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Middle Grades STEM Innovation and Design Courses: From Data to Design (P12 Resource Exchange)

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After 14 years in the middle and high school math and engineering classroom where Mr. Rosen was working on the integration of engineering and robotics into the teaching of the core curricula classrooms. He has now been at Georgia Tech's CEISMC for the past 8 years working on curriculum development and research on authentic STEM instruction and directing the state's FIRST LEGO League competition program. Mr. Rosen has authored or co-authored papers and book chapters that address issues of underrepresented populations participation in engineering programs and the integration of robotics and engineering into classroom instruction.

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Roxanne Moore is currently a Research Engineer at Georgia Tech with appointments in the school of Mechanical Engineering and the Center for Education Integrating Mathematics, Science, and Computing (CEISMC). She is involved with engineering education innovations from K-12 up to the collegiate level. She received her Ph.D. in Mechanical Engineering from Georgia Tech in 2012.

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Marion Usselman is a Principal Research Scientist and Associate Director for Federal Outreach and Research at the Georgia Institute of Technology's Center for Education Integrating Science, Mathematics and Computing (CEISMC). She earned her Ph.D. in Biophysics from the Johns Hopkins University and has been with CEISMC since 1996 developing and managing university-K-12 educational partnership programs. She currently leads up a team of educators and educational researchers who are exploring how to integrate science, mathematics and engineering within authentic school contexts and researching the nature of the resultant student learning

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The NSF STEM+C project, AMP-IT-UP, has created three STEM Innovation and Design courses for grades 6-8 Engineering and Technology classrooms. Each 18-week course incorporates the practices of experimental design, data visualization, and making decisions based on evidence, as well as 21st century skills, entrepreneurial skills, and grade-level appropriate math, science, and engineering disciplinary content. The courses deliver a project-based inquiry pedagogical experience and incorporate both skill and content activities that develop and strengthen the practices.

The STEM Innovation and Design courses (STEM-ID) build skills within the individual courses, and become more complex at the higher grades, but are stand-alone and do not require earlier courses as a prerequisite. During each course, students utilize an electronic Engineering Design Log to document their design process and to serve as a repository for test data and other evidence to support the student's final design solution. The STEM-ID courses involve the use of pneumatic systems, 3-D visualization software, robotics, and 3-D printing technologies to enhance the learning environment and experience. The AMP-IT-UP project website contains teacher instructional materials, student sheets, videos, and other files needed for instruction. All of these materials are available for free download, and will be demonstrated in the Curriculum Exchange.

Course Synopses

6th grade course: "Carnival Tycoon"

Students explore the engineering design process and entrepreneurial thinking in the context of a carnival. The course begins with students making a sales pitch for a new carnival food stand based on market research. Students then run experiments using a pneumatic catapult, and they must design a new carnival game board with appropriate odds of winning. After developing their skills in engineering drawing, they re-design the catapult cradle to change the performance characteristics of their carnival game.

7th grade course: "Flight of Fancy"

Students take on the role of a new airline company and redesign airplanes to be more comfortable, profitable, and environmentally friendly. This is accomplished through a series of challenges, starting with a test flight of different Styrofoam gliders. Students then examine interior layouts, learn 3-D modeling using design software, and finally, re-design a plane using a balsa glider as a model.

8th grade course: "Robot Rescue"

Students further their understanding of the engineering design process and entrepreneurship. The course begins with a short design challenge that requires the students to design and 3-D print a cell-phone holder. Students then conduct experiments using a bio-inspired walking LEGO© robot. The course ends with an open-ended challenge to design a rescue robot capable of navigating variable terrain. During these challenges, students use LEGO® MINDSTORM NXT, 3-D CAD modeling software, and 3-D printing technologies.

AMP-IT-UP 6th Grade—Carnival Tycoon

During this 18-week 6th grade course, students will explore the engineering design process and entrepreneurial thinking in the context of a carnival. The course begins with students making a sales pitch for a new carnival food stand based on market research. Students then run experiments using a pneumatic catapult, and they must design a new carnival game board with appropriate odds of winning. Then, after some skills development in engineering drawing, they re-design the catapult cradle to change the performance characteristics of their carnival game. Students will incorporate math and science content, including data representation, probability, experimental procedures, profit calculations, drawing, and measurement.

Data Challenge:

In this challenge, students respond to a simple survey asking them basic background information, such as number of siblings and favorite dessert. This survey is used to introduce the idea of data and its many forms. Students are then introduced to the idea of marketing in entrepreneurship by watching a 'Shark Tank' video. Students study how data is used to make an effective sales pitch for a product. Students then make their own sales pitches based on the class survey data and some additional research to pitch a carnival food stand. Students are asked to develop a sign or logo for their food stand to be used as visual media during their presentation.

Systems Challenge:

Students are challenged with the redesign of a carnival game. They begin by doing market research—playing existing carnival games and documenting the probability of winning. They are then presented with a pneumatic catapult and are asked to design a 'game board' onto which projectiles launch with certain areas designated as 'winning' zones. Students learn to establish sound experimental procedures and learn the basics of how the pneumatic system works before developing a design concept. This concept is then tested for validity by performing many trials and presented to the class along with expected profit for the game.

Visualization Challenge:

Students learn the basics of isometric and orthographic sketching by drawing simple geometries and cube configurations. Students must review the notions of planes and how planes relate to how objects are viewed in 3D. Students begin to understand the idea of hidden lines in engineering drawings, and can translate drawings to design artifacts and vice-versa.

Design Challenge:

Carnival ride operators have asked for a better way to return the rafts from the end of the 'River Rapids' ride back to a holding tank. Using the pneumatic catapult, students must re-design the end effector or 'cradle' to launch these rafts back into the holding tank efficiently at the end of the day. Students must draw their designs, fabricate prototypes using folded card stock, and test their designs using proper experimental procedures. Students must present their designs at a final design review.

AMP-IT-UP 7th Grade-- Flight of Fancy

During this 18-week 7th grade course, students will pose as new airline companies and redesign airplanes to be more comfortable, profitable, and environmentally friendly. This will be accomplished through a series of challenges, starting with a test flight of different Styrofoam gliders. Students will then examine interior layouts, learn 3D modeling in IronCAD, and finally, re-design a plane using a balsa glider as a model. In addition, students will incorporate math and science content, including measurement, proper experimental procedure, data analysis, and profit calculations.

Data Challenge:

In this challenge, students explore different types of aircraft through a short research project. Then, using NASA templates, students create their own Styrofoam aircraft from meat trays. They will work in small groups to test aircraft with different wing and tail configurations. Students will have to establish a procedure for throwing the aircraft using multiple trials to get more accurate distance measurements. Students should reflect on variables and forces that affect glider performance.

Skills and Systems Challenge:

In this challenge, students are challenged with redesigning aircraft for a major airline. To begin the redesign challenge, they will need to understand the problems airlines currently face and do some market research. For this challenge, they will be asked to configure the interior of the fuselage, or the main cabin of the aircraft. After setting up different seating configurations in the classroom and measuring the seat sizes (and trying to climb over people to get in and out of their row), students should create an interior design for an aircraft that is comfortable and practical for the market they are trying to serve.

Visualization Challenge:

Students will work through tutorials in IronCAD, a 3D modeling package, to visually render a balsa glider that will be given to them. Students will have to measure the balsa gliders using rulers, calipers, and protractors, and use that information to replicate the model plane assembly in IronCAD.

Design Challenge:

In the final design challenge, students will tie everything together to redesign the balsa glider for improved performance characteristics. Students will use IronCAD to make changes to the glider design and fabricate new components by cutting thin balsa wood. Students will be asked to compare their new glider design to baseline data from the original (given) glider using proper experimental procedures and data analysis techniques. The semester should end with sales pitches from each of the student teams, presenting their company name, intended market, re-designed balsa glider, performance data, interior design, and predicted profit.

AMP-IT-UP 8th Grade Robot Rescue Challenge

During this 18-week 8th grade course, students will use further their understanding of the engineering design process and entrepreneurship. The course begins with a short design challenge, requiring the students to design and 3D print a cell-phone holder. Students then conduct experiments using a bio-inspired walking robot. The course ends with an open-ended challenge to design a rescue robot capable of navigating variable terrain. During these challenges, students will use LEGO® MINDSTORM NXT, 3D CAD modeling software, and 3D printing technologies. In addition, students will incorporate math and science content, including modeling, data analysis, scientific procedure, friction, and systems thinking.

Mini Design Challenge:

This opening challenge is designed to instill the importance of the design process, communication, documentation, and precise measurement in the design of new products. Beginning the course this way sets the tone for entrepreneurial thinking—products are designed for a client. Students will work with a partner and each design a desktop holder for their partner's cell phone per their partner's requirements. Students must document the requirements and design a solution that meets their partner's approval. Designs are rendered in a CAD package and dimensions are tested. Final solutions are 3D printed for additional testing and presentations.

Systems & Investigation Challenge:

During this challenge, students explore the behavior of a walking robot on a variety of surfaces under different operating conditions. We focus primarily on sound scientific procedure, collection of quality data, and relevant science content, including gait, friction, force, velocity, and data analysis. In terms of skills development, students will learn basic NXT programming and 3D CAD modeling, both of which will be used heavily in the design challenge. In addition, students will collect data regarding the robot's motion on a variety of surfaces. This data will be referenced during the final design challenge, as students will be asked to design a robot that is robust to changes in surfaces. Students will gain understanding of how surface interaction influences the movement of living and non-living things.

Design Challenge:

The final design challenge requires students to design a rescue robot capable of navigating a course that contains both surface and elevation changes. Students will be asked to navigate the entire engineering design process, including adequate documentation of the design requirements and constraints. They will also encounter performance objectives such as time—how fast can the robot traverse the course? Students will design new legs for the walking bot that can accommodate the varying terrain. These legs will be designed using CAD software and will be 3D printed for prototyping. Students may also make minor modifications to the physical robot design and the program. When the challenge is completed, students will pitch their designs to the class as they did in the first challenge.