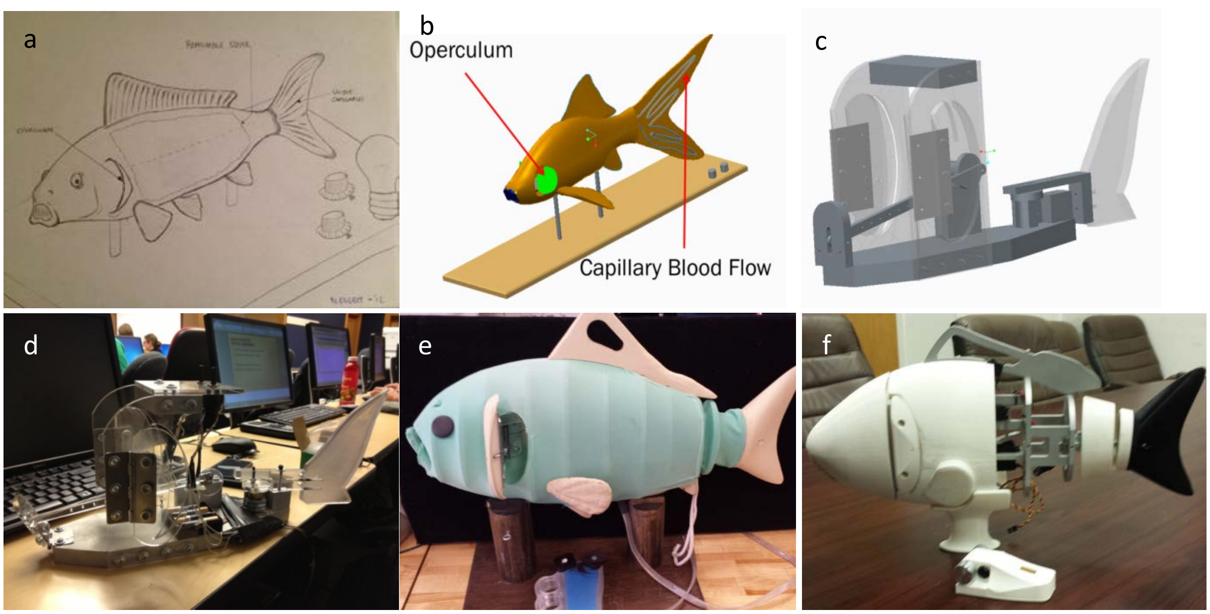

Fig 5: Outcomes of three phases of the Product Development (PD) course and subsequent independent studies. The team progressed to build a model of a goldfish to teach how temperature and physical activity affects the breathing rate of a goldfish.
(a) End of phase 1 of PD (four weeks): Selected concept description. (b) & (c) End of phase 2 of PD (three weeks): Detailed design of the final product and functional prototype. (d) End of phase 3 of PD (three weeks): Functioning prototype manufactured at university. (e) End of first independent study (10 weeks) : An advanced functioning prototype designed and manufactured at the universityby the students. (f) End of second and third independent study (10 weeks each) : A final product for the NJAAS.

Partnership with Nonprofit Industry: New Jersey Academy of Aquatic Sciences (NJAAS)

The partnership between Drexel University and NJAAS connects the academy educators with undergraduate students who are enthused with Science, Technology, Engineering and

Mathematics (STEM) education, and equips the academy with hands-on and interactive devices to help teach biology and engineering in the academy's afterschool programs.

NJAAS serves as the stakeholders during the course and a primary stakeholder and recipient of devices developed by groups who carry the project forward with independent study subsequent to the course. Educators from the academy visit the university during the course and interact with undergraduate students via interviews and lectures. They introduce undergraduate students to the biological concepts taught during the academy's educational programs and provide feedback to the students when the teams present their initial designs (phase 2) and prototypes (phase 3). This is intended to help undergraduate students understand the requirements of an educational device and how well their designs meet those requirements. The interaction of the academy staff increases with groups who remain with the project subsequent to the course. The undergraduate students also visit the academy to observe the academy's outreach programs. The interaction with the academy is intended to help students understand the level of accuracy required to teach biology. Although the devices cannot replicate the animal system exactly, a device's design and performance must be biologically relevant so that inaccurate views about the biological system are not developed. Jacob *et. al* identified that collaborative partnership in which researchers and practioners are involved in an iterative dialogue around problem construction and solution implementation, can promote scientific knowledge in society[7]. Similarly, the partnership encourages an iterative dialogue between engineering students and educators to build devices that can teach biology and engineering effectively and accurately. The academy staff provides the undergraduate students with valuable feedback to develop devices and experiments that can be incorporated into the academy's curriculum.

Fig 6: Educator from NJAAS interacting with prototypes of goldfish (Images on left and middle) and archerfish (one image on right) and providing the design team with feedback.

Through NJAAS's educational programs, we are able to introduce students from traditionally underrepresented groups in engineering to non-traditional, interdisciplinary engineering through the lens of biology. The academy serves nearly 40,000 individuals per year across all age groups through educational programs. The primary audience at the academy for this partnership is approximately 700 middle- and high-school students in the Camden school district. The fully developed devices are taken to the academy during the outreach programs to teach middle- and high- school students about biological phenomena. In addition to being used for demonstration during lectures, these devices can also actively engage the middle- and high- school students through experimentation. To enhance the engagement the middle- and high-school students can also participate in assembling a system before experimenting with it. One way to engage the middle- and high- school students directly with the devices is to allow them to investigate about a biological phenomenon by manipulating inputs and observing outputs. For instance, the middle- and high- school students can explore how the metabolic rate of a goldfish changes with temperature and physical activity by actively manipulating temperature and physical activity on a device, and observing changes in breathing rate.

Through the partnership, the academy receives biologically-inspired robotic devices to improve content delivery. The educators at the academy use these devices to engage their audience with experiments and demonstrations during the outreach programs. Prior to this partnership, the academy did not have devices that actively demonstrated physiological functions such as locomotion, metabolism, predatory habits, etc. Additionally, staff can use these devices to introduce their audience to interesting facets of engineering. One of the challenges faced by the educators at the academy is the disconnect between information taught by the educator and a corresponding live demonstration of an animal. For example, if the educator teaches about the phenomena of a horseshoe crab flipping over and then takes the group of students to see a live horseshoe crab, it may not execute the same behavior. This can sometimes disappoint the students or hamper their knowledge retention. The biologically accurate educational devices can bridge this gap between what the academy students are taught and what they see.

Observations and Outcomes

The outcomes discussed in this section are based on observations made by teaching assistants and faculty during the course and independent studies, feedback from undergraduate students during course and independent study, surveys conducted with middle-school students in a museum, and feedback from academy staff.

1. This partnership between Drexel University and NJAAS through the development of biologically-inspired educational devices, addresses the challenges identified by the National Science Board (NSB) by developing broader skill sets for undergraduate students, improving perception of engineering and retaining college-level students. The partnership plays a vital role in the execution of the course by providing a real world customer during all phases of the course. Based on feedback from undergraduate students, the presence of a real customer from the academy contributed to their creative thinking and problem solving. Initially, the undergraduate students in the course expressed discomfort towards the integration of biology and engineering. As the course progressed, many students identified that it helped them apply engineering solutions to an unfamiliar problem, bringing maturity in their engineering skills. This course is one of the few courses taught at the university that allows undergraduate students to get hands-on experience in design and manufacturing before they enroll in senior design. The undergraduate students were particularly engaged when constructing prototypes

of their proposed devices (Fig 4, 5d). During the second and third phases of the course where the students developed the 3D solid models for the device and the functional prototypes, teams often lost sight of the goals of the product. They students began to concentrate on completing the device regardless of whether the device taught teaching accurate biology and engineering. The availability of feedback from a real world customer was a key factor that helped the students make design trade-offs for the device to meet the primary needs of an accurate educational device. Students appreciated that the course replaced traditional exams with oral presentations where they received feedback from potential users of their devices. Partnership with the academy changes the university course from being motivated by a real world problem, to having a problem to solve for a real customer. The academy serves as a real world customer, provides scientific advice, exposes students to other STEM careers, provides an opportunity for undergraduate students for follow-on development in an area that the students may not have thought was an engineering domain, and gives several undergraduate students an opportunity to meet K-12 students and be mentors (although for a short time).

2. A small number of teams have returned after the completion of the course to further develop their devices and have shown development of a greater skill set. Although a significant portion (estimate 60%) of the teams claim to be excited about the projects and consider further development, not all projects merit further advancement, and not all of the teams that do well, have the time nor the desire to engage in a more terms of product development. Five teams have refined their devices beyond prototypes. The devices developed by these teams were: swimming turtle (Fig 7a,b), goldfish (Fig 6), archerfish (Fig 6), head-neck dynamics(Fig 7c), and dinosaur limb (Fig 7d) . In 2013, during the development of the goldfish and archerfish, the progress of students was documented. Based on the feedback from four graduate teaching assistants, who have taught the course multiple times, all the undergraduate students (total student =11) showed better communication, presentation, design, engineering, and problem solving skills compared to during the ten week product development course. During the extended ten week independent study, the undergraduate students go through iterative dialogue with the educators at the academy. The educators provide with feedback at various stages of the development to ensure that the device can successfully engage and teach biology and engineering to middle- and high-school students. The undergraduate students, who participate in the extended ten week independent study, develop a great appreciation towards a formal design course and the importance of learning design needs before producing a device. They have expressed that their dedication towards the design of the device and the course increased after they visited NJAAS and interacted with the students and educators there. They have also expressed that the partnership with NJAAS helped them learn and appreciate the biological phenomenon better than they would have in the absence of the partnership. A quote from a student from the archerfish team: “I

always thought archerfish was really cool, but in the last couple months [through the course and independent study], I learned why".

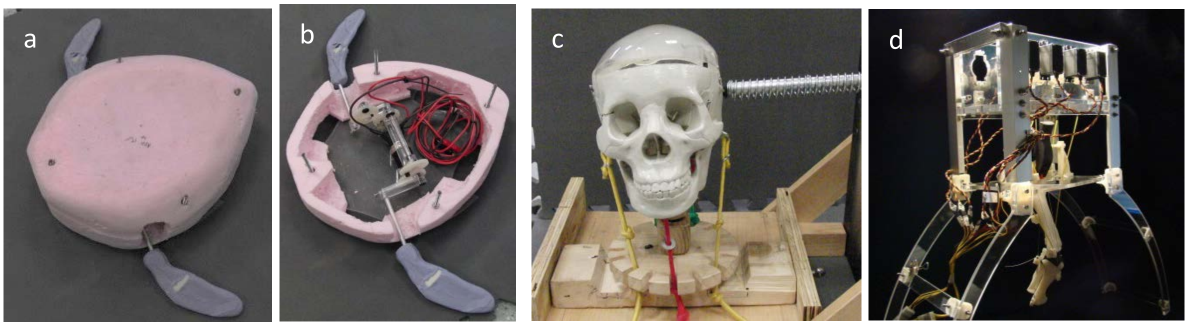

Fig 7a, b: Model of a swimming turtle developed during and independent study after the completion of course
Fig 7c: Model of head-neck dynamics being developed through an independent study, currently.
Fig 7d: Model of a dinosaur limb

3. The developed devices have successfully introduced middle school students to non-traditional, interdisciplinary engineering through the lens of biological systems and have excited them about learning engineering and design. Based on a survey of 112 middle school students at Academy of Natural Sciences of Drexel University in Philadelphia, after observing a demonstration of a biologically-inspired educational device, the students were interested in learning the design and engineering of the device as much as learning the biology. The interest in design and engineering is higher than what was recorded during a previous survey at the same museum with middle-school students. In the previous survey, the students were not exposed to a dynamic device. They were only shown pictures of biologically-inspired robots. During the survey with a live demonstration of the biologically-inspired device, middle-school students asked multiple questions about the design, engineering and biology related to the device. The most popular design and engineering questions asked by students were "Did you make this?", "How did you make this?" and "How long did it take you to make this?" Students were inquisitive about the structure and functioning of the device. They expressed that by squeezing the device, looking around it, touching it, and asking additional questions like "Where is that noise coming from?" and "Is this waterproof?" A few students also expressed interest in joining the undergraduate team to develop similar products. In addition to the design and engineering questions, a few students verbally expressed their biology learning through comments like "I didn't know this about the goldfish", "This explains the breathing of the goldfish really well", and "I wouldn't have noticed this by looking at a goldfish in an aquarium". The middle-school students also asked other biology related questions like "Do the fish feel cold in cold water?", "What happens at moderate temperatures?" and "Do fish also breathe in oxygen?" This shows that the device encourages investigation and inquisitiveness in young students.

4. The partnership has provided the academy with enthused undergraduate students who are interested in teaching STEM to youngers audience and devices for teaching biology and engineering to middle- and high-school students during NJAAS's afterschool programs. Prior to this partnership, the academy has not had a direct collaboration with engineering students who are interested in developing devices to aid the educational programs at the academy. The educators from NJAAS have expressed great appreciation towards this partnership, and have used one fully developed device (Goldfish) during their outreach program with a group of 20 middle school students. The academy has collaborated with people from science fields like chemistry and biology but this partnership is the first collaboration of the academy staff with engineers. The collaboration has helped the academy staff to tune their lessons to incorporate engineering topics. The science education manager has expressed that this interest would not have developed in the absence of partnership with the university. In 2013, two undergraduate student teams (total 11 students) returned after the course, to refine their prototypes into final devices for the academy to use. The response of the science education manager and chief operating officer and executive vice president to the devices developed at the end of independent study has been completely positive. On a scale from 1 to 5, 5 being excellent and 1 being poor, the academy staff rated the two devices as shown in Table 2. The staff confirmed that these devices will bridge the gap between what a student is verbally taught and what the student visually sees during their educational programs. They are positive that the synchronization between what is taught and visually seen will improve the experience for the middle- and high-school students. The educator who used the device during a program appreciated the ability to perform controlled repeatable demonstrations of a biological phenomenon synchronized with his lecture content. After the use of the goldfish in a

Category	Device 1: Archerfish		Device 2: Goldfish	
	Staff Person 1	Staff Person 2	Staff Person 1	Staff Person 2
Adaptability to curriculum	4	5	5	4
Ability to attract middle and high school students	5	5	5	5
Ability to teach biology	5	5	5	5
Ability to teach design and engineering	4	5	5	5
Ability to engage for 35 – 45 minutes	5	5	5	5
Safety	4	4	4	3
Robustness	4	4	3	3
Cost	4	4	5	4
Aesthetics	3	3	4	5
Ease of Use	3	3	5	4
Ability to promote STEM	4	4	5	5

Table 2: Response of NJAAS staff to two devices developed in 2013 at the end of ten week independent study.
Staff person 1: Science Education Manager
Staff person 2: Chief Executive Officer and Vice President

classroom with 20 middle school students, the science education manager from the academy expressed three major ways in which the device helped the outreach program. First, the dynamic device was successful in capturing the attention of the 20 middle school students, which is half the battle. Second, the device was a great tool to explain the students the movement of the gills and what they were going to look for in the real goldfish when they count the gill flaps in an upcoming activity. Third, the students actively engaged with the device after the lesson and related the engineering of the device to biology. For instance, the students actively turned a knob, observed the robotic fish breath faster, and successfully connected the mechanism of the device to what it meant for the biological fish. This meets the objective of introducing middle and high school students to non-traditional facets of engineering through the lens of biology. After using the device during the education program, the science education manager also expressed: "There are additional biology topics that I can think of to add to the curriculum, which I would have never done without the device".

Future Work

The project team will continue to assess the partnership and its effect on undergraduate learning to meet the NSB challenges better. Undergraduate students will be surveyed at greater length for feedback for further development of the course as well as the partnership with NJAAS. Each quarter the College of Engineering generates course evaluations for all engineering courses. The surveys measure student satisfaction based on learning outcomes and ABET a-k criteria[8]. These course surveys will also be utilized as a key tool in future assessment. The faculty professor who teaches the course will continue to track the number of students who show interest in further pursuing their work through research in the laboratory, short-term projects or senior design projects.

The fully developed goldfish device will be exposed to a larger set of audience (middle and high school students) in museums, schools and during outreach programs at NJAAS to measure its effectiveness in exciting students about engineering. The response of the students will be recorded through surveys and observation to assess the goodness of the device to teach biology and encourage learning about engineering. Attention will be paid to attract girls, underrepresented minorities, and all creative students, so that the field recruits the best and the brightest of the entire student population. This will further help addressing NSB challenges.

The project team will continue to collaborate through development of educational devices, to further improve the engineering course and NJAAS outreach programs. This will be achieved through active dialogue between NJAAS educators, undergraduate students, and graduate students in the instructor's lab (LBSA). Graduate teaching assistants of the course, faculty at the university and academy educators will work together to develop curricula to teach biology, engineering and principles of design common to both, during the academy's outreach programs. Further assessment will measure the increase in interest in careers in biology and engineering. This will be achieved through undergraduate student focus groups, course surveys, academy staff interviews, performance-based assessment of course activities, and academy student participation surveys.

Conclusion

This partnership has been advantageous for the academy as well the university and has helped address the challenges identified by the National Science Board. The project-based course provides engaging, hands-on learning for undergraduate students, that is different from typical classroom learning. The direct connection with a real customer has improved the undergraduate students' creative thinking, manufacturing, scientific analysis, business and communication skills. The undergraduate students are able to learn design with a direct practical application and develop devices to expose middle- and high- school students to exciting facets of engineering. The academy is equipped with biologically-inspired devices that make their educational programs engaging and exciting. In addition to enhancing the biology education at the academy, the academy is also able to expand their educational programs to include engineering topics.

Acknowledgments

This material is based upon work supported by the National Science Foundation under the following grants: NSF CAREER-1150681and NSF EFRI BSBA-0938043. We also thank the Academy of Natural Sciences of Drexel University for their support and cooperation during the execution of surveys for middle- and high- school students.

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