innovate the intersection of entomology and technology

What do insects, 3D printing, and integrated STEM education have in common?

by
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In *The Medici Effect*, Johansson (2004) discusses how innovative ideas often bring together seemingly unrelated subjects, ideas, concepts, and cultures. Locating innovative intersections among STEM subjects is key to the integrated STEM learning process by focusing on interdisciplinary content and skills that are centered on real-world problems or issues rather than specific subject domains (Wang, Moore, Roehrig, & Park, 2011). Integrated STEM approaches to learning provide an interesting pathway to encourage student interest and promote learning in more authentic contexts that are often lacking in schools. However, many STEM lessons fail to make connections across STEM disciplines, including many technology and engineering education courses, which are considered STEM education. These STEM courses lack integrating math and science content by not explicitly making connections, failing to teach core STEM content, and/or not integrating content into authentic learning contexts (Sanders, 2009). Students might be more engaged and excited about learning STEM subjects and pursuing STEM careers if they identified cross cutting connections and experienced the process of engineering design to solve real-world problems in authentic contexts (Stohlmann, Moore, & Roehrig, 2012). Many educators embrace the overall concept of integrated STEM, but there are

Image 1 (above): D-BAIT unit pilot students benchmarking fishing lure designs and recording data in their engineering notebooks.

Image 2: D-BAIT unit pilot students and professor observing collected specimens in an aquarium tank.

limited examples that provide STEM connections within authentic contexts.

STEM Education

While the demand for well-educated and skilled workers in STEM fields continues to grow, the pipeline of students supplying these fields does not (National Academies, 2010). Curricula in engineering and K-12 pre-engineering are being further improved to create a more effective integrated STEM education program and increase the flow of students into engineering and technology careers (Prevost, Nathan, Stein, Tran, & Phelps, 2009). Exposure and access to STEM educational activities and programs is important for middle and high school students since this developmental stage is where interest in these fields is developed and nourished (Brophy, S., Klein, S., Portsmore, M., & Rogers, C., et. al., 2008).

Ambiguity still surrounds STEM education and how it is most effectively implemented. STEM education is a popular slogan often used to imply something innovative and exciting (Sanders, 2009). Yet it often refers to the status quo of a disconnected education in the subjects of science, technology, engineering, and mathematics. This disjointed approach of subjects taught in individual silos is no longer helping America remain globally competitive (Sanders, 2009). Although K–12 research indicates integrated STEM teaching is effective, barriers still exist for students to pursue STEM career pathways partially due to lack of STEM role models (National Academies, 2011), deficiencies in career readiness, and general accessibility to post-secondary education opportunities for students from rural settings, from underrepresented minorities, and low SES populations (Sipple & Brent, 2008).

Engineering design is an ideal STEM content integrator; as a pedagogical approach it provides an authentic learning context to enhance STEM learning and can motivate students to pursue STEM careers (Katehi, et al., 2009; NRC, 2011). Furthermore, integrated STEM teaching blends scientific inquiry and engineering design, creating an ideal platform to infuse innovative additive manufacturing technology in the classroom. Understandably, teachers often struggle to locate authentic contexts for teaching STEM subjects, lack STEM pedagogical content knowledge, and lack awareness of STEM workforce practices (U.S. Department of Education, 2010). While teachers are knowledgeable in their own content area, few have worked in collaboration with teachers in other disciplines to implement an integrated STEM lesson. Implementation of integrated curriculum can be challenging, and few teachers have learned the knowledge and skills to do so confidently or have the self-efficacy to teach integrated STEM approaches (U.S. Department of Education, 2010; Sanders, 2009; Stohlmann, et. al., 2012; Nadelson, et. al., 2012).

Engaging Students in Integrated STEM Approaches

One strategy that may help overcome the void within the STEM pipeline is to engage and motivate students from diverse backgrounds to experience the integrated nature of STEM content (Stohlmann, et. al., 2012). A barrier that remains in STEM education approaches includes growing student curiosity and interest in STEM subjects by providing a realistic context where science and math intersect with technology and engineering design in a meaningful way. Guiding students to experience the interrelated connections between science, technology, engineering, and math not only can pique their curiosity about learning math and science subjects through technology education, but also provides a rationale for learning STEM subject content. People learn better when topics are more specific and within a context (Bransford, NRC, & NRC, 2000).

An integrated STEM approach allows students to obtain a mindset equipping them to think critically and innovatively. Quality STEM education will increase the pipeline of students choosing careers in STEM fields (Stohlman, Moore, & Roehrig, 2012). Improving STEM education will increase the literacy of all people in technological and scientific areas as well (Katehi, Pearson, & Feder, 2009; NRC, 2011). However, STEM education is often interpreted to mean improving science and mathematics, being mostly taught disconnected from one another in individual silos (Breiner, et. al., 2012; Sanders, 2009; Wang, et. al., 2011), with little integration and attention given to technology or engineering (Bybee, 2010; Hoachlander & Yanofsky, 2011).

Can Integrated STEM Education Make a Difference?

What if high school students were given an opportunity to learn a unique science that could pique their curiosity of the natural world? What if this new science knowledge was linked to a design challenge that required this science knowledge in order to design effective solutions? What if the design challenge involved a problem that students could relate to from prior experiences? What if students used advanced innovative technology to prototype solutions? What if students were required to generate mathematical models to predict design results? Each of these questions challenge educators to dig deeper into the approach to STEM education. Many STEM teachers desire to locate authentic design challenges that engage and motivate their students, but may lack instructional models, guidance, or confidence in implementing them (Stohlmann, et. al., 2012; Wang, et. al. 2011). The following integrated STEM unit was created to provide teachers with an instructional model and to see if linking mathematical modeling, scientific inquiry, engineering design, and innovative technology through an uncommon intersection would generate a lesson that was meaningful, engaging, and effective in improving student learning of STEM content.

Integrated STEM D-BAIT Unit (Designing Bugs And Innovative Technology)

In the following integrated STEM unit plan, the lessons will demonstrate the key principles of integrated STEM education. These principles are designed to teach students STEM content through science inquiry experiences, mathematical modeling, engineering design, and 3D printing design solutions. In this STEM unit called D-BAIT (Designing Bugs And Innovative Technology) students engage in a design activity that links the science of entomology, the study of insects, engineering design, and innovative technology. The inspiration for this project came from learning that many fishing lures were designed to capture the interest of fishermen rather than the mouths of fish. The D-BAIT unit was created as an introduction to biomimicry through an everyday context. Most students have gone fishing or know a fisherman; however, a student may never have considered a fisherman as a scientist. Experts in fly-fishing use entomological knowledge to match their bait (artificial flies) with insects hatching in or near the water being fished. The innovative idea around which to integrate STEM subjects creates an entirely new lure that resembles and behaves like prey found in the natural environment. Using an idea to intersect seemingly unrelated subjects or paths is described by Fran Johansson in *The Medici Effect* (Johansson, 2004), which inspired the D-BAIT lesson ideas. Teachers can adapt this lesson or develop their own around an idea that intersects STEM subjects.

Image 3: Prototype fishing lures mimic insects.

Entomology is extremely important to the world as insects impact the majority of the food humans consume as well as the environment in which humans live (Hevel, 2005). This field provides science and technology educators with an extremely diverse science to teach key content within biology, physics, chemistry, and potentially other sciences, because insects are the most diverse form of life on earth. This diversity provides a very large possible range of biomimicry-inspired lesson plans. In this unit, students first learn about entomology and observe how insects behave in the field. After evaluating existing lure designs, students create a prototype of a fishing lure through using the engineering design process and applying knowledge of biomimicry, mimicking an insect that commonly becomes a food source for fish. Biomimicry, or life-imitating, is a discipline that studies nature's best ideas and uses those designs to solve human problems (Debs & Kelley, 2015). Using CAD software, students develop a prototype of a lure and print it on a 3D printer. Students calculate the buoyance of their prototype to determine if it will float or sink, and then test their prediction by testing the prototype in water. The prototype can also be tested by fishing with it, giving the student further opportunity to evaluate his or her design's effectiveness as fish bait. Integrated pedagogical STEM approaches employed by the instructor include the following:

1. Maintaining an engineer's notebook (Kelley, 2011)
2. Conducting scientific inquiry investigations
3. Completing a Know, What, How, Learn, Apply, Question (KWHLAQ) report (Barell, 1995) during the inquiry investigation
4. Learning about engineering design and applying it in developing a solution
5. Designing lure prototype using CAD software

Table 1 D-BAIT Unit Lessons, Activities, and Standards

Session	Standards	Description
Introduction		Provide students with an overview of the unit, the schedule, the content, purpose, projects, facility and equipment.
Entomology Introductory Lesson		Introduce the field of entomology with a focus on aquatic entomology considering what insects live in the local environment and which type fish prefer to consume. Instruction will include pictures, examples, and possible live specimens incorporating a scientific inquiry approach to learning.
Entomology Field Observations, Counting Activity	HS-LS2-1, 2	Introduce entomology field observation activity introducing scientific practices to study the given area, to understand what and how to observe, how to quantify and record observations and numerical data, and where to look for insect populations in the water and nearby environments (if possible). Instructor will lead and supervise time of student observation in observation area and assist in collection of specimens.
Observation Data Analysis Using Scientific Inquiry Approach and Quantitative Concepts with Graphing	HS-LS2-1, 2; HSF-IF.C.7; HSN-Q.A.1; HSS-ID.A.1;	Discuss what was observed and how the numerical data was quantified. Discuss the implications of the data and make inferences about what it indicates concerning the environment observed (water quality, insect biodiversity, etc.). Model and graph the numerical data on a computer to predict the quantity of species and populations that were observed or possibly missed. Discuss the mathematical concepts that allow prediction of total insect populations and diversity of species using graphing techniques, equations, and asymptotes.
Using Aquatic Insect Observations as Bio-indicators of Water Quality	HS-LS2-6, 7; HS-LS4-5; HS-ESS3-4	Discuss how aquatic insects can be used as bioindicators of water quality in waterways since they are sensitive to environmental changes such as pollution. Calculate the biotic index based upon the tolerance scores of the observed insect life if possible (Speelman & Carroll, 2012). Discuss and evaluate what possible solutions might be used to reduce impacts of pollution.
Aquatic Entomology - Food Webs, Taxonomy		Introduce the concepts of food webs and taxonomy focusing on the aquatic entomology and fish to classify various species observed. Using an inquiry approach, have students analyze observations and data to classify the types of local insects and fish, and to identify possible food webs. Collect live aquatic insect specimens.
Insect Behavior, Fishing, and Lure Design and Function		Discuss how aquatic insects behave in water and develop explanations of how this may relate to their consumption by fish. Consider how fishing lures are designed and behave in aquatic environments to mimic live specimens. Collect live aquatic insect specimens.
Entomology Lab Observations of Specimens and Connection of Behavior and Fishing Lure Design	STL 1:F,G, J, 3:F, H	Observe behavior of live specimens and lures in an aquatic lab environment. Observe similarities and differences in behavior. Have students develop and present explanatory theories predicting how lures may behave as live specimens in attracting fish. Consider how fishing lures are designed and behave in aquatic environments to mimic live specimens. Discuss similarities and differences between live specimens and lures. Evaluate lure designs using a decision matrix for similarities to live aquatic insects and develop explanations for possible effectiveness of their function for attracting fish. Have students communicate ideas and results of these investigations verbally and in written form in science notebooks.
Introduction to Design and to the Engineering Design Process	STL 8, 9	Discuss the attributes of design including the criteria and constraints and efficiency. Introduce the engineering design process including how various components relate and form a feedback loop. Consider how modeling, testing, evaluating, and modifying are used to create practical solutions.
Examine Fishing Lures and Design Characteristics	STL 8, 9	Discuss how fishing lures are designed and manufactured with consideration as to how this informs criteria, constraints, and efficiencies.
Introduction to CAD software and 3D printing	STL 2:M, N, 3, 12:I, J, P	Introduce the basics of CAD software (as needed), and how it used in engineering design. Discuss how prototypes might be developed and important considerations for using 3D scanning and printing techniques.
CAD Lab	STL 2:M, N, 3, 12:I, J, P	Discuss and work through CAD tutorials and hands-on experiences in the CAD lab as necessary.
CAD Lab, Design of Fishing Lure, Modifications and 3D Prototype Printing	STL 2:M, N, 3, 9, 11:H, J, O, Q, 12:I, J, P	Students will design and develop prototype models for 3D printing. They may make modifications in CAD and then print them again for testing.
Testing of Prototype Lures	STL 11:K, R	Students will fish with their prototype lures to observe and evaluate the designs (if possible do this with the class or group of students).
Evaluation of Prototypes and Wrap-up	STL 11:K, R	Discuss the effectiveness of the fishing lure designs and prototypes. Students present ideas and results of their investigation. Discuss with students what they learned, enjoyed, and reflection upon how to improve the design.

6. Learning about 3D printing equipment, processes, and software
7. Mathematical modeling of prototype buoyancy
8. Managing cooperative learning skills by:
    a) Establishing team norms.
    b) Planning with Gantt charts.
    c) Creating and completing a decision matrix (Kelley, 2010).

D-BAIT Unit Description and Standards

Science standards are located in *Next Generation Science Standards High School Biology* (*NGSS*, 2013). Technology standards are from *Standards for Technological Literacy* (*STL*) published by the International Technology and Engineering Educators Association (ITEA/ITEEA, 2000/2002/2007). Mathematics standards are from *Common Core Mathematics Standards* (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010). Table 1 provides an overview of the unit lessons with possible connections to various standards. These topics could be formatted or adapted to fit various time frames and schedules.

D-BAIT Unit Pilot Test

The authors (Kelley & Knowles) piloted the unit described above with a group of undergraduate students, guiding them through the scientific inquiry and engineering design process to create a prototype fishing lure using project-based instruction. The students worked collaboratively through the design process as they engaged in inquiry investigations, conducted benchmarking exercises, built models, and created final prototypes. After learning about the science of entomology and collecting specimens in the field, students began with brainstorming ideas that could meet the consumers' needs. Eventually, students printed fishing lure 3D prototypes that were designed on CAD software. Final design ideas were informed by researching and analyzing existing designs, findings from inquiry investigations, and results from mathematical analysis.

During the pilot run of this unit, pre-service technology teacher education students at Purdue University participated in lessons just as their high school students would during the lessons. The pilot test of the unit allowed instructors and pre-service teachers to further reflect and refine the unit to ensure successful implementation in secondary classrooms. The pilot unit took place over a six-week period, with students meeting once per week for a three-hour class.

The first day was designed to introduce science inquiry within the context of entomology in order to understand scientific truth regarding insects within the fish food chain. Students were taught how learning entomology helps us better understand the natural relationships between insects, all other living things, and the overall environment. The class used inquiry to investigate the issue that, other than fly fishing, most hard-bait fishing lures do not resemble insects that live in aquatic habitats. Students were challenged to consider how insects become food sources for fish and how insects move in the water. Students documented discoveries in a "KWHLAQ" report to help them better understand the problem and what they already know about the problem. A KWHLAQ report captures answers to the following questions based on the students' existing knowledge of the subject. A KWHLAQ report asks: a) What is known?; b) What needs to be known?; c) How it will be researched?; d) What is expected to be learned?; e) How it will be applied?; f) and, What questions remain after the inquiry has been completed? (Barell, 1995). This report is recorded in students' engineering notebooks. A student example can be found in Table 2.

Table 2: Student KWHLAQ Example

K – What do you already **know** about the subject?	Insects have six legs.
W – **What** do you want/Need to find out?	We need to know what bugs do on the water, if they struggle, swim, jump, etc... This will help us understand what fish are attracted to.
H – **How** and where will you search for the information? How will you organize your investigations?	We will search for this information by getting experts in the insect field to give us information and teach us how bugs work. This encompasses their bodies, instincts, and more.
L – What do you expect to **learn**?	I expect to learn the bugs' bodies and how they move.
A – How will you **apply** what you have learned to other subjects?	I will apply the information I learned when drawing my designs and trying to mimic what bugs do in/on the water.
Q – What new **questions** do you have following your inquiry?	I want to know if fish are attracted to bugs noises.

Once students composed their KWHLAQ report, they conducted field work at Fairfield Lakes, a local county park with multiple stocked ponds, to make entomological observations. The instructor for the class invited Dr. Holland, an associate professor in Entomology at Purdue University, to assist in further investigation of the insects. Dr. Holland helped the class study terrestrial and aquatic insects by catching them in nets and placing them in an aquarium. He then explained in further detail how and why bugs move in the water and various methods of propulsion and loco-

Image 4: A prorotype design that mimics nature.

motion. Additionally, students learned that some insects have colors that indicate to predators that they possess a toxin that can make animals and fish sick if consumed. This information was helpful for students to learn when they consider what colors to avoid in final prototype solutions. This field experience built the foundation for the project, as students were able to visualize what fish eat in their natural habitat and possibly why they consume particular insects and avoid others.

During the second day, students benchmarked fishing lure designs and were asked to create a decision matrix (Kelley, 2010). The class used this matrix to find the most important elements of each lure to help inform the new designs. Next, the students created several sketches of lures based upon the information gathered from the entomological study and lure decision matrix. Once the class created these sketches, they chose one design to improve upon.

The next session was reserved for creating a drawing using CAD software. Once created digitally, students ran different analyses on the design, such as calculating the buoyancy to determine if the 3D printed lure would sink or float.

Subsequently, students printed their designs and tested them in an aquarium filled with water to see if their mathematical analysis results were accurate. Students also learned how to calculate the buoyancy manually by measuring the volume of water displaced by the lure after observing its properties in water.

To complete the unit, students would paint lures and add hooks to test at a pond or lake to see if the lure could catch fish. After testing the final designs, students would then reflect on why their bait did or did not catch any fish and be encouraged to redesign the prototype if necessary.

Summary

While some students may not be interested in fishing, the unit was designed to allow all students to relate to a common pastime. All students may not enjoy fishing, but many have either participated in fishing or know someone who does, making the context authentic and engaging. Students engage in engineering design by brainstorming ideas, iterating design solutions, and addressing constraints and criteria outlined in a design brief to meet the needs of a client—a pro fisherman seeking a new designed artificial bait. Not only does this unit contain an authentic design component, the entomology connection exposes students to a whole new science and how that science knowledge is used for everyday purposes. Final design solutions will need to leverage knowledge obtained from scientific investigations and analysis testing of prototype solutions to create the most informed design solutions. This provides an authentic link between science, technology, engineering, and math in a palatable context.

Tran and Nathan (2010) noted that innovative pre-college curricula “have the potential to deliver a broadly inclusive technical workforce as well as citizenry who are able to participate in the emerging technological and globalized society” (p. 155). Mathematics and science need to be purposely designed and explicitly implemented in the curriculum to promote learning of these subjects in technology and engineering programs (Tran & Nathan, 2010). This integrated STEM approach could be an important avenue in overcoming the shortage of those pursuing STEM degrees in the United States, better prepare students to succeed in STEM disciplines, and increase the talent pool entering the STEM career pipeline.

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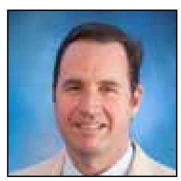

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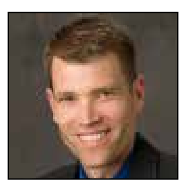

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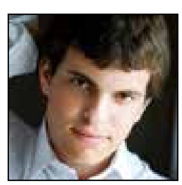

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