EbD™ IN KUWAIT
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The 2019 ITEEA STEM Showcase provides a forum to feature your best exemplar of technology and engineering instruction! Apply today to share your STEM idea, technique, or best practice related to learning activities, marketing materials, career guidance, facility design, program design, assessment methods, equity, or classroom and laboratory management techniques. In addition to regular Showcase presentations, the 2019 Showcase will also provide special Showcase subthemed areas for “STEAM” and “Collaborations and Partnerships.” Showcasers are asked to illustrate a single element of technology or engineering teaching and learning that exemplifies good STEM instruction to share with conference participants. ITEEA will be compiling these exemplars to share online as well with our members.

Questions? Email kdelapaz@iteea.org.
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The 2019 conference theme focuses on how technology and engineering bring STEM to life for all children PreK-12 and beyond. Students who study technology and engineering through an integrative STEM education approach learn about the technological world that inventors, engineers, and other innovators have created. This conference promotes sharing best practices for how technology and engineering bring STEM to life.

Strand 1: Demonstrating best practice through classroom instruction PreK-12 and beyond.
Strand 2: Identifying and discussing research that supports best practice in technology and engineering education.
Strand 3: Showcasing partnerships that support and strengthen technology and engineering education through integrative STEM Education approaches.
Strand 4: Preparing preservice and inservice technology and engineering teachers to deliver effective I-STEM Education.

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Notice: The 2017-2018 ITEEA Board of Directors election ballot, including candidate biographies, was emailed to Professional and active Life Members in late September. Exercise your right to vote by completing your ballot promptly! Ballots must be completed on or before October 31, 2018. Be sure that ITEEA has your correct email address—to review or update it, log on to your member profile on the ITEEA website by clicking on the green member login box at www.iteea.org.
Prior to this partnership, technology and engineering education was not a part of public primary or secondary education in Kuwait. Kuwait teacher education programs do not prepare technology and engineering teachers. The relationship between the SACGC and ITEEA has founded technology and engineering education as a discipline in Kuwait and has drawn math and science teachers together in partnership to implement integrative STEM education for the first time.

ITEEA’s STEM Center for Teaching and Learning™ (STEM CTL™) conducted an on-site visit in July 2015 to provide facility evaluations, staff professional development, implementation strategies, and recommendations for curriculum modifications (Mentzer, Harms, & Reed, 2015). The ITEEA consultation team (Dr. Nathan Mentzer, DTE, Philip A. Reed, DTE, Meshari Alnouri, and Mohammad Barbarji, DTE)
Mentzer, Mr. Henry Harms, and Dr. Philip Reed) toured the Fab Lab Kuwait (http://fablabkuwait.sacgc.org/) and six middle schools: two in Kuwait City (Neusaiba & Abdulla Hassan), two in Ahmadi (Sawda & Ahmed Mhashari), and two in Jahara (Halima & Abdullatif). The tours included one school for boys and one school for girls in each location. The schools that were visited were comprised of basic rectangular classrooms with individual desks and chairs as well as a mixture of projectors, LCD panels, and whiteboards (Figure 1b). Each site also contained one or two computer laboratories with approximately 20 PCs, projectors, and a SmartBoard. The Neusaiba girls' school had the unique opportunity of utilizing a science laboratory including six lab benches with water, gas, and electrical utilities as well as storage cabinets and a mixture of supplies for Earth science, physics, and biology instruction (Figure 1a).

During the 2015-2017 site visits, the team was hosted by Mr. Me-shari Alnouri, who facilitated the implementation and upkeep of the Engineering byDesign™ curriculum for the SACGC. The STEM CTL™ team met with SACGC administrators and English, science, and mathematics coordinators. The six subject supervisors reviewed the curriculum and shared examples of similar technological design activities that had recently been conducted within the gifted program. The SACGC administrators also spent a considerable amount of time educating the STEM CTL™ team on Kuwaiti cultural and traditional values. The ITEEA consultation team drew many parallels to the middle school Exploring Technology and Inventions and Innovations courses through tours around town to view architecture and discussions on water, utilities, solar energy, climate, and technological and engineering challenges that impact Kuwait. Discussions with the program administrators, as well as the mathematics and science supervisors, confirmed that these topics should be contextualized in these EbD™ courses.

EbD Implementation in Middle School: Planning and Professional Development

ITEEA’s STEM CTL™ utilized the information from the July 2015 site visit to establish an aggressive EbD™ implementation plan...
with the SACGC. In September 2015, less than one month after the site visit, a 10-day professional development course was provided for SACGC teachers by an ITEEA EbD™ National Teacher Effectiveness Coach (NTEC), Mr. Henry Harms, for Exploring Technology (Grade 6) and Inventions and Innovations (Grade 7).

A five-day professional development opportunity was provided for the Technological Systems course in September 2016 for 23 SACGC Grade 8 teachers and supervisors by NTEC Dr. Nathan Mentzer (Figure 2).

During the on-site visits, the ITEEA team met with SACGC administrators and teachers, and toured facilities. These interactions helped leverage the standards-based nature of curriculum to deliver a culturally relevant pedagogical approach. As one example, water is a critical resource, and water towers are a cultural icon. Structural design challenges in the U.S. are often focused on bridges. In Kuwait, we focused structural challenges around water towers. As another example, traffic in Kuwait City is an issue. The Grade 8 technology course has a significant focus on systems—traffic systems become a rich, relevant system to contextualize the lessons. Additionally, SACGC administrators (Sadeq Qasem and Meshari Alnouri) met with ITEEA staff in Reston, VA as well as during the 2017 ITEEA conference. Online meetings and email correspondence also helped during the initial implementation of EbD™ at the middle school level to provide support for teachers and administrators.

In the program’s initial implementation, there were a few challenges that were identified and resolved in the first year. The main challenge was that the curriculum was written in English. All the Grade 6 and 7 EbD™ curriculum was translated to Arabic very quickly over the summer of 2015. The next challenge was the co-teaching taking place within each EbD™ class. Since there were no technology education teachers in the gifted program (or the public schooling system in general), it was decided that having a mathematics and science teacher in the classroom at the same time would facilitate implementation. This would allow the teachers to contextually navigate the material along with support from Mr. Meshari Alnouri, who assisted when clarification was needed. The last, and smallest, challenge was the teachers’ inexperience with tools and machines. Few, if any, teachers had experience with power or bench tools and needed training to give them confidence prior to expanding beyond middle school curriculum.

Programmatic Evaluation

In March 2017, the fourth on-site visit was conducted by Dr. Philip Reed to provide a program review and recommendations during the second year of SACGC implementation of Engineering byDesign™ in Grades 6-8 (Reed, 2017). The program review included class observations, discussions with teachers, meetings with administrators, and facility tours. The classrooms observed...
contained dyads of teachers, one mathematics and one science, who had received the proper EbD™ course training and support materials. Classes were capped at 20 students, but most classes had 12-15 students. All students had design journals and access to tablet computers (Figure 3).

Our observations showed that all instructors used the EbD™ 6E lesson planning model (Burke, 2014; Figure 4) to deliver their lessons and effectively keep students engaged (Figure 3). Teachers used a variety of instructional strategies, including videos, projected notes and illustrations, whiteboards, and journals, among others. The Sawda Girls School, for example, used the jigsaw group strategy where students worked with multiple groups to conduct research, add journal entries, and then combine thoughts in order to present a group brief to the entire class. The EbD™ teachers all had students use their design journals, work in groups, and provide oral feedback to their classmates. Student engagement was apparent by the range of participation in discussions, hands raised, and attention to the instructors. Several students elected to present their journal reflections and/or comments in English. It was clear that the teachers observed were comfortable using instructional technology as well as a range of instructional strategies.

Facilities
The on-site visit in March 2017 revealed impressive new facilities based on STEM CTL™ recommendations and ITEEA facility standards (ITEEA, 2013). The middle school facility observed (the SACGC Academy) consisted of technology laboratories with tables or science laboratories with benches. All rooms contained a class set of tablets, whiteboards, and multimedia projectors. The SACGC has provided each laboratory (including the local middle schools and the academy) with a tool bench containing assorted hand tools and a storage cabinet complete with the supplies needed for the respective EbD™ course(s) taught in the facility (Figure 5). Additionally, each lab has been provided the following tabletop power equipment: drill press, scroll saw, combination disk/belt sander, band saw, and vacuum. The laboratory in the Boys Academy contains a side room for the power equipment (Figure 6).

The Boys Academy also contains a Fab Lab used for after-school activities that contains a CNC router, laser cutter, two 3D printers, a ceramics room, and several other rooms with modeling kits and additional equipment (Figure 7).

Additionally, there is a second staffed Fab Lab at the Boys Academy to help designers and entrepreneurs in the community. This lab contains three precision machining centers, a coordinate measuring machine, a food dryer, an extensive set of fischertechnik™ automation kits, breakout rooms, and an abundance of other tools and equipment (Figure 8).
Kuwait SACGC Faculty Become ATECs in 2017

In the summer of 2017, under the guidance of Mr. Sadeq Qa-sem, Section Head of Program Curriculum Development at the SACGC, two EbD™ National Teacher Effectiveness Coaches, Dr. Nathan Mentzer and Mr. Mohamad Barbarji, delivered a two-week workshop for four teachers and one administrator to prepare them to be EbD™ Authorized Teacher Effectiveness Coaches (ATECs). In the workshop, we focused on three main elements: refining and mastering their pedagogical content knowledge; preparing them to teach other teachers; and team teaching. We began the workshop with a needs assessment that included discussion and our observation of a lesson delivery by the participants. Based on these data, we created a routine where we modeled delivering lessons to teachers, critiqued participants practicing the delivery of lessons, and reflection.

During and after each model lesson, we reflected with the teachers about the pedagogical decisions we (and they) were making and the rationale for making these choices. We assigned each of the teachers to focus on their specialization—one was going to become an ATEC for Grade 6, one for Grade 7, one for Grade 8, and one for Grade 9. The administrator had attended all the summer institutes to date, taught and coached other teachers on the curriculum, and had a Ph.D. in education. She had participated in supervising the EbD™ implementation, and as a result was able to demonstrate competence as an ATEC in all four grades.

Each participant taught three lessons during the workshop. During and after each lesson we reflected and provided direct and specific feedback. We noted strengths and opportunities for improvement and were very impressed with the participants’ growth from the first to third lessons. Interestingly, we began to provide the critical feedback privately, but the teachers all wanted to hear our evaluation of each participant’s teaching so they could collaboratively reflect, learn, and develop. One of the benefits of all five participants earning their ATEC as a collaborative team in four different EbD™ courses was that they were very attentive to vertical alignment between the grades. They learned what is happening in grades prior to theirs (for example, how the 6th grade will be implementing design journals and what explicitly should go in them) and what came after their grade level (for example, using CAD and 3D printing in the 9th grade builds on lessons on 2D and 3D shapes in the previous grades). Interestingly, we also discovered a few humorous translation issues along the way: EbD™ curriculum was translated literally word for word into Arabic by an expert linguistic translator rather than a conceptual translation done by an expert in the content area. As a result, one of the lessons called for “self-healing mats” (one student) to cut balsa wood on their desks with razor knives. The literal translation was “Band-Aids.” We discovered this when one of the teachers was preparing to deliver the lesson and wanted to know why he needed 16 Band-Aids for the students. While a first aid kit is an essential part of the lab environment, we don’t prescribe handing out Band-Aids as a proactive measure.

The third week of the 2017 summer professional development was a summer institute for the Grade 9 Foundations of Technology course. We were joined by a dozen more teachers, some new to EbD™, some new to the school and country—all preparing to teach in the giftedness program in the fall. During the week, we modeled lessons and engaged the teachers in the learning activities and reflection. As a capstone event for the ATEC participants from the prior weeks, we strategically identified lessons for them to teach, including how to use design journals, sketching, CAD modeling, tool and machine safety, as well as some of the Foundations of Technology (FoT) lessons.

Next Steps

A team comprised of Dr. Nathan Mentzer and Mr. Mohamad Barbarji has plans to go to Kuwait during the first week of April 2019 to review implementation and refine teachers’ pedagogical content knowledge. We will collect evidence of teacher efficacy through a review of teacher and student artifacts (portfolios, design journals, video-recorded lessons, reflection, etc.). We plan to use these data to create an appropriate five-day workshop for
fostering giftedness and creativity: implementing Engineering byDesign™ in Kuwait

the Grades 6–9 teachers that includes both whole-group instruction and grade-band-specific instruction.

Current middle and high school teachers are certified in mathematics or science education. These teachers have done an admirable job implementing the EbD™ curriculum because of the support they have received from SACGC (i.e., translation of materials, classroom and lab space, release time, professional development support, etc.), their networking, and their adherence to the 6E lesson model. The dyad teaching model works well because science educators are comfortable delivering lab-based instruction, and mathematics teachers ensure math content is developmentally appropriate and relevant. By planning together, the dyads are more efficient at assembling materials and providing lessons that offer differing perspectives, which is important for adding a Kuwaiti cultural context to the curriculum.

In conclusion, ITEEA's STEM Center for Teaching and Learning, in collaboration with the Sabah Al Ahmad Center for Giftedness and Creativity (SACGC), have done groundbreaking work to establish Technology and Engineering Education as a discipline in the country of Kuwait. Currently, implementation is flourishing in Grades 6–9. With the new Academy adding one grade each year, it is hiring new teachers and expanding its offerings into high school this year for the first time. Within the next few years, the goal is to offer Grades 6-12 and, based on the success in middle school, we hope EbD™ expands further into the secondary programs.

References


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analyzing 3D-printed artifacts to develop mathematical modeling strategies

Introduction and Background
Algebra has consistently been identified as a gatekeeper subject because of the role success in algebra has on students’ ability to graduate from high school, their readiness for college-level mathematics, and their opportunities for employment (Loveless, 2013; Rech & Harrington, 2000). The importance of algebra has led to efforts to reform mathematics curriculum in schools across all grade levels so that algebraic reasoning is encouraged beginning in early elementary grades (e.g., National Council for Teachers of Mathematics, 2000; National Governors Association Center for Best Practices, 2010). In addition to algebraic reasoning, the National Mathematics Advisory Panel (2008) specified “fitting simple mathematical models to data” (p. 16) as one of the major topics of school algebra.

Mathematical modeling can be found in algebra curricula standards at both the national and local levels. The National Council of Teachers of Mathematics (2000) specifies the

by
Kimberly Corum and Joe Garofalo

While working on the modeling activity, the students also experienced the benefits of teamwork and persistence.
Mathematical Modeling

Mathematical modeling is the process of representing real-world situations using mathematics as a way to understand and solve a specified problem (Daher & Shahbari, 2015; Bliss & Libertini, 2016), and the model itself is the mathematical description of the real-world situation (Lesh & Lehrer, 2003). A model-eliciting activity (MEA) is “a problem-solving activity constructed using specific principles of instructional design in which students make sense of meaningful situations and invent, extend, and refine their own mathematical constructs” (Kaiser & Sriraman, 2006, p. 306).

The purpose of MEAs is the modeling process itself rather than the application of known procedures to produce a final solution. As a result, MEAs can accomplish several goals. By emphasizing the modeling process, MEAs encourage students to think mathematically and provide them with an opportunity to showcase their mathematical capabilities (Daher & Shahbari, 2015). MEAs also provide students with multiple entry points to a problem because they encourage authentic problem solving. Problem solving is defined as, “engaging in a task for which the solution method is not known in advance” (National Council of Teachers of Mathematics, 2000, p. 52). Because there is not a prescribed procedure for MEAs, mathematical modeling tasks are open-ended, and the final models themselves can vary (Bliss & Libertini, 2016).

Methods and Materials

The Laboratory School of Advanced Manufacturing (Lab School) is a joint venture among the Make to Learn Lab at the University of Virginia, Charlottesville City Schools, and Albemarle County Public Schools. With support from the National Science Foundation, the Make to Learn Lab, working with the Smithsonian Institution, is developing a series of Invention Kits that allow students to reconstruct historical inventions (e.g., solenoid, motor, generator, speaker). Technological literacy requires an understanding of technology as a human creation, its influence on historical inventions and innovations, and its relationship to other fields of study (ITEA/ITEEA, 2000/2002/2007). By reconstructing historical inventions (e.g., solenoid, motor, generator, speaker) using modern manufacturing techniques, students will be able to develop a deeper understanding of the relationships among technology, science, engineering, and mathematics.

The Deriving Ampere’s Law task, which is the realistic model-eliciting activity used in this study, was developed to extend the mathematics connections associated with the Solenoid Invention Kit. A solenoid is a coil of conductive wire; when electric current flows through the wire, the coil generates a magnetic field (Figure 1).

The strength of the magnetic field produced by a solenoid ($B$) is dependent on the number of wraps of wire that comprise the solenoid ($N$), the length of the solenoid ($L$), and the electrical current ($I$). This relationship is known as Ampere’s Law, $B = \mu \frac{N \cdot I}{L}$, where $\mu$ is a constant dependent on several factors. The Deriving Ampere’s Law task addresses several learning objectives across the STEM disciplines, including electromagnetism, direct and inverse variation, and problem solving (Table 1).

Table 1. Selection of Content Standards Aligned with the Deriving Ampere’s Law Task.

<table>
<thead>
<tr>
<th>Science (NGSS)</th>
<th>Mathematics (CCSS)</th>
<th>Engineering (NGSS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS-PS-3: Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.</td>
<td>6.EE.C.9. Use variables to represent two quantities in a real-world problem that change in relationship to one another.</td>
<td>MS.ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.</td>
</tr>
<tr>
<td>HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field...</td>
<td>HAS.CED.A.2. Create equations in two or more variables to represent relationships between quantities...</td>
<td></td>
</tr>
</tbody>
</table>
Development of the Deriving Ampere’s Law Task

In order to produce magnetic field strength measurements that would allow a wide range of students to be successful with this task, a set of prewrapped solenoids was designed and calibrated. Solenoid tubes of varying length were 3D-printed (Afinia H79 and uPrint SE) and then hand-wound. The final prewrapped set included six solenoids: four solenoids with 50 wraps of wire, but varying lengths (1 inch, 2 inches, 3 inches, 4 inches) and two additional solenoids measuring 2 inches, but varying wraps of wire (100 wraps, 150 wraps). A variable power supply was used to vary electric current, and PASCO’s PASPORT Magnetic Field Sensor was used to measure magnetic field strength. The sensor connected to the accompanying SPARKVUE software via Bluetooth using the PASCO AirLink interface (Figure 2, page 14).

The Deriving Ampere’s Law task was pilot-tested in April 2016. During this pilot test it was discovered that a slight shift in the placement of the coils of wire would drastically alter the magnetic field strength generated by the solenoid. While students were able to successfully derive Ampere’s Law, the inaccuracies in data collection did cause some confusion. Following this pilot test, the solenoids were recalibrated, and epoxy putty was used to secure the coils on each of the solenoids. With the newly recalibrated solenoids, the data was collected under laboratory conditions (Table 2). The power supply used for this task reliably held 3.16 A, which is why the solenoids were calibrated using this current value.

Prior to participating in the Deriving Ampere’s Law task, students used a rudimentary tangent galvanometer to explore the differences in the magnetic field strengths generated from a straight wire versus a coiled wire. Students developed a qualitative understanding that coiled wire generated a stronger magnetic field. They also spent time making and wrapping their own solenoids, which were later used to construct a motor, a generator, and a speaker.

Of the twelve students who participated in the Engineering Academy, six were purposefully selected to participate in the Deriving Ampere’s Law task. The students were grouped based on the mathematics coursework they had completed during seventh grade. The three students in the first group had already completed algebra (algebra group), and the three students in the second group had not yet taken algebra (pre-algebra group). The algebra group consisted of one male student and two female students. The pre-algebra group consisted of two male students and one female student.

The Deriving Ampere’s Law task was presented as four separate investigations (see Sidebar, page 17). In the first investigation, students were asked to relate the strength of the magnetic field produced by the solenoid to the number of wraps of wire, with the other independent variables held constant. Similarly, in the second investigation, students were asked to relate the magnetic field strength to the length of the solenoid. In the third investigation, students were asked to relate the magnetic field strength to the electric current. For each of the first three investigations, students were asked to develop a model that could be used to predict magnetic field strength. Once students had developed separate models for each of the independent variables, the fourth investigation challenged students to create a new model that related magnetic field strength to the three independent variables.

Implementing the Deriving Ampere’s Law Task During a Summer Engineering Academy

The Deriving Ampere’s Law task was implemented in June 2016 during the Summer Engineering Academy, an annual enrichment program hosted at the Make to Learn Lab in the Curry School of Education at the University of Virginia. A total of twelve rising eighth-grade students from two different local middle schools were selected by their principals to participate in the two-week-long Academy. These students worked alongside their science and engineering teachers, Curry faculty, and doctoral students to manufacture solenoids, a generator, a motor, and a speaker in order to understand the science behind these historic inventions.

The students required varying levels of scaffolding to complete the task; however, both groups were able to successfully derive

<table>
<thead>
<tr>
<th>Table 2. Solenoid Data Collected Under Laboratory Conditions.</th>
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<tr>
<td>Number of Wraps (W)</td>
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<td>50</td>
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Ampere’s Law. Students were able to relate the number of coils of wire, length of the solenoid, and current output to the strength of the magnetic field both qualitatively and quantitatively. All of the students recognized the pattern in the data they collected (e.g., as the number of coils increases, the magnetic field strength increases; as the length of the solenoid increases, the strength of the magnetic field decreases).

The students who had completed algebra referred to both the direct and inverse variations by name. These students also applied their understanding of slope (e.g., for each increase of 50 wraps, there was an increase of 36 Gauss) and used this to generate a linear equation (e.g., \(y = 0.72x\)) for the direct variations. Those who had not yet completed algebra did not recognize the types of variation, but were able to numerically predict magnetic field strength for different solenoids, even for those that they did not have (e.g., a solenoid wrapped with 200 coils would have a magnetic field strength of 144 Gauss). With additional support, these students were also able to generate equations for the individual variables (Figure 3). Students worked similarly when analyzing the relationship between current and magnetic field strength. Both groups were able to immediately recognize that the relationship between the length of the solenoid and the magnetic field strength was nonlinear. Those students who had studied algebra were able to generate the equation \(y = \frac{72}{x}\) without much difficulty. Those who had not previously studied algebra had difficulty with this at first, but eventually arrived at the same equation.

Both groups initially struggled when asked to derive an equation that incorporated all three independent variables. The students who had completed algebra initially made several intuitive attempts at combining the equations (e.g., adding terms, averaging them), but found that their equations did not work for their collected data. Once these students were reminded of the direct and inverse relationships they had previously identified, they were able to combine the equations in a way that preserved the types of variation (see Figure 4). The students who had not completed algebra were prompted to discuss the nature of direct and inverse variation prior to beginning the fourth investigation. With the types of variation in mind, all students were able to recognize the structure of the relationship as \(\frac{\text{wraps \times \text{current}}}{\text{length}}\) and they all came up with an equation similar to \(y = 0.46 \frac{NI}{L}\).

At the conclusion of the task, all students felt a sense of pride and accomplishment that they were able to derive Ampere’s Law. One student commented, “We figured out an equation without really any help. We went through the same process that a scientist [Ampere] went through, and we figured it out and we’re seventh graders. That’s pretty cool!” All of the students shared that this task was unlike anything that they had done in their mathematics classes. Unlike typical mathematics tasks, these students

Deriving Ampere’s Law Task: Investigation Descriptions

**Investigation 1: Relating Wraps of Wire to Magnetic Field Strength**

For this investigation, students are provided with a set of three solenoids. The length of the solenoid (2 inches) and the electric current (3.16 A) are held constant, but the solenoids vary in the number of wraps of wire (50 wraps, 100 wraps, and 150 wraps). There is a direct relationship between the number of wraps of wire of a solenoid and the strength of the magnetic field produced. When graphed, the data generates a straight line and the resulting equation, using the data collected under laboratory conditions (Table 2), is: \(B = \frac{36}{50} N\).

**Investigation 2: Relating Solenoid Length to Magnetic Field Strength**

For this investigation, students are provided with a set of four solenoids. The number of wraps of wire (50 wraps) and the electric current (3.16 A) are held constant, but the solenoids vary in length (1 inch, 2 inches, 3 inches, 4 inches). There is an inverse relationship between solenoid length and the strength of the magnetic field produced. When graphed, the data generates a curved line, and the resulting equation, using the data collected under laboratory conditions (Table 2), is: \(B = \frac{72}{L}\).

**Investigation 3: Relating Electric Current to Magnetic Field Strength**

For this investigation, students are provided with a variable power supply to measure the magnetic field strength of a single solenoid at varying levels of electric current. The other two independent variables (number of wraps of wire and solenoid length) are held constant. There is a direct relationship between electric current and the strength of the magnetic field produced. When graphed, the data generates a straight line, and the resulting equation, using the data collected under laboratory conditions (Table 2), is \(B = \frac{900}{79} I\).

**Investigation 4: Developing a Final Model for Ampere’s Law**

For this investigation, students are asked to review the models generated from the three previous investigations and come up with one model relating the three independent variables (number of wraps of wire, solenoid length, and electric current) to a single dependent variable (magnetic field strength). Using the data collected under laboratory conditions (Table 2), the final model is: \(B = 0.456 \frac{NI}{L}\).
were provided with an open-ended problem without a prescribed procedure. They appreciated the opportunity to explore varied solution strategies. As another student explained, “Usually in class, we do worksheets on stuff that the teacher’s been talking about on the board. [This] was something different. We had to think using our own brain to try to figure out what to do.”

Discussion

The use of the Deriving Ampere’s Law task accomplished two content-specific learning goals. First, the students who participated in the activity developed a better understanding of multivariable mathematical modeling, which was the intended goal of this model-eliciting activity. These students were able to apply knowledge that was learned in their pre-algebra and algebra classes (e.g., slope, direct variation, inverse variation) to a contextualized problem. In particular, one of the students recognized that the strategy he used to experimentally derive Ampere’s Law (i.e., identifying types of variation and arranging variables accordingly) could be applied more generally to other variables and modeling situations that involve both direct and inverse variation. Second, the students who participated in the activity also developed a better understanding of the connection between electricity and magnetism. While working through the Solenoid Invention Kit, these students came to understand that a current passing through conductive wire produces a measurable magnetic field, which can then be used to recreate a variety of artifacts. As an extension to the Solenoid Invention Kit, the Deriving Ampere’s Law task helped students develop a quantitative understanding of how different properties of solenoids (e.g., solenoid length, number of wraps of wire) affected the strength of the magnetic field generated by a solenoid.

Furthermore, working on the Deriving Ampere’s Law task provided these students with the opportunity to meaningfully engage in a scientific process. To complete the task, students had to collect and analyze experimental data. Students in both groups realized the importance of testing and verifying their hypotheses against collected data without any prompting. They also utilized multiple representations of their data (e.g., numerical, graphical) when developing their models. For example, when analyzing linear data, some students recognized that the data was linear from their data table and used a graph to confirm that. When analyzing nonlinear data, some students graphed the data to get a better sense of the relationship before settling on an equation.

The Deriving Ampere’s Law task is a complicated activity, and the open-ended nature of the task provided these students with an opportunity to recognize when and how to work as a team. For example, students in both groups allocated responsibilities during data collection (e.g., adjusting the power supply, positioning the probe). After the data was collected, students in both groups determined when working individually versus working collaboratively would be the most...
analyzing 3D-printed artifacts to develop mathematical modeling strategies

effective for data analysis. At times, the students would first work independently and then share their initial observations. At other times, the students would first collaborate with one another to assign responsibilities (e.g., deciding who would graph the collected data), and once the responsibilities were completed, the students would then regroup.

The Deriving Ampere’s Law task also fostered students’ stick-toitiveness. These students persisted for upwards of three hours to complete the task, without any obvious signs of tiring. For example, even when the students had arrived upon a final model after more than two hours of work, they still took the time to test this model against their collected data. It is worth noting that the activity took place outside of a traditional classroom setting and that the Summer Engineering Academy was scheduled during the students’ summer vacation. All of the students were motivated to complete the activity, and they voiced a sense of pride and accomplishment when they were able to successfully derive Ampere’s Law.

Conclusion

More and more schools are acquiring advanced manufacturing equipment. Activities that incorporate the use of this equipment for the purpose of teaching some academic content can either be designed or redesigned for other educational purposes as well. In the case above, the original purpose of the Solenoid Invention Kit was to help students understand the connection between electricity and magnetism. However, the kit was extended to address mathematical modeling and problem solving through the Deriving Ampere’s Law task. An ancillary outcome was that students experienced the benefits of teamwork and persistence. We believe these examples illustrate that 3D printing can be used in schools to address a variety of educational goals.

References


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This is a refereed article.
Countless research studies have shown that employing a variety of instructional methods results in greater student engagement, higher graduation rates, and better student achievement overall (Shernoff, et al., 2003). In order to incorporate a large variety of methods into the classroom, it is important to make use of external resources to help ease the workload of the teacher and supplement the existing curriculum. The school's surrounding community, its businesses, organizations, and programs can provide a wealth of instructional enhancement, expanded resources, and curricular enrichment. Perhaps the most noticeable result of a positive school and community relationship is its direct impact on classroom instruction. Connections with local organizations can help provide extended material resources to the classroom, social support for students and parents, and financial support to help teachers accomplish projects and goals that are otherwise unattainable with school resources. Capitalizing on help available from local businesses—like inviting experts in particular subject fields to the classroom—can enhance classroom instruction and address learning objectives that may be difficult for the teacher to accomplish (Fiore, 2002). Methods of using these community resources include guest speakers in the classroom, job shadowing, internship opportunities for students, developing service learning programs, and community service projects. All of these approaches enhance the existing curriculum and impact student learning by bringing expertise to the classroom and incorporating a variety of instructional methods to reach all students.

Using input from local businesses and organizations can
also enhance the curriculum by providing a practical application of the course objectives. Workplace employees may have a better view of what type of knowledge and skills are necessary to succeed in the working world. Using community and industry guidance to develop teaching methods or activities brings a real-world perspective to the technology and engineering education curriculum that gives students an accurate view of the workplace. Providing an applicable education to students gives them the “knowledge, skills, and attitudes necessary to function effectively as citizens” (Westheimer & Kahne, 2002, p. 14). Bringing this type of real-world perspective to a curriculum has benefits for students in the classroom and, more importantly, when they enter the working world.

Creating and sustaining a positive school and community relationship not only helps teachers and students, but the school as a whole. When local organizations and businesses realize the willingness of the school to collaborate and interact, they are more likely to have a positive outlook on the role of the school in the community. Westheimer and Kahne (2002) describe the benefit of collaboration between school and community to be the encouragement of "outward-looking perspectives" in students and a "renewed focus on civics and citizenship." Involving students in community activities can also develop social creativity and produce active citizens that promote positive change (Banathy, 1993). If students can develop these positive attitudes and abilities, surrounding citizens and organizations are likely to take notice and realize that the school can be an invaluable resource to the community. Impacts on student learning that can be generated by a positive school and community relationship are listed by category in Figure 1.

It is clear that a positive relationship between the school and its surrounding community can greatly impact student learning. Teachers deliver enhanced instruction with a variety of strategies; students are provided with greater opportunities and develop better attitudes towards community involvement; the school gains a better reputation with its local citizens; and local businesses and organizations realize the potential of the educational institutions in the betterment of the community. However, developing this mutually beneficial relationship takes time and effort. The most important point to keep in mind is that all parties involved need to benefit in order to develop a strong, sustainable relationship that will have the greatest impact on student learning.

Classroom Procedures

Use the following procedures and determinations of success to guide your efforts in developing a positive relationship between your school and the community. The following procedures are suggestions that sequentially build upon each other to provide the foundations for this type of relationship.

1. At the onset of each school year or semester, connect with students and parents, describe your curriculum, and point out possible community connections.
2. Discover possible connections that local businesses and organizations may have with your curriculum, and determine which of these can provide assistance that would positively impact student learning.
3. Make visits to or establish contact with the parents, local businesses, and community organizations that could be of benefit to your instruction.
4. Create and maintain a list of the contacts that demonstrate willingness to establish a relationship with the school.
5. Plan and implement a community involvement activity that will be beneficial to all the parties involved.
6. Demonstrate ways to show gratitude to the people who made your community relationship possible.

Figure 1. Major benefits of a positive school and community relationship.
7. Reflect on how well the collaborative activity impacted instruction and student learning.
8. Apply feedback and reflection to improve future collaborations between the school program and community resources.

### Determinations of Success

As the process of developing a positive school and community relationship is initiated and moving forward, it is important to evaluate progress at each procedural step to make sure the end result will be as effective as possible. As you find connections between your curricular area and the local community, implement a collaboration activity and attempt to sustain the resulting relationship; use the table below to help determine if each particular procedure has been successful or not. For each step, you should clearly notice the evidence of successful completion. If success is not completely experienced or noticed for a particular procedure, use the further suggestions to help make your efforts more effective. These suggestions refer back to the Detailed Procedures Guide that explains each procedural step and provides a few examples of evidence.

Finally, the ultimate goal of establishing and sustaining a school and community relationship is to have a positive impact on student learning. At the end of any collaboration between your students and the parents, community businesses, and local organizations, several impacts on student learning and achievement should be noted. While they can be categorized into three major sections—enhanced instruction, curricular application, and community perception—there are many different ways these impacts can be noticed and documented in a learning environment. Some of these impacts are listed by category on page 23.

The process of developing a strong, sustainable relationship between your school, its families, and the surrounding community is not one that takes place in one week, a semester, or even a whole school year. In order to develop a relationship that will be lasting and effective, this process may take several years to complete. Keep in mind that if you do not achieve success in

<table>
<thead>
<tr>
<th>Procedural Phase</th>
<th>Evidence of Successful Completion</th>
<th>Further Suggestions if No Evidence of Success</th>
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<tbody>
<tr>
<td>1. At the onset of each school year or semester, distribute a letter to students</td>
<td>✓ Parents demonstrate an accurate knowledge of your curriculum and possible community connections.</td>
<td>A Attempt to reestablish contact with parents through other proven methods.</td>
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<tr>
<td>2. Discover possible connections that local businesses and organizations may have with your curriculum, and determine which of these can provide assistance that would positively impact student learning.</td>
<td>✓ You can compile a list of local organizations and businesses whose involvement would benefit your instruction and student learning.</td>
<td>✓ Network with fellow curriculum teachers (both in and out of the district) who could provide recommendations of valuable community relationships.</td>
</tr>
<tr>
<td>3. Make visits to or establish contact with the parents, local businesses, and community organizations that could be of benefit to your instruction.</td>
<td>✓ You have met with or communicated with representatives of each prospective business or organization and have recorded their correct contact information.</td>
<td>✓ Try alternative methods of communication.</td>
</tr>
<tr>
<td>4. Create and maintain a list of the contacts who demonstrate willingness to establish a relationship with the school.</td>
<td>✓ The parents, businesses, and organizations on your list of contacts consistently respond to communication and even take the initiative to establish contact themselves.</td>
<td>✓ If contacts on your list do not demonstrate willingness to participate, try other parents and organizations that may or may not already be on your list.</td>
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<td>5. Plan and implement a community involvement activity that will be beneficial to all the parties involved.</td>
<td>✓ Gather artifacts that demonstrate the activity's positive impact on student learning and benefits to participating community members.</td>
<td>✓ Ask your participating parents and community members for suggestions as to how they can contribute to your curriculum.</td>
</tr>
<tr>
<td>6. Demonstrate gratitude to the people who made your community relationship possible.</td>
<td>✓ Parents and community members communicate their appreciation for being involved in the activity and ask for future opportunities.</td>
<td>✓ Have your students write letters, emails, or send pictures demonstrating their appreciation of the community involvement.</td>
</tr>
<tr>
<td>7. Reflect on how well the collaborative activity impacted instruction and student learning.</td>
<td>✓ You realize which parts of the community involvement activity were successful and which were not. ✓ You generate a list of possible ways to improve future collaboration.</td>
<td>✓ Ask participating parents and community members for feedback about how the activity went and how to improve future collaboration.</td>
</tr>
<tr>
<td>8. Apply feedback and reflection to improve future collaboration between school and community.</td>
<td>✓ Future parent and community involvement has a greater impact on student learning and is better received by the involved parties.</td>
<td>✓ Then seek assistance from outside sources to address feedback issues and improve future collaboration between school and community.</td>
</tr>
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your initial attempts, it is important to keep trying and find other ways to develop this important collaborative relationship.

References


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**Enhanced Instruction**

- Better student engagement during learning activities
- Higher student achievement on assessments
- Students understand the course objectives more accurately and completely
- Students are provided access to more resources and opportunities than previously available.

**Curricular Application**

- Students demonstrate realization that curriculum could be helpful in their futures.
- Students gain the opportunity to apply what they’ve learned in a real-world setting outside the classroom.
- Students are better able to decide an appropriate career path.

**Community Perception**

- Students demonstrate expanded knowledge about local community and its businesses and organizations.
- Students become concerned about the livelihood and well-being of the community as a whole.
- Students take the initiative to reach out to the local community and develop a relationship.
This month’s Safety Spotlight focuses on holding students accountable for their safety actions in STEM (science, technology, engineering, and mathematics) labs and makerspaces. Most teachers should understand the importance of a proper safety program. As STEM educators, we should review the safety rules and regulations for our labs/makerspaces with our students every year. We must also demonstrate the appropriate practices for all hazardous tools or pieces of equipment. It is critical that we document students’ knowledge of this information via safety tests and supervised demonstrations. Additionally, we are required to keep students’ safety tests with passing scores on file as evidence of their safety knowledge.

Part of instructors’ professional and legal responsibilities is to not only teach safety, but to also hold students accountable for their safety actions in the lab/makerspace. Over time I have tested many strategies to hold students accountable for safety violations. I have tried clipboards, notes on a seating chart, highlighted seating charts, an iPad, Siri notes, and even a PDA (if you do not know what a PDA is, Google it). Despite the technological advantages of some of these devices, they all required additional instructor work.

Inspired by Industry
Last year I tried something different that assisted with my hectic teaching schedule. While teaching as an adjunct for Millersville University of Pennsylvania, I was reminded that, in industry, employees are required to earn work permits or credentials prior to performing a hazardous task. Work permits signify that the individual near the hazard has had appropriate training to properly address associated safety risks. The permits also provide a form of legal documentation that demonstrates that the employer provided appropriate training (as mandated by OSHA) in the event of an accident. There are several types of work permits utilized in industry; some examples include confined

by
Scott Farmer
space, cold work, hot work, excavation, height, or electrical permits. Many of those may not be applicable in STEM labs or makerspaces, but they provide the opportunity to discuss the importance of safety and the various hazards students may encounter if pursuing a career in industry.

The work permit system adapts the industry permit concept for use in STEM labs or makerspaces. The customized permits have a small list of general safety rules for the lab or makerspace on one side. On the other side they denote the class and year for which the permit is applicable. The permits are copied on color-coded cardstock to help differentiate between the various class sections using the lab or makerspace each semester. The color-coding also helps identify which students have permission to use certain tools/equipment if they visit after school or during study hall to work on projects while supervised (e.g., CNC permits are a different color than metalworking equipment permits). The permits also have three “Xs” on this side to help document safety violations, and two phone pictures signifying mobile phone usage infractions while in the lab (Figure 1).

**How the System Works**

The work permit system is fairly simple. After a student passes all of the required safety tests, they are issued a permit dated and signed by the instructor. If the student violates a minor, non-accident-related safety rule (e.g., not wearing safety glasses, throwing an object, horseplay, etc.) they get a hole punched through one of the Xs on their permit. (I purchased a star-shaped punch so that students could not replicate it with a generic hole punch.) The first hole punched constitutes a warning, whereas the second hole punched results in a teacher detention with parent contact. Three hole punches on the same permit results in the loss of the permit and right to work in the lab, as well as an office referral for further disciplinary action. For major safety violations, the instructor always reserves the right to revoke the student’s permit and lab access.

Badge holders and clips can be purchased online at a minimal cost. Students should be required to wear their permit at all times when they are in the lab (unless performing an activity where the permit would create a safety hazard, in which case the permit should be kept nearby or could be hung from a permit board near the entrance of the lab). I have been implementing the work permit system at my school district for the past year, and I can honestly say that I LOVE it! After issuing these permits, students clip them on, knowing where they stand in terms of safety infractions and mobile phone usage. It serves as a reminder to students that each day they will be held accountable for what they do (or don’t do) in terms of safer work practices. It also teaches them to be more responsible technologically literate citizens. If they lose their permit by misplacing it or by violating multiple safety rules, they have to take all of the safety tests again in order to be issued a new permit. This system has worked well because the expectations are clear and tangible, providing an equitable way to teach students about accountability while maintaining a safer learning environment.

**Resources for Instructors**

Copies of the work permits created using Adobe Illustrator are available in Google Drive (https://drive.google.com/drive/folders/0B8TFIW31JiNKR0NsYmxCZTdvckE?usp=sharing) and can be accessed via the QR code in Figure 2. Please feel free to download the files and modify them to suit your school district’s needs. If you modify more than just the names, please upload your modifications to the folder to share with others.

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design fixation and divergent thinking in primary children

Designers of all ages and engaged in all disciplines can benefit from divergent thinking exercises and approaches to design.

S uppose you are standing on the side of the road waiting for a bus while dressed professionally for a meeting (e.g., pants, blouse/dress shirt, belt, dress shoes). As a car drives by, an important paper is whisked from your hand onto the busy street about six feet in front of you. This paper is of utmost importance to you and cannot be replaced. You look around and realize there are no other individuals nearby, you have nothing in your pockets but your wallet and keys, and there will be no break in cars for several minutes. Knowing you cannot safely stop traffic or retrieve the paper by entering the road, you must come up with a different solution. How will you get the paper? Go ahead and think it through in your mind—what would you do?

Now that you have an idea in place, think it through more carefully—how exactly will you proceed? What specific steps will you take? What could go wrong? Is there a better way?

by Scott R. Bartholomew and Emily Yoshikawa Ruesch

Figure 3 (above). As students are introduced to the Design Challenge, teachers often provide examples of solutions or approaches to solving the problem, which can result in design fixation on the provided example solutions.
Now, instead of standing on the road in professional attire, you are wearing a pair of athletic shorts and a t-shirt, and have a water bottle in your hand. The paper is still incredibly valuable and must be retrieved, but instead of coming from a meeting, you are coming from the gym. Does your solution change? Were your plans frustrated? How did the differences in the scenario change your approach?

Fixation

Research has shown that once a potential solution to a problem has settled into one’s mind, it can be difficult to break from the original idea and move in a different direction (Cardoso & Badke-Schaub, 2009; Jansson & Smith, 1991). When designers are given examples (whether as models, photographs, sketches, or drawings), they often fixate on those examples and fail to move creatively away (Atilola & Linsey, 2015; Cardoso & Badke-Schaub, 2009). This original-idea fixation can limit a designer’s creativity and ability to generate new ideas (Toh, Miller, & Kremer, 2014), as they may use more energy trying to force their original idea into working than they might in developing new and innovative approaches that might produce a better outcome (Hout, 2013).

Fixation is not a problem confined to professional designers or adults; rather, idea fixation manifests itself in students of all ages and in a variety of context areas as well (Nicholl & McLellan, 2007). In fact, many classes with problem-based learning and design-oriented opportunities utilize educational practices that may lead students down procedural paths that encourage fixation (McLellan & Nicholl, 2011).

Think about the students you teach/know/interact with—have you ever noticed that, as students work either alone or in groups, they are often more willing to fail with their original idea than they are to test a new and potentially better approach? This fixation on original ideas can be almost “natural” and may impact the design process detrimentally, as students can become fixated, automated, and robotic (McLellan & Nicholl, 2011).

Our recent work with Kindergarten students involved in an open-ended design problem revealed that design fixation is a real concern for students as young as Kindergarten (6-7 years old). This piece looks at our experiences as well as several suggestions—both anecdotal and research-based—that may be useful in assisting students to overcome design fixation.

Fixation in Kindergarten Design

Our recent research efforts with Kindergarten students involved the children working on an open-ended engineering design problem around stopping spiders from climbing where they were not wanted (see Yoshikawa & Bartholomew, 2017). An initial step in this process of designing involved the students working in groups, with a worksheet designed to assist them in generating ideas, designing, and finally prototyping a solution to the proposed problem (Figure 1).

This worksheet was broken down into three portions, with specific areas for students to work through different steps in designing.

1. Students were asked to provide three possible solutions to the problem. After they had listed initial solutions, they were invited to go look at the materials cart and return to planning.
2. After looking at the materials, the students were asked to provide three additional solutions based on the materials available.
3. Students were asked to draw a picture of a potential solution to the problem. This could be based on their initial ideas and/or their ideas derived from the available materials or other sources.

As researchers and observers, the authors noticed an almost immediate trend of design fixation among the students; conscious efforts were made to observe student tendencies and investigate the results on student success. At the conclusion of the project,
all student work was collected (portfolios and prototypes) and, using qualitative analysis (Boyatzis, 1998) of the student portfolios, it was determined that, of the 17 students included in this exploratory research project, 11 demonstrated multiple trends of fixation in their designing. These trends—exhibited by Kindergarten students in this study—can be seen in students of all ages and across a wide variety of contexts (McLellan & Nicholl, 2011; Imai, 2000). We separated the findings into three categories, based on idea-fixation research, which align with work done by Purcell & Gero (1996) and Zahner, Nickerson, Tversky, Corter, & Ma (2010).

1. **Original-solution fixation.** Students listed several ideas but did not deviate from their originally listed solution in designing or prototyping.

2. **Original-concept fixation.** Students offered only one “type” of solution, with all their suggestions appearing as slight variations of the originally listed idea.

3. **Problem fixation.** Rather than fixating on a particular solution, some students instead fixated on the problem. Their solutions ended up coming in the form of “Band-Aid” approaches—ideas meant to solve the problem only temporarily instead of a more developed, long-term solution that may have involved materials and ideas not directly connected to the problem at hand. For example, some student solutions revolved around, “catching the spider,” or, “grabbing the spider,” as opposed to a potential long-term idea for keeping the spider out.

While many students were still able to express some form of creativity, the student designs often showed the inhibiting effects of fixation (e.g., lack of broad solution exploration). Additionally, student ideation in this project often stalled quickly due to the inability of students to see beyond an original solution or conceptual approach. With only 6 of the 17 students not displaying fixation traits, the necessity for assisting students in overcoming design fixation should be emphasized by all teachers working in creative and ill-structured design problems. International standards support this idea with an emphasis on assisting students to overcome design fixation—even at an early age (ITEA/ITEEA, 2000/2002/2007).

**Divergent Thinking**

A potential remedy that may assist in overcoming idea fixation is embodied in the research and practice around *divergent thinking* (McCrae, 1987; Wells, 2016). Divergent thinking is the process of generating creative ideas and potential solutions by exploring a wide array of possible approaches, solutions, and remedies for an open-ended problem (McCrae, 1987). Divergent thinking activities such as brainstorming, play, and storytelling are approaches that can foster innovation, creativity, and success in open-ended situations (Ziv, 1983; Cooper, 1995; Baer, 1993). Specific approaches and activities to foster divergent thinking in students are highlighted below.

**Play.** Lieberman (1965), specifically researching young children, found that, “playfulness in kindergarten children provides clues to ease in functioning in a structured-test situation measuring ideational fluency, spontaneous flexibility, and originality” (p. 222). Lieberman argued that play, something that comes naturally for young children, can promote brainstorming and idea stimulation. Think about little kids role-playing and devising “adventures”—these scenarios often follow very unscripted and diverse pathways (Gmitrová & Gmitrov, 2003). Allowing and facilitating a more “playful” classroom environment where students are encouraged to have fun, use their imaginations, and build off the ideas of others are all ways divergent thinking can be fostered in students.

**Productive Failure.** Another approach for fostering divergent thinking in students involves guiding them through productive failure (Kapur, 2008). Productive failure is a process of persisting through multiple design approaches and solutions while learning and adapting from previously unsuccessful attempts (Simpson & Maltese, 2017). Although common jargon and perceptions identify failure negatively as a “bad” outcome, research shows that responding positively to failed attempts, and learning from those attempts, can launch students to greater gains and achievement (Holmes, Day, Park, Bonn, & Roll, 2014; Kapur, 2017; Lorenzet, Salas, & Tannenbaum, 2005). Kapur and Bielaczyc (2012) identified several key traits associated with the design task, student participation, and the social structure that can help facilitate a productive failure environment for students, including building on students’ prior knowledge in new learning scenarios and highlighting critical ideas and concepts for success. Further, students
need to be adequately challenged within a safe, collaborative environment that allows them to constructively critique others while also building off of the suggestions of others.

**In the Classroom**

Teachers can, and should, make a conscious effort to provide an environment that facilitates divergent thinking. Several intentional procedures may assist teaching with this approach:

**Do not offer solutions.** When presenting an open-ended problem to students, teachers should resist providing possible examples or solutions. While it may be easy, when explaining the problem or the criteria and constraints, to suggest an example of a solution, teachers should avoid this practice, as research shows that even if students do not choose to follow an initial provided solution, it can be hard to stray significantly from the originally suggested idea (McLellan & Nicholl, 2011). For example, in our research study, the teacher mentioned that students could build something “like a screen” to stop the spider; this suggestion ended up contributing to idea fixation in many students, as they were unable to move away from the initial idea of a screen-like trap or door.

**Allow for playful brainstorming.** At the outset of an open-ended design problem, encourage “crazy” ideas that push the limit and move beyond the “obvious” solution to problems. As students are allowed to be open with ideas, new networks for brainstorming may open up, and when students know that any idea is an option for brainstorming, the playful aspects of the process may help them to continue to grow and brainstorm in the future (Russ, 2003). The removal of impractical solutions can be accomplished in future steps of the design process as students move forward.

**Encourage brainstorming after research.** Traditional design process models (Figure 4) often denote students researching possible solutions as part of the initial efforts towards design (Hynes, Portsmore, Dare, Milto, Rogers, Hammer, & Carberry, 2011; Wells, 2016). In addition to the initial brainstorming process, it can be beneficial to continue brainstorming ideas throughout the design process as students learn from experience, failure, and success during their designing. This subtle change of encouraging brainstorming throughout the design process can help students generate solutions and divergent thinking (Agogué, Kazakçı, Weil, & Cassotti, 2011).

**Make failure and success productive.** When students come across problems, assist them in thinking through why something may have failed. Was it a consideration of the material or structure of the product, or possibly a weakness inherent in the solution? Encouraging students to learn from and in their failures can turn these roadblocks into building blocks. Teachers should strive for a classroom environment that encourages productive failure and creativity.

**Allow and encourage complete redesign.** Some limitations on resources (i.e., time or materials) may not allow for a complete redesign in every assignment, but students should not come to expect that designing is finished after the first prototype and testing. Industry designers would never expect to be “finished” after their first attempt at a solution, and it is harmful to teach our students to think this way. An environment that doesn’t allow for
redesigning can lead to a fixation on solutions, as students are determined to make one idea work, despite the flaws, for fear they will have no other option/time prior to submission. Allowing students time and flexibility to experiment and prototype with multiple ideas will open the doors for divergent thinking and approaches.

Conclusion

Think about the initial challenge we put forth—how would you retrieve the piece of paper from the middle of the street? Were your ideas fixated on an initial concept, approach, or idea? What if the scenario changed slightly and you had a hat, sunglasses, and a jump rope? What if the paper had a paper clip attached to it? What if it were a game instead of real life, and you weren’t worried about the potentially life-or-death ramifications of your attempts? Would a traffic-pattern analysis change your approach to solving the problem?

Designers—of all ages and engaged in all disciplines—can benefit from divergent thinking exercises and approaches to design. Teachers should keep these principles and suggestions in mind as they work to engage students in activities that may broaden their creativity and improve their designs.

References


design fixation and divergent thinking in primary children


McLellan, R. & Nicholl, B. (2011). If I was going to design a chair, the last thing I would look at is a chair: Product analysis and the causes of fixation in students’ design work 11–16 years. *International Journal of Technology and Design Education, 21*(1), 71-92.


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This is a refereed article.

ITEEA Elementary STEM Council’s Innovative Grand Design Challenge!

The winning Challenge earns a one-year I-STEM Education Group Membership as well as one free hotel night in Kansas City, AND a spot in ITEEA’s STEM Showcase!

The NAE Grand Challenges were designed to cause students and educators to think about solutions and challenges affecting all of our lives. It’s now time for elementary-aged students to get in on the action and show the world that they can solve big STEM design problems as well. ITEEA’s Elementary STEM Council is sponsoring the Global Design Challenge for Elementary STEM to provide students with a chance to solve a real problem and show the world that everyone can help find solutions to these global challenges.

The Global Design Challenge: elementary STEM students will work in small design teams to develop a better product or tool that can be used to give small children doses of liquid medicine. Learn full details about the Challenge at [www.iteea.org/News/282/134048.aspx](http://www.iteea.org/News/282/134048.aspx).

Questions can be directed to Michael Daugherty, mkd03@uark.edu; Virginia Jones, vjones@patrickhenry.edu; or Thomas Roberts, otrober@bgsu.edu.

Submission Deadline: December 31, 2018
The purpose of this article is to provide educators with resources to help students establish a deeper understanding of the application and role of statistical analysis within the design and innovation process. Quantitative analyses are often taught and applied through design activities, especially during testing or experimenting phases of design. However, we posit that quantitative analytics and statistical procedures are also extremely useful during the early phases of the design process (i.e., problem validation, customer analysis, problem framing). Also, we believe that when quantitative analyses are conducted within the early stages of design, the related engineering concepts are more closely connected to the human element of design. This can potentially provide more culturally relevant and authentic contexts for students to learn essential engineering concepts and skills such as the proper application of statistics to validate a problem or the economic feasibility of potential design solutions.

As a result, the lesson resources provided here can present students the opportunity to identify, define, and validate potential design problems/opportunities before attempting to design a product, thus potentially saving time, energy, and other resources. To do so, the students can be intentionally taught concepts related to quantitative analyses while linking them to entrepreneurial thinking in terms of recognizing the value proposition of potential solutions. The Advancing Excellence in P-12 Engineering (AEEE) project identified Engineering Statistics and Probability as one of the core engineering concepts fundamental for setting the foundation for students to conduct the quantitative analyses that engineers and other related professionals perform (Strimel et al., 2018). In addition, the

by
Lisa B. Bosman,
Steve O’Brien,
Susheela Shanta, and
Greg J. Strimel
AEEE project highlights entrepreneurial thinking as a fundamental engineering subconcept for enabling students to better frame problems, address customer needs, and plan for the exploitation of technological innovations. The instructional materials provided in this article have been designed to address these fundamental engineering concepts while being flexible with respect to project length (e.g., one-time, semester long, etc...), project assessment method (e.g., report, PowerPoint, poster, video, prototype, etc...), and project concepts (e.g., description statistics, regression, hypothesis testing, etc.), depending on the needs of the students.

Fundamental Engineering Core Concepts and Subconcepts

The AEEE project established a taxonomy of engineering knowledge that includes a variety of content areas, two of which are Quantitative Analysis and Ethics and Society. Each of these content areas is comprised of a series of core concepts and subconcepts deemed important for all students to learn in order to become engineering literate. Within these content areas are the core concepts of Engineering Statistics and Probability and

<table>
<thead>
<tr>
<th>Dimension: Engineering Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element: Fundamental</td>
</tr>
<tr>
<td>Content Area: Quantitative Analysis</td>
</tr>
<tr>
<td>Core Concept: Engineering Statistics and Probability</td>
</tr>
</tbody>
</table>

Overview: Engineering Statistics and Probability is important to Quantitative Analysis because engineers use statistics and probability concepts in evaluating the effectiveness of possible solutions. In this area, students should learn how to collect and analyze data through a variety of statistical and probability models.

Table 1. Sample Progression of Learning for Engineering Statistics & Probability

<table>
<thead>
<tr>
<th>Level 4</th>
<th>I can successfully evaluate and justify my possible solution through applying the most appropriate statistical or probability analysis method. (Performance Task)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 3</td>
<td>I can recognize when statistical/probability techniques are needed to solve a given problem. (Basic)</td>
</tr>
<tr>
<td>Level 2</td>
<td>I can statistically summarize a set of data through its descriptive statistics (mean, median, mode, standard deviation, etc.). (Basic)</td>
</tr>
<tr>
<td>Level 1</td>
<td>I can determine the likelihood of a certain event through basic probability rules. (Basic)</td>
</tr>
<tr>
<td>Level 3</td>
<td>I can apply advanced probability models appropriately, such as the binomial distribution and geometric distribution, to determine the likelihood of an event taking place. (Advanced)</td>
</tr>
<tr>
<td>Level 2</td>
<td>I can justify the likelihood of a certain event through the appropriate distribution table. (Proficient)</td>
</tr>
<tr>
<td>Level 1</td>
<td>I can describe a linear regression line for a set of data including two variables. (Basic)</td>
</tr>
<tr>
<td>Level 3</td>
<td>I can develop hypotheses and do statistical hypothesis testing, and then describe the result with possible statistical errors (Type I and II) in plain words. (Advanced)</td>
</tr>
<tr>
<td>Level 2</td>
<td>I can apply the appropriate method of statistical hypothesis testing to test the given hypotheses for a certain problem. (Proficient)</td>
</tr>
<tr>
<td>Level 1</td>
<td>I can identify the most appropriate method of statistical test and inference for given hypotheses. (Basic)</td>
</tr>
</tbody>
</table>
validating the value proposition of engineering design problems through quantitative analysis

**Engineering-Related Careers.** The Engineering Statistics and Probability core concept is comprised of the subconcepts of (a) recognizing, selecting, and applying appropriate probability and statistics concepts and practices, (b) basic statistics (normal distributions, percentiles), (c) probability, (d) regression, and (e) inferential statistics and tests of significance (e.g., t-tests, statistical tolerance).

The Engineering-Related Careers core concept is comprised of the subconcepts of (a) career recognition, (b) trade organizations, (c) professional licensing, and (d) entrepreneurship. In addition, sample progressions of learning to integrate these concepts into future or existing engineering coursework were created in an effort to deepen students’ engineering design practices and ultimately increase their abilities to produce optimized solutions to authentic problems (Tables 1 and 2). Relatedly, the instructional resources provided in Tables 3 and 4 have been developed to address the concepts of Engineering Statistics and Probability (Basic descriptive statistics, regression, and tests for significance) and Engineering-Related Careers (Entrepreneurship).

**Table 2. Sample Progression of Learning for Engineering-Related Careers**

<table>
<thead>
<tr>
<th>Dimension: Engineering Knowledge</th>
<th>Element: Fundamental</th>
<th>Content Area: Ethics and Society</th>
<th>Core Concept: Engineering-Related Careers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overview:</strong> Engineering-Related Careers are important to Ethics and Society because there are a variety of careers and employment opportunities in the engineering and technology industry. In this area, students should learn various engineering-related careers and general requirements and procedures to be an engineer, designer, innovator, entrepreneur, or technologist.</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 4</th>
<th>I can successfully appraise careers and employment opportunities to create a long-term plan to pursue my career goals. (Performance Task)</th>
</tr>
</thead>
</table>
| Level 3 | **Professional Licensing**
|         | I can create a plan to achieve career-related goals in terms of education, training, or work experience to achieve necessary professional qualifications. (Advanced) |
|         | **Recognition of Engineering-Related Careers**
|         | I can select one or more engineering-related careers that I am most interested in and then explain typical employers, education, and specialties for each of the careers. (Advanced) |
|         | **Trade Organizations**
|         | I can examine an industry standard developed by a trade organization and evaluate how the standard can be applied to practice and industry. (Advanced) |
|         | **Entrepreneurship**
|         | I can develop a business model in conjunction with a technological innovation. (Advanced) |

| Level 3 | **Professional Licensing**
|         | I can explain the requirements and procedures to obtain a licensure as a professional in an engineering- or technology-related career as well as the actions necessary to maintain the licensure. (Proficient) |
|         | **Recognition of Engineering-Related Careers**
|         | I can select one or more engineering-related disciplines that I am most interested in and identify a variety of career options in each. (Proficient) |
|         | **Trade Organizations**
|         | I can explain functions of more than one trade organization within the engineering and technology industries. (Proficient) |
|         | **Entrepreneurship**
|         | I can explain business functions (e.g., marketing, sales, human resources, finance, research, production, etc.) needed to validate and launch a technological enterprise. (Proficient) |

| Level 2 | **Professional Licensing**
|         | I can describe the importance of licensure and professional training in technological industries. (Basic) |
|         | **Recognition of Engineering-Related Careers**
|         | I can list and distinguish between a variety of engineering-related disciplines. (Basic) |
|         | **Trade Organizations**
|         | I can describe the importance of trade organizations within engineering and technology industries. (Basic) |
|         | **Entrepreneurship**
|         | I can describe how entrepreneurial thinking can enable the exploitation of technological innovations. (Basic) |

**References**


Table 3. Lesson Overview

Lesson Purpose: Quantitatively investigate the value proposition for a potential design scenario (before attempting to solve it). This can aid in students developing more informed design practices by engaging them in the process of clarifying problem specifications and performing investigations and analyses before generating design ideas.

Socially Relevant Context: Potential “ubiquitous” project ideas are provided below (Note: these ideas are categorized as ubiquitous to level the playing field for all students). Depending on the situation, a teacher may find the use of socially or culturally relevant design scenarios more appealing and relatable to students. Selection of an innovation or context of innovation is based on the teacher’s knowledge of his/her students and the situational characteristics of the school or classroom. However, students alone may struggle with producing ideas. Hence, the teacher should prepare ideas that, from experience, were either chosen by students or are pertinent to the social context (and are likely to be more relevant for the student[s]). Such ideas may include:

- Enhancing the public transportation experience
- Better assistive technologies
- Create the perfect carrying bag, purse, or backpack
- Improve aspects of the prom experience
- Students define their own culturally relevant problem

Core and Subconcepts in Engineering:
1. Engineering Statistics and Probability
   - Basic descriptive statistics
   - Regression
   - Tests for significance
2. Engineering-Related Careers
   - Entrepreneurship

Connected STEM Standards:
- Standards for Technological Literacy
  - Standard 6, Benchmark I: The decision whether to develop a technology is influenced by societal opinions and demands, in addition to corporate cultures.
  - Standard 11, Benchmark M: Identify the design problem to solve and decide whether or not to address it.
  - Standard 13, Benchmark K: Synthesize data, analyze trends, and draw conclusions regarding the effect of technology on the individual, society, and the environment.
- Common Core State Standards for Mathematics
  - CCSS.MATH.CONTENT.HSS.IF.C.7.A
  - CCSS.MATH.CONTENT.HSS.IF.C.7.B
  - CCSS.MATH.CONTENT.HSS.IF.C.7.C

Learning Objectives:
1. Demonstrate basic statistical analysis calculations and interpretations of hypothesis testing related to observational study, surveys, and experimental design.
2. Describe the role of statistical analysis during the design prototype, testing, and validation process.
3. Justify the value proposition aimed at an opportunity, which incorporates customer desirability, technology feasibility, and/or business viability.

Driving Questions: Who is the client or customer? Does the idea for “New Product X” have potential value in the defined customer base?

Enduring Understanding(s): Understand that significance in statistics is more complicated than “average of population A is higher than average of B.” Statistical tests are often necessary to determine if there are significant differences between two sets of data. This information can then be used to validate/invalidate a hypothesis for a novel product design (such as, the color of a button on the new calculator from gray to purple will result in more teenagers buying the product).

Career Connections: Potential career relationships can be discussed as entrepreneurial-minded engineers or engineering entrepreneurs. Kriewall and Mekemson (2010) describe these potential career emphases as follows:
- An Entrepreneurial Engineer is an individual instilled with an entrepreneurial mindset that is not necessarily aimed at the creation of a start-up business. Instead, they are interested in becoming an engineer who can design value-added products and processes that create customer demand.
- An Engineering Entrepreneur is an individual aimed toward designing, launching, and running a business venture with high risks and uncertainty.

Materials/Equipment/Software: Data analysis is required. Thus, students should have access to Microsoft Excel [or Google Sheets], or another statistical software application.

Required Student Prior Knowledge and Skills: Potential student competencies necessary for activity success are basic numeracy and basic statistics (mean, median, mode, standard deviation, range). The lesson will add in methods for data analysis and data collection (methods) as the project progresses. It is recommended that instructors collaborate with statistics/mathematics teachers for the delivery of this activity.

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Table 4. Engineering Design-Based Lesson Plan

<table>
<thead>
<tr>
<th>Engage</th>
<th>Sets the context for what the students will be learning in the lesson as well as captures their interest in the topic by making learning relevant to their lives and community.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Most people have an “idea” that they often think of and believe will be the solution to the world’s problems, be the next “big thing,” or be their ticket to millionaire status.</td>
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<td>In this lesson, students will validate the value proposition of their innovative “ideas” through quantitative analyses while exploring and applying the attributes of an entrepreneurial mindset. An entrepreneurial mindset can enable students to think and act in a particular way to discover, evaluate, and exploit opportunities by understanding the value proposition of a new idea, identifying the potential market, and adapting ideas to meet the needs and desires of various customer segments. Bosman and Fernhaber (2017) emphasize that, although one may not be an entrepreneur aiming toward starting and operating a business, an individual can think and act as an entrepreneur in an effort to discover, evaluate, and exploit opportunities for innovation.</td>
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<td>To engage the students, teachers can ask them to think about their “big idea” and charge them with creating a “Napkin Drawing” of their idea to present to the class.</td>
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<tr>
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<td>o Napkin Drawing Concept:</td>
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<tr>
<td></td>
<td>▪ On one sheet of paper, articulate what your idea is and why it matters.</td>
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<td></td>
<td>▪ Be visual. A simple diagram or sketch can best illustrate the commercial application of the idea.</td>
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<td></td>
<td>▪ Use simple language that even a young child would understand.</td>
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<td></td>
<td>▪ On one sheet of paper, articulate your idea in 1 to 2 minutes.</td>
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<td></td>
<td>▪ Need help with sketching? <a href="https://www.youtube.com/watch?v=3t9E00N2O">www.youtube.com/watch?v=3t9E00N2O</a></td>
</tr>
<tr>
<td></td>
<td>Teachers can nurture engagement by allowing students to view a video or case study of an entrepreneurial success story, providing a context for the lesson’s overarching challenge or issue. A video of two successful female entrepreneurs who built a business around the art of sketching can be found at <a href="https://vimeo.com/52170646">https://vimeo.com/52170646</a>.</td>
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<td>If some students have trouble generating an idea, you can ask them to think about one of their favorite activities and answer the following questions:</td>
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<tr>
<td></td>
<td>o How do you feel when completing the activity and why do you feel that way?</td>
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<td></td>
<td>o What about the experience is important to you and why?</td>
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<td></td>
<td>o What’s your favorite part about the experience and why?</td>
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<tr>
<td></td>
<td>o What do you hate about it and why?</td>
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<tr>
<td></td>
<td>o How might you improve this experience?</td>
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<td></td>
<td>The d.School at Stanford offers a variety of resources and activities to engage students in the innovation process.</td>
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<tr>
<td>Explore</td>
<td>Enables students to build upon their prior knowledge while developing new understandings related to the topic through student-centered explorations.</td>
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<td></td>
<td>After students share their ideas via napkin drawings and listen to the ideas of their peers, they can begin to form teams around the most interesting ideas. These teams will begin to explore the value proposition of their ideas.</td>
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<td></td>
<td>A good value proposition is crafted as a statement that is a hypothesis about the value an idea holds for its related customer base. It should be quantifiable in the terms that it either reduces a pain point for, or provides a gain to, a potential customer. It should specifically articulate “what the product might be able to do” and “why the consumer will be interested in what the product has to offer.” This hypothesis should be testable so that it can either be accepted or rejected as an economically feasible design problem through data collection and quantitative analysis (Hypothesis Testing).</td>
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<tr>
<td></td>
<td>Remember, that according to Stevens &amp; Burley (2016) “across most industries, it appears to require 3,000 raw ideas to produce one substantially new commercially successful industrial product” (p 16). Therefore, it can be important to validate a value proposition prior to exhausting resources in the creation of a prototype of a potential product.</td>
</tr>
<tr>
<td></td>
<td>Students can now work in the teams they formed to quickly establish the value proposition of their selected idea. Strategyzer provides an Ad-Lib Value Proposition Template that students can use to form a testable hypothesis of “how their product will help a specific customer segment” (<a href="https://www.trager.nl/sites/default/files/ad-lib-value-proposition-template_0.pdf">www.trager.nl/sites/default/files/ad-lib-value-proposition-template_0.pdf</a>).</td>
</tr>
<tr>
<td></td>
<td>There are also a variety of freely available resources via Steve Blank’s website (<a href="https://steveblank.com/slides/">https://steveblank.com/slides/</a>) that offer a good introduction to the value proposition.</td>
</tr>
<tr>
<td>Explain</td>
<td>Summarizes new and prior knowledge while addressing any misconceptions the students may hold.</td>
</tr>
<tr>
<td></td>
<td>The success of the project is highly correlated with prior knowledge in the following areas: Excel and/or Google Sheets, basic algebra, and statistical analysis. In addition, new knowledge will need to be presented, including the following: engineering design and entrepreneurial thinking, value proposition, application of inferential statistics, human-centric design, and the importance of the consumer’s viewpoint. Teachers can promote explanation through a discussion or assignment considering how and why decisions were made about a specific design, introducing students to concepts related to data collection, market and consumer analysis, minimal viable products, importance of features, and design thinking.</td>
</tr>
<tr>
<td></td>
<td>Vocabulary: Entrepreneurial Thinking, Value Proposition, Design Thinking, Human-Centered Design, Quantitative Analysis, Statistical Significance, Data Collection, Survey and Experimental Research Design, Alternative Hypothesis (Ha), Null Hypothesis (Ho), and Probability.</td>
</tr>
<tr>
<td></td>
<td>During this portion of the lesson, teachers will introduce the concepts of Test Cards and Learning Cards as well as the analytical process of hypothesis testing used to validate or falsify their value-proposition assumptions.</td>
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<tr>
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<td>o Test Cards help students to state their value-proposition hypothesis, plan how they will test the hypothesis, determine the metrics involved, and identify the criteria for success. (<a href="https://blog.strategyzer.com/posts/2015/3/5/validate-your-ideas-with-the-test-card">https://blog.strategyzer.com/posts/2015/3/5/validate-your-ideas-with-the-test-card</a>).</td>
</tr>
<tr>
<td></td>
<td>o Hypothesis Testing: Students may benefit from reviewing statistical tutorials through free online resources, such as Khan Academy (<a href="https://www.khanacademy.org/math/statistics-probability/significance-tests-one-sample/idea-of-significance-tests/v/simple-hypothesis-testing">www.khanacademy.org/math/statistics-probability/significance-tests-one-sample/idea-of-significance-tests/v/simple-hypothesis-testing</a>). The steps involved in hypothesis testing can include: (1) define the point of interest, (2) state the null and alternative hypotheses, (3) specify an appropriate statistical test, (4) set upper limit on the probability of Type I error (alpha level), (5) Compute the test statistic, (6) calculate the p-value, (7) state the decision of the test (reject or fail the null hypothesis), and (8) state any assumptions necessary for the results to be valid.</td>
</tr>
</tbody>
</table>
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Table 4. Engineering Design-Based Lesson Plan, continued

- **Example Value Proposition Hypothesis Testing:** Design a New Wearable Fitness Device
  - Background: A student group has done quite a bit of online research and believes there is an untapped market for wearable fitness technology for high school students participating in sports. According to a recent Forbes article, “More than half of the people surveyed (52%) were interested in buying devices like fitness monitors to track physical activity and manage personal health.”
  - Part 1: Test Card
    - Step 1: Hypothesis – We believe that 52% of high school students are looking for devices to help them track their personal health.
      - Null Hypothesis (H₀): \( p = 0.52 \) (or greater for high school students) That is, no difference from the Forbes study finding.
      - Alternative Hypothesis (Hₐ): \( p < 0.52 \) That is, findings for high school students are less than 52%, not consistent with the study.
    - Step 2: Test – To verify (accept or reject) the null hypothesis, we will survey high school students about their interest in wearing fitness technology devices.
    - Step 3: Metric – Using a measurement tool (a survey for this example), students are asked to respond (yes/no) to (a) if they actually wear a fitness technology device and (b) if they desire to wear a fitness technology device.
    - Step 4: Criteria – We are right (accept the null hypothesis) if results of the hypothesis test provide a p-value greater than or equal to a significance level, which would infer \( p = 0.52 \) or greater. This provides confidence in targeting high school students for the development of a new wearable fitness technology.
  - Part 2: Learning Card
    - Similar to the Test Card, the Learning Card provides a fill-in-the-blank approach to collect the necessary customer data to test the stated hypothesis.
    - Learning Cards include documenting the hypotheses you tested, listing what you discovered while interacting with potential customers, recording your deductions/insights gained from the hypothesis test, and stating how you will take action upon the insights gained.
    - The Learning Card is used to clearly articulate the findings involved with the hypothesis-testing process described in Part 1. These results are then used to state the decision to either reject or fail the null hypothesis as well as to articulate any assumptions necessary for the results to be considered valid.

**Engineer:** Requires students to apply their knowledge and skills using the engineering design process to identify a problem and to develop/make/evaluate/ refine a viable solution.

- During this section of the lesson, students will complete Test Cards and Learning Cards for their proposed design idea, use surveys, observations, customer interviews, or experimental design methods to collect and analyze data, and conduct hypothesis testing (from a conceptual basis) to validate the proposed value associated with their team’s idea.
- Students will then decide whether or not their idea is economically feasible. If so, they will develop a potential plan of action for moving forward with their idea. If not, they will determine ways in which they could pivot their idea based on the data they collected.

**Evaluate:** Allows students to evaluate their own learning and skill development in a manner that enables them to take the necessary steps to master the lesson content and concepts.

- Students will present (poster, presentation, and/or video) the results of their value-proposition validation process. Students should state their initial ideas, their value-proposition hypothesis, the data collection methods, their hypothesis testing procedure, whether or not the idea was validated, and potential ways their findings could be used to improve or pivot their ideas.

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Introduction

After dropping the atomic bombs that ended World War II, much of mankind moved towards taking “nuclear swords and beating them into plowshares,” thereby promoting peaceful uses for atomic energy. Many applications were considered, and today we use atomic energy for a wide variety of everyday things. One suggested application was a concept known as atomic boilers—the use of atomic energy for heating and cooling of residential homes as well as on-site generation of electricity.

In this application, a small atomic reactor would be installed in a home, with this reactor running on a charge of nuclear fuel that lasts perhaps five to seven years. For that time, heat and electricity would be available to the homeowner via the reactor, after which a new charge of fuel would provide electricity and heat for another five to seven years.

In today’s energy-hungry world, your class is challenged with designing how this whole process might work. As the students go through this activity, stress how they use energy today and the safety of various energy uses, such as storing the energy equivalent of 20 sticks of dynamite in home garages [car gas tanks], having natural gas delivered to homes for cooking, home and water heating, etc.

Above: The Next Generation Nuclear Plant will produce heat and hydrogen for industrial manufacturing as well as electricity for homes. Source: Wikimedia Commons.

by

Harry T. Roman
Strive for students to accomplish this design challenge objectively and not dismiss it outright because nuclear power tends to scare away rational thought.

Starting the Design Process

Have students conduct research about atomic energy and specifically how reactors work. What kind of reactor might work best for a home? Have small reactors been used before? How? Keep in mind that about 10% of the U.S.'s total energy economy is supplied by nuclear means. Some electric utility companies use large nuclear power plants to supply as much as 40% of their customers’ electricity demands. How is this done? The key challenge here is to apply miniature nuclear reactors to one's home—most likely in the basement or perhaps a secure and nearby underground enclosure. Nuclear reactors have been launched into space, so they can be made small. Why couldn't they be built into a home? The reactor fuel used in both a commercial nuclear power plant and a residential application being considered would use non-weapons-grade-level fuel, which is diluted. This fuel would not be capable of being exploited for nuclear weaponry and is not easily upgraded without complex recycling technology.

Think of the entire process for such an application and then consider various concerns about the steps of the process:

- Building a suitable space/enclosure for the reactor in the home
- Installing the reactor and its fuel charge
- Replacing the fuel charge every five to seven years
- Safety and monitoring of the reactor/fuel
- Shut-down of the reactor
- Disposing of the fuel charge
- Disposing of the reactor

Common sense tells us to consider that regulatory agencies at the federal and local levels would be involved heavily; but we routinely utilize regulatory agencies for other applications (e.g., city inspectors for structural, plumbing, heating, and electrical concerns). Selling a home often involves home inspections by potential buyers. Concern with lead in drinking water and other such environmental concerns can trigger regulatory activities. Oil-polluted soil, say from an abandoned heating oil storage tank near the house, would cause great concern to regulatory officials as well.

What special considerations would be necessary with a nuclear-powered home? How about the design of the basement area where the reactor and fuel would be installed? Who changes the nuclear fuel out every five to seven years? How could this be accomplished via qualified nuclear service personnel? Where might the expended fuel go after removal? How would the movement of fresh and depleted nuclear fuel around city streets be tracked and monitored?

Be Objective

Residential application of atomic power can have some significant benefits as well. Don't hesitate to address them. Think of people in homes in the aftermath of a major storm. In a self-sufficient nuclear-powered home, loss of utility-provided power is not a concern. Is a residential nuclear option valuable against storms and other natural disasters? What about tornados and earthquakes and floods?

Homeland security is another consideration if the electric energy delivery system is somehow compromised. A residential energy-generating system like an atomic boiler could be a valuable way to keep electricity flowing at the local levels. Does this help to justify atomic boilers?

This exercise is an excellent example of doing a comprehensive 360-degree look at all the aspects of a bold new way to provide energy to our homes.

Another way to look at this is to consider a nuclear submarine, where hundreds of sailors eat, sleep, and work in the vicinity of a rather large nuclear reactor.

Have fun with this challenge.

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