

AC 2010-252: JUST DESSERTS: MECHANICAL ENGINEERING MEETS COMPUTING OUTREACH

Karen Davis, University of Cincinnati

Just Desserts: Mechanical Engineering Meets Computing Outreach

Karen C. Davis, Ph.D.

Stephanie Heil

Allison Mayborg

Adam Pulskamp

University of Cincinnati
Cincinnati, OH 45221-0030

Abstract – This paper describes high school STEM lessons created by three undergraduate Mechanical Engineering students. The students participated in a classroom outreach program called Computer Science Investigations (CSI: Cincinnati) as part of the Mentoring for Connections to Computing effort funded by the National Science Foundation's Broadening Participation in Computing program. The CSI program performs computing-themed pre-college outreach with a team of undergraduates who deliver original lessons with hands-on activities and interact with high school students in their classroom. This paper describes three lessons: (1) pipe design layout based on CAD drawings for an industrial bakery kitchen, (2) computer vision systems using optical illusions and cupcake decorating, and (3) manufacturing of plastic pellets using the creation of pixel cookies as a hands-on classroom activity. The undergraduate mentors leverage their industrial and academic experiences to create the lessons and act as role models for college and professional success. Evaluation of the activities includes a mapping to academic content standards, student interest surveys, and mentors' reflections on their experiences.

1. Introduction

The Computer Science Investigations (CSI: Cincinnati) project brings undergraduates in engineering and computing-related fields into urban STEM classrooms to interact with and teach high school students. CSI: Cincinnati is funded under the National Science Foundation's Broadening Participation in Computing program and its goals include: (1) introducing underrepresented populations of high school students to computing topics, field of study, and the profession in a fun but challenging way, and (2) training computing undergraduates to mentor youth and teach computing topics.

The team of 7 undergraduate mentors and a professor visited a Cincinnati Public School district high school mathematics class. The class of twenty 11th and 12th graders was 50% female, 73% African-American, and 8% Hispanic. The team developed and taught 7 lessons that related computing topics to everyday life and showcased career opportunities. The lessons were aligned with Ohio Department of Education Academic Content Standards for math, science, and technology [1]. For each visit, one student conducted the lesson while the rest of the team members sat with small groups of students to interact informally and assist with the lesson activities. Materials developed for activities include an online repository, lesson plans, supply lists, activity descriptions, and other supporting documents [2, 3].

In this paper, we present lessons developed by three Mechanical Engineering majors in the areas of pipe design layout, computer vision systems, and plastic production, based on the students' professional experiences. The students acquired the necessary background for their lessons while participating in the University of Cincinnati's co-operative education (co-op) program. In addition, two of the students attended the 2009 ACM SIGCSE conference and the CS Unplugged [4] workshop. All of the CSI activities are unplugged because they are designed for delivery in a classroom, not a computer lab.

Co-op has historic roots at the University of Cincinnati (UC), dating back to its inception 1906. In the College of Engineering at UC, all 9 undergraduate degree programs are 5-year programs with mandatory co-op. Students are required to complete 4 co-op terms but many complete 6-8 terms. Co-op terms alternate with academic terms during the students' middle 3 years.

The undergraduate students serve as role models who convey their significant responsibilities and achievements as a result of their college educations and field experience. They are able to relate factors that contributed to their success as well as their enthusiasm for their majors and future careers to the high school students.

Sections 2-4 illustrate the lessons and Section 5 describes our evaluation efforts.

2. Pipe Design Layout

Adam Pulskamp, a Mechanical Engineering senior, worked at three companies during his six co-op quarters. At Hixson, he worked as a Design Engineer designing plumbing and HVAC systems for new production and office facilities for companies nationwide. His second employer was U.S. Steel where he worked in plant engineering designing and implementing safety systems throughout the plant. His final co-op was with Engineering Excellence as an Associate Engineer conducting energy audits to help companies reduce their energy consumption. He used his experience designing plumbing systems to create his lesson for the students.

Summary of the Lesson Objectives: In this lesson, students learn about the different uses of industrial steel pipes used in plant design and how the process is supported by computer-aided design software. Students design a building's pipe layout with different kinds of constraints, e.g., different kinds of rooms, pipes, and pipe contents. The example is based on actual layout used for Hixson's Kitchens of Sara Lee project.

Materials: two worksheets: (1) Case File: *Building Floor Plan*, and (2) Case File: *Rules and Routing Information*; PowerPoint presentation: *Computer Science Investigations: Pipe Layout Design*; computer and projector; CAD building layout printouts (large size); colored pencils; pipe cleaners; straws; scissors; tape; and Sara Lee pies (payment for completed Case Files).

Activities:

1. Show PowerPoint presentation; engage students interactively as much as possible.
2. Give out Case File worksheets (one per student), as shown in Figures 1 and 2. Have each student brainstorm the piping layout for one system and sketch it with colored pencils. The students are responsible for designing layouts for three lines: natural gas, hot water, and cold water. The students have to decipher the legend and match it to the building floorplan, follow the rules, and create a design that correctly satisfies all the constraints. The rules are:
 - pipes over office area and kitchen are made of straws.
 - pipes in process rooms must be pipe cleaners.
 - pipes cannot pass through freezers.
 - hot water must be a closed loop, with no more than 1 full length of pipe cleaner creating a dead end.
 - pipes must be installed in layers so they do not cross both over and under each other.
 - all pipes must be installed at 90 degree angles.

In addition, the students used coordinating colors for the three types of pipe contents: for example, green straws and pipe cleaners for natural gas, red for hot water, and blue for cold water.

3. Then have the students work in groups of three or four to combine their ideas into a single piping design for the building layout.

4. Using pipe cleaners, straws, and tape, have the students simulate their design on the larger building printouts. Completed designs are shown in Figure 3.
5. When the Case File is complete, pick them up and distribute pie slices.

Connections to Computing: The lesson emphasizes the challenges of manual layout design. Class discussion asks the students to reflect on how computer software (CAD) can be used to ease or improve the design process, and the undergraduate student reinforces this in his presentation by showing screen shots of features of CAD tools. Since this lesson is designed to be self-contained within a classroom environment (not a computer lab), the students do not directly use any CAD software themselves. The professor concludes the discussion by showing a large size printout of a VLSI component/wiring diagram to relate their layout activity to computer chip design and how software supports hardware design in this industry.

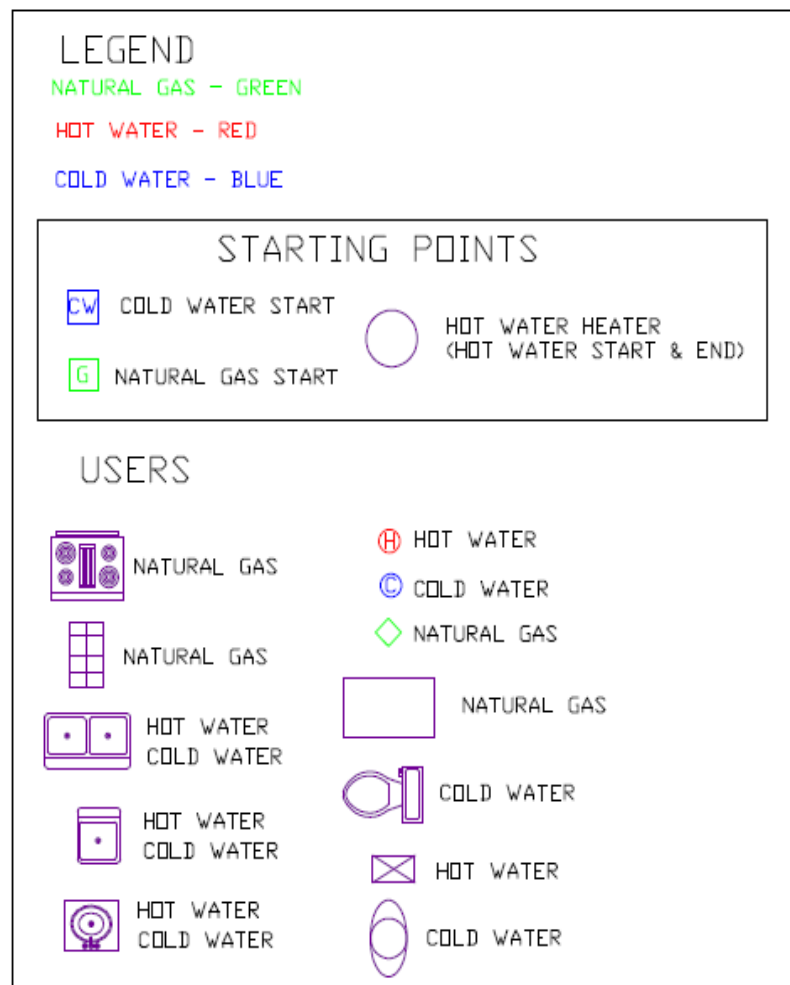


Figure 1. Case File: Routing Information

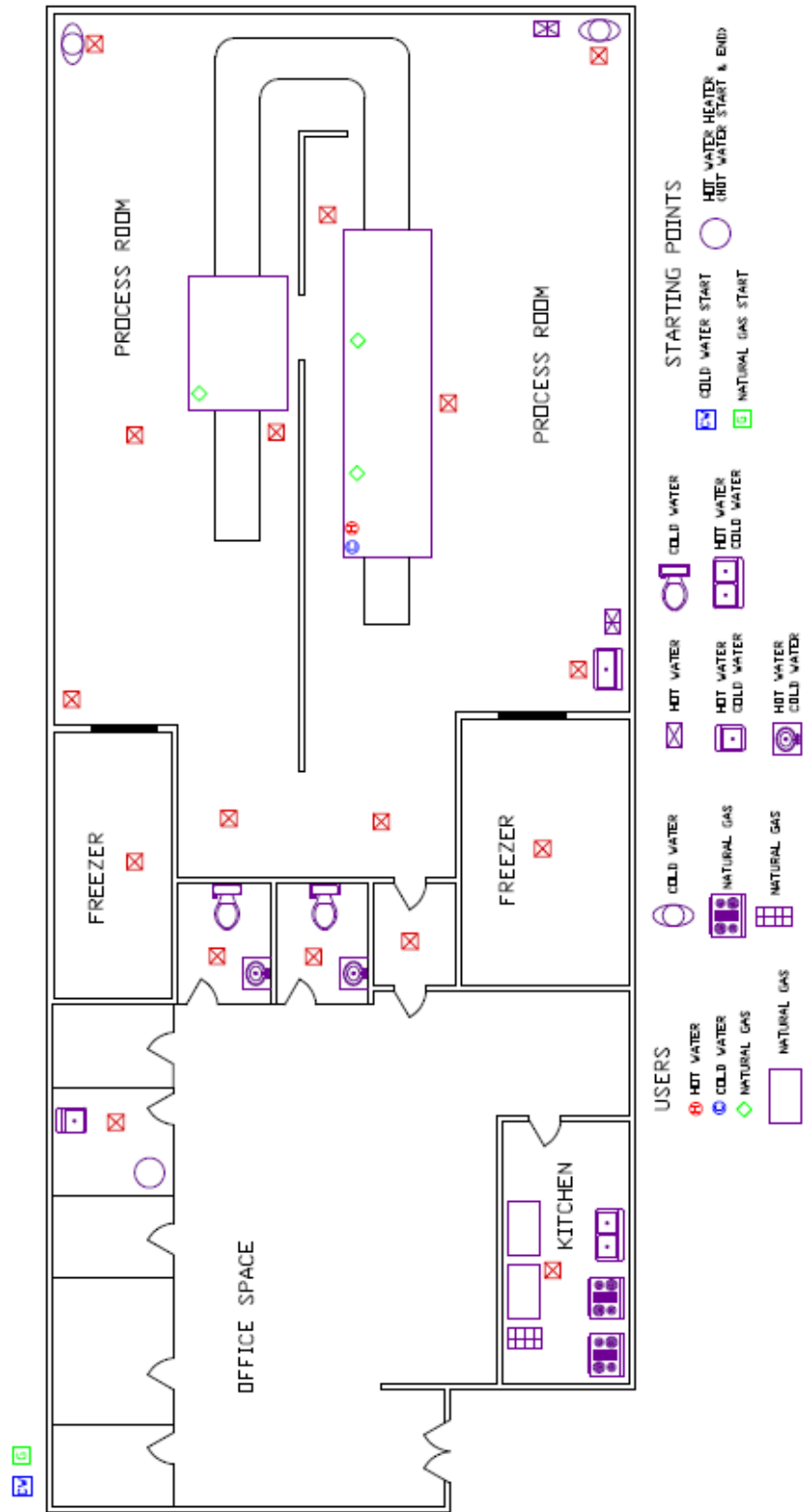


Figure 2. Case File: Building Floor Plan

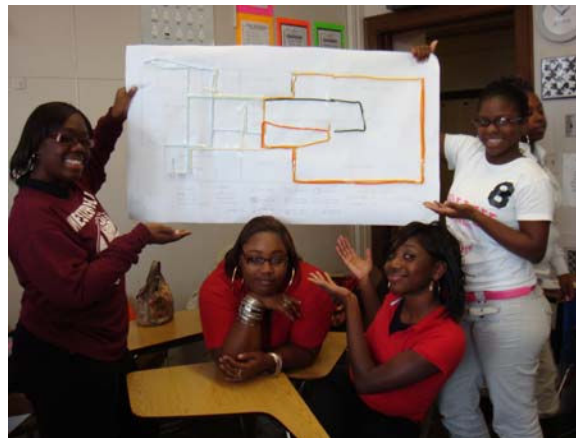


Figure 3. (a) Individual brainstorming on pipe layout design; (b) completed design on CAD layout.

3. Vision and Precision

Allison Mayborg graduated from the University of Cincinnati in June of 2009 with a degree in Mechanical Engineering. During her co-op terms at three different companies, she worked in various industries, roles, and locations. At L'Oreal USA Manufacturing, Allison worked in the packaging area for shampoo and conditioner, running time studies and starting up a new packaging line. She then went to work for Duke Energy in the generation maintenance service group. She provided technical support for capital projects at the coal fired power plants in the Midwest region. Her next assignment with Duke Energy took her to Charlotte, North Carolina where she worked on specific capital projects for four boilers and air preheaters during a spring outage. For her last co-op quarter, she worked for Procter and Gamble in the packaging development group. Most of that work was done at a manufacturing facility in St. Louis, Missouri developing specifications, standards and test methods for a new product. After graduation, Allison moved to Augusta, Georgia for a full time manufacturing opportunity with Procter and Gamble. Diverse co-op experiences helped with the design and delivery of her lesson “Vision and Precision.”

Summary of the Lesson Objectives: Students follow verbal directions (e.g., “Draw a vertical line. Draw a horizontal line about 1/3 of the way down across the vertical line” and so on.) The directions should produce a kite, but they often do not. The point of the exercise is that instructions must be precise in order for a computer to carry them out. Next, students view a PowerPoint presentation that introduces concepts related to human vision and computer vision. The presentation includes optical illusions and 3D chalk art by artist Julian Beever. The concept of using computer vision to automatically recognize objects is introduced. Figure 4 illustrates two different examples of industries (consumer product packaging and agricultural inspection) that utilize computer vision systems for quality control. The students are divided into small groups to write instructions for decorating cupcakes. They also draw top and side images that could be used by a vision system to recognize their cupcake decorations. The directions are carried out as literally as possible by the undergraduate mentors (this is messy and silly) to emphasize the importance of precise directions. The students may eat their cupcakes (or spares) afterward.

Materials: worksheet: Case File: *Following Directions*; PowerPoint presentation: *Computer Science Investigations: Vision and Precision*; computer; projector; cupcakes; and decorating supplies (icing and sprinkles).



Figure 4. Vision Systems in product and produce inspection

Activities:

1. Handout the Case File worksheet and do the first activity: follow directions to create a drawing. (The verbal directions should have the students produce a picture of a kite; often the pictures do not look like kites.) Discuss the importance of being precise and how computers can only follow precise instructions.
2. Show PowerPoint presentation; engage students interactively as much as possible.
3. Divide the class into small groups to design a cupcake decoration and instructions (excerpt from the Case File is shown in Figure 5) The rules for cupcakes are that they must (1) have a base frosting, (2) use at least three colors, and (3) have sprinkles. The boxes in Figure 5 are intended to be a simple hand-drawn color sketch that matches the students' decorating instructions.
4. Perform the instructions as literally as possible to highlight how a computerized system would fulfill imprecise instructions.
5. Pickup completed worksheets and eat the results or the extra cupcakes.

When you are finished writing your instructions, give to your group leader. Remember, they are going to follow YOUR instructions, so make sure you are telling them what you want them to do!



If you were putting your cupcake through at vision system to check for all of the necessary requirements, what picture would you show the computer for comparison???

Top View:	
Front View:	Side View:

Figure 5. Creating Specifications for a Computer Vision System

Connections to Computing: This activity highlighted careers using computer vision systems for product quality assurance and emphasized the precise nature of computer programming.



Figure 6. A student and results ready for virtual inspection and consumption

4. Pellets and Pixels

Stephanie Heil, a Mechanical Engineering senior, worked at SABIC Innovative Plastics (formerly General Electric Plastics) during her six co-op quarters. In her first term, she worked on process quality to produce plastic used in FDA and healthcare applications. Her following terms included process optimization, safety upgrades, and cost saving projects involved in manufacturing plastic pellets. She used these experiences to create her lesson about the life of a plastic pellet and making pixel cookies. Pixel cookies are built from dough extruded through a square hole and organized into a block of dough by layering the strands; the blocks are then sliced vertically to create a pixilated image. More information and examples are available on the internet [6].

Summary of the Lesson Objectives:

In this lesson students learn about the lifecycle of plastic, starting from chemical powders and other materials used to create extruded plastic pellets (illustrated in Figure 7). The processes are controlled by computers, and several different application controls screens are presented (shown in Figure 8). Commercial products created using the plastic pellets are illustrated. The activity involved designing, constructing, and baking pixel cookies using extruded dough. A student and two mentors are shown in Figure 9 baking cookies.

Materials:

- worksheet: Case File: *Pellets and Pixels*
- PowerPoint presentation: *Computer Science Investigations: The Life of a Plastic Pellet*
- computer and projector
- cookie dough [6]
- toaster oven, oven mitts, spatula, butter knife
- parchment paper (cut into small squares)
- anti-bacterial wipes

Activities:

1. Show PowerPoint presentation; engage students interactively as much as possible.

2. Handout the Case File: *Pellets and Pixels*. Have the students draw and color their design on the 6x6 grid; they will then compute how many strands of extruded cookie dough they need.
3. Have students clean their hands with anti-bacterial wipes prior to picking up dough.
4. After acquiring the dough strands, arrange them in a cube structure to match the design.
5. Slice the cube vertically to create square cookies, place on the parchment paper, and bake in the toaster oven. (Preheat the oven to 350 degrees, bake for about 10 minutes.)

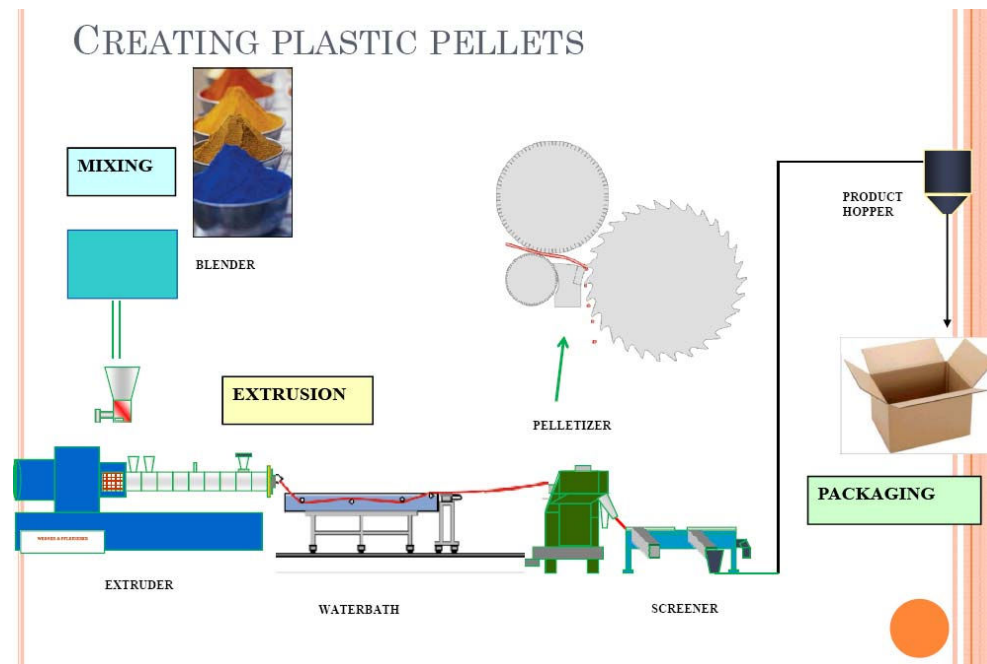


Figure 7. Manufacturing of plastic pellets

HOW ARE COMPUTERS INVOLVED?



Figure 8. Control system activities for pellet manufacturing



Figure 9. Baking student designed cookies in class

Modifications to the Lesson: In Spring 2009, the non-air-conditioned classroom was very warm, especially when a toaster oven was turned on, and the cookie dough was difficult to handle. The single oven also caused long delays in baking the cookies, resulting in down-time that we did not anticipate. As a modification to the lesson delivered in Fall 2009, we baked cookies in advance as a treat for the students and had the students use Play Doh Fun Factories to extrude Play Doh instead of edible cookie dough (shown in Figure 10). The design constraints remained the same, but there was no actual baking done in the classroom and the hands-on portion of the exercise was increased. This seemed to raise student engagement and reduce frustration and downtime. Examples of students and Play Doh pixel cookies are shown in Figure 11.

Connections to Computing: This lesson introduced an example of control system used in a manufacturing process for the purposes of plant safety as well as product quality. The concept of a computerized image being composed of picture elements (pixels) was also introduced.



Figure 10. Using Play Doh instead of cookie dough in the classroom



Figure 11. Pixel cookies with Play Doh: (a) plaid pattern, (b) UC logo.

5. Evaluation

Table 1 gives a summary of the Ohio Department of Education mathematics, science, and technology standards that were addressed in the three lessons presented here. All of the lessons discussed here use a design process and team work (technology), use scientific investigation to create models (science), and use engineering problem-solving to address multi-step, non-routine problems (mathematics). Listing the applicable standards aids teachers in deciding how our lessons can be incorporated into their classrooms and assures school administrators that the activities contribute to the accountability their curriculum must demonstrate.

Evaluation of the CSI lessons consisted of pre- and post-surveys from participating high school students and reflective exit survey answered by the undergraduate mentors. Results regarding the three lessons in this paper are summarized here. *Pipe Design Layout* was one of three lessons taught in Winter 2009 that were evaluated together. When asked “Which lesson did you learn the most from?” 64% of the respondents identified the pipe design lesson. The students commented that they liked that it was hands-on and “that certain pipes had to be laid in certain ways.” In the Spring of 2009, *Vision and Precision* and *Pellets and Pixels* were evaluated along with one other lesson on multi-tasking. The computer vision lesson and the multi-tasking lesson both rated 44% for “Which lesson did you learn the most from?” while the plastic and cookie lesson was rated only 12% for this question. In the free-form answers about “What did you learn?” 4 of the 17 respondents commented on how important it is to write precise directions. We have yet to evaluate the modifications to the *Pellets and Pixels* lesson conducted in Fall 2009, but they certainly appeared to improve the students’ engagement with the activity.

The undergraduate students serving as mentors completed an exit survey reflecting on their experiences. All three mentors felt that the high school students were impacted by their lessons. Some representative prompts and quotes are:

- What were your expectations about what you would be doing before the classroom activities started? Was the reality different from your expectations?

I expected to be doing boring activities that were already made up and we just had to teach them. The reality was that we actually got to make the lessons and create something that we were interested in. The students were really receptive to the activities because they were so creative. It was interesting participating in the lessons and seeing the reactions of the students and hearing their comments while the presenter was teaching. The “ah-ha” moments are the best. It is fun to see their minds working and problem solving, not just regurgitation of information.

- Did preparing a lesson help you learn anything about computing? About teaching? Explain and illustrate what you learned.

Preparing a lesson helped me learn a little about computing, but watching others’ lessons taught me more as my field does not use it as much. I learned about teaching and how to create a lesson plan. It was interesting to be up in front of students teaching. It taught me about patience and how to try and keep the students involved.

I learned a ton about computing! The biggest thing that I learned was about the world’s fastest computer which can do 1 quadrillion computations per second. Although this is fast, this still doesn’t compare with that of a brain which has billions of neuron connections and controls many body functions at once estimating that it can do 10 quadrillion things per second. The students I think really enjoyed this fact.

These quotes illustrate how our undergraduate students use their creativity and backgrounds to mentor younger students to increase interest in computing through applications in other fields such as Mechanical Engineering, as well as provide some insight into what the mentors themselves learned during creation and delivery of classroom lessons.

6. Related Work

A related effort at the University of Cincinnati, NSF Project STEP [5], places engineering graduate fellows into high school STEM classrooms for intensive interaction with students and teachers. Lessons developed by students, faculty, and teachers are discussed in the literature [7-11].

Ohio Department of Education Academic Content Standards: <i>Technology</i>	Pipe Layout Design	Vision and Precision	Pellets and Pixels
Standard 1: Nature of Technology (9-12)			
B. Apply technological knowledge in decision-making.	x		
Standard 3: Technology for Productivity Applications (9-12)			
A. Integrate conceptual knowledge of technology systems in determining practical applications for learning and technical problem-solving.		x	x
B. Identify, select and apply appropriate technology tools and resources to produce creative works and to construct technology enhanced models.		x	x
Standard 5: Technology and Information Literacy (9-12)			
D. Evaluate choices of electronic resources and determine their strengths and limitations.		x	
Standard 6: Design			
A. Identify and produce a product or system using a design process, evaluate the final solution and communicate the findings.	x	x	x
B. Recognize the role of teamwork in engineering design and of prototyping the design process.	x	x	x
C. Understand and apply research, development and experimentation to problem-solving.	x		x
Standard 7: Designed World (9-12)			
E. Classify, demonstrate, examine, and appraise manufacturing technologies.	x	x	x
F. Classify, demonstrate, examine and appraise construction technologies.	x		

Ohio Department of Education Academic Content Standards: <i>Science</i>	Pipe Layout Design	Vision and Precision	Pellets and Pixels
Scientific Inquiry			
(9-10) A. Participate in and apply the processes of scientific investigation to create models and to design, conduct, evaluate and communicate the results of these investigations.	x	x	x
(11-12) A. Make appropriate choices when designing and participating in scientific investigations by using cognitive and manipulative skills when collecting data and formulating conclusions from the data.		x	

Ohio Department of Education Academic Content Standards: <i>Mathematics</i>	Pipe Layout Design	Vision and Precision	Pellets and Pixels
Mathematical Processes Standard			
(8-10) A. Formulate a problem or mathematical model in response to a specific need or situation, determine information required to solve the problem, choose method for obtaining this information, and set limits for acceptable solution.	x	x	x
(11-12) A. Construct algorithms for multi-step and non-routine problems.	x	x	x
(11-12) J. Apply mathematical modeling to workplace and consumer situations, including problem formulation, identification of a mathematical model, interpretation of solution within the model, and validation to original problem situation.	x	x	x

Table 1. Ohio Department of Education Academic Content Standards used in CSI lessons

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