Rosie Revere’s Orangutan Dilemma: Integrating Computational Thinking through Engineering Practices in the Elementary Classroom

Tyler S. Love and Carolyn J. Griess

Introduction

For many years computational thinking has been taught in elementary/primary education classrooms in other countries, but in the U.S. this has only been a focus within the past few years due to the drastic shortage of computer scientists. Early exposure to computational thinking has been shown to motivate students to pursue STEM careers, especially computer science (Jin, Haynie, & Kearns, 2016). Despite this recent focus on teaching computational thinking in the early grades, many U.S. teachers still lack innovative pedagogical approaches to deliver these concepts. In the U.S., computational thinking at the elementary level is often taught using pre-assembled devices or virtual simulations/games programmed via drag and drop software (e.g., Scratch, Hour of Code). More engaging approaches that encourage inquiry and creativity when teaching computer science concepts are needed in U.S. elementary classrooms (Jin et al., 2016). In this article we present a design challenge focused on teaching third and fourth grade students computational thinking skills based on a scenario from a children’s book. The nature of this lesson lends itself to be modified for other grade levels or contexts to integrate literacy and computational thinking through authentic engineering design scenarios.

Applying computational thinking and the engineering design process are important skillsets for students because of the increasing number of engineered devices in our world that operate using programmed electronics and artificial intelligence (e.g., smart traffic signals, smart home devices). This importance is reflected in the Next Generation Science Standards
(NGSS), in which computational thinking is one of the eight science and engineering practices. It is also embedded throughout various standards within the Standards for Technological Literacy (ITEEA, 2007), the national standards for K-12 technology and engineering education. It is most meaningful to teach young students to apply these skills within the context of authentic hands-on, scientific inquiry and engineering design challenges that provide instant feedback (Love & Bhatti, 2019). This hands-on approach that integrates computational thinking and engineering design is better known as physical computing – the programming of interactive physical systems or devices via software (Cápay & Klimová, 2019). Physical computing encourages interdisciplinary learning, entrepreneurial thinking, and it fosters creativity by helping students bridge the gap between the digital and physical worlds. It also helps nurture the interaction (programming and feedback) between students and programmed devices. For example, it requires students to apply the engineering design process when developing prototypes that integrate computational devices, therefore making the students creators of technology, not solely users (Genota, 2019). Physical computing has demonstrated many learning benefits. It appeals to various learning styles by presenting computational concepts not only on the screen, but through tangible objects. Additionally, it has been shown to increase female students’ confidence in programming (Rubio, Romero-Zaliz, Mānoso, & de Madrid, 2015) and have a greater influence on student learning in comparison to traditional screen-based only experiences (Sentance, Waite, Hodges, MacLeod, & Yeomans, 2017).

**Literacy Connection**

The context for this design challenge comes from Rosie Revere’s Big Project Book for Bold Engineers (Beaty, 2017). Rosie Revere is an elementary student with aspirations of
becoming an engineer. This book invites students to help Rosie participate in engineering challenges. The design of the book features engaging illustrations, age-appropriate directions and explanations, and intriguing engineering design scenarios that engage students in critical thinking and problem-solving. Also, Rosie helps students cope with success and failure as it is a natural part of the engineering design process.

In this particular book, Rosie’s Uncle Fred is a zookeeper. Uncle Fred is having a problem keeping the orangutans in their cages/enclosures overnight because they have designed strategies to escape. While they are out of their cages, they cause all sorts of shenanigans in the zoo with other animals. In this design challenge Rosie needs the students to engineer a solution that will keep the orangutans from escaping their enclosure (Beaty, 2017, p. 38).

The Engineering Design Challenge and Constraints

This lesson is well suited for the elementary classroom thanks to the incorporation of simple, low cost materials (Figure 1). It addresses a number of student learning outcomes (Figure 2) that integrate concepts and standards (Figure 3) from multiple content areas. Simply stated, this design challenge requires students to create a program that controls the actions of sensors within an electronic circuit. One solution we posed to students was that Rosie wanted to help Uncle Fred by adding lights to the orangutans’ enclosures. These lights needed to be programmed to turn from green to red when an orangutan escaped the enclosure. Rosie anticipated that Uncle Fred will be awoken by the red light, run to the primates’ habitats, and return the mischievous orangutans to their enclosures before they cause any problems.
### Figure 1

**Materials Used in the Design Challenge**

The following items are required for each group of 2-3 students:

- 1 Crumble Starter Kit ($50.00)
- 1 Crumble Friendly Buzzer ($5.50)
- 1 Crumble Friendly Reed Switch and Magnet ($6.00)
- 3 AA batteries
- Computer with a USB port (Windows, Mac, or Chromebook)
- Crumble Software (Free download, see Internet Resources)
- Safety glasses/goggles (ANSI Z87.1 rated)

The following items are recommended for each group of 2-3 students:

- Scissors
- Multi-cutter tool from TeacherGeek®
- Cardboard
- Styrofoam
- Tape, Glue, or Low Temp Hot Glue Guns
- Paper/index cards and colored pencils
- Popsicle sticks, coffee stirrers, or kebab skewers
- Drinking Straws
- Small plastic container filled with pebbles or pennies to simulate the Orangutan
- Activity worksheet (see NSTA Connection)

### Figure 2

**Student Learning Outcomes for the Engineering Design Challenge**

- Following the procedures demonstrated by the teacher and the tutorials on the Crumble website, students will create a circuit and program that changes the light when the switch is pressed.
- Students will troubleshoot problems with their circuit and program to develop a programmed electronic circuit.
- Using consumable materials provided by the instructor, students will safely design a prototype of an enclosure with a door for the orangutans.
- Students will integrate their electronic components, program, and enclosure to create a working alarm system for Uncle Fred.
- Students will discuss how their alarm system works by describing details about key electronic, programming, and engineering design concepts.
To complete this design challenge students will need to use some small electronic components and a device called the Crumble. The Crumble is a durable, cost effective, reusable controller that can be programmed using free, user-friendly drag and drop software (similar to Scratch) to control various external sensors. It has been widely used in the United Kingdom for a number of years, and shown to be successful for teaching coding through open-ended, hands-on design challenges at the elementary (Gomersall, 2017) and middle school grade levels (Love & Bhatty, 2019). The Crumble was selected for this design challenge over other microcontrollers primarily due to its cost and usability for children. When compared to other microcontrollers with similar sensor kits appropriate for students this age (ex. Lego Mindstorms...
EV3 $350, SAM Labs $160, Hummingbird $117, and Micro:bit $65), the Crumble ($62) provides a more cost-effective option for schools, especially when considering the initial cost divided over multiple years of use. (*Note: The previously mentioned costs each reflect a set that can accommodate up to 3 students. An entire class set would cost more.) For teachers and students, the Crumble is relatively easy to learn how to use thanks to the wealth of instructional resources available (see Internet Resources). For this design challenge grades three and four were specifically selected because of the motor skills needed for students to connect the alligator clips used for the circuit, and the computational thinking skills required to develop a successful program using the free drag and drop software.

**Instructional Procedures**

*Day 1 - Setting the Context (60 minutes):*

- Demonstrate the basics of electricity and electronics. Show what happens when you connect the battery terminals directly to a LED or a buzzer, what happens when you remove one of the wires? Allow students to brainstorm what is happening. A common response was that there was no power, but students often did not trace the flow of electricity through a circuit. You can use the analogy of a garden hose (wires) and water flowing through it (electricity) to produce an output of spraying water (turn on a LED/buzzer). If the hose has a kink, is disconnected, or has no water source it will not work, just like an electric circuit.
- Introduce students to key vocabulary terms such as: the engineering design process, electricity, circuit, programming, prototype, LED, electronic sensor (switch and buzzer).
- Show the Crumble preview video (see Internet Resources) and provide a brief overview of the Crumble.
- Review the Rosie Revere story with students and provide the context for the design challenge.
- Ask students to Think-Pair-Share ways in which they could use the Crumble to help Uncle Fred. Students should write their responses in their engineering design journal and then post on a flipchart or white board. Students often associated the switch as something that needed to be human controlled. You should demonstrate how the switch can be controlled if placed under a platform and allow students to further brainstorm how that could be used. The following is an example of some teacher questions and student responses:
“Does the orangutan weigh a certain amount of pounds like a person or a dog?” Students were able to relate to this. “What force keeps the orangutan from floating away?” Students indicated gravity. “How would gravity effect a switch that is placed under the orangutan’s enclosure?” Students had ah-ha moment realizing that the weight of the orangutan could press the switch, allowing an alarm to go off when the orangutan left the enclosure.

- Formative Assessments: Ask students to write a constructive response in their journals using the key vocabulary terms to describe what they saw happening during the circuit demonstration. The flipchart and design ideas in their journal can also serve as excellent formative assessments.

**Day 2 - Learning to Use the Crumble (60 minutes):**

- In groups of 3, walk students through the Getting Started with the Crumble video (see Internet Resources). Help them get the circuit connected correctly and program the Crumble to turn on a light with a switch. For students who finish early they can attempt the Police Car Lights project on the projects page of the Crumble website. Allow students to experiment with the various light colors (Note: Crumble calls their lights “sparkles”).
- Discuss with students what each line of the Crumble program is telling the sensors (see Figure 6).
- Walk students through the tutorial for a switch (see Internet Resources).
- Ask students to develop design sketches for their enclosure given the materials available (Figure 1).
- Formative Assessment: Students must demonstrate how their circuit will work and describe each step of the program to the instructor so they can receive permission to move onto another sensor programming tutorial or challenge.

**Day 3 – Building a Prototype and Integrating the Crumble (45 minutes):**

- Help students troubleshoot their circuit and program so the switch and light operate as described in the design challenge scenario.
- Students should begin constructing their prototype while wearing ANSI Z87.1 impact rated safety glasses/goggles.
- Students should test and redesign their prototype as needed while documenting their changes in their engineering design journal. Many students had preconceived notions about what an enclosure at a zoo should look like. For most, they designed solutions depicting a cage with some sort of door. However, some students expressed concerns about the well-being of the orangutan and said they did not think a cage or bars were needed because the orangutan should learn to stay on the platform after seeing the alarm go off a few times when they leave the enclosure and get caught by Uncle Fred.
This provided opportunities for discourse about there being no single correct design, and incorporating key engineering design considerations such as empathy.

- The Crumble sensors should be integrated into the prototype.
- Students that finish early or have an advanced understanding of the Crumble could complete the reed switch or buzzer tutorial and use those in place of the micro-switch or sparkle light (see Extension section).
- Formative Assessments: Instructor should look for detailed prototype drawings with labels in students’ engineering design journals. Students should be able to explain in writing or verbally why they believe the selected solution is best.
- Summative Assessments: Examples include a vocabulary quiz, a written explanation describing what each step of their program is doing, a written reflection about the how the engineering design process was used to develop their final design and how they addressed any challenges encountered, or use the rubric provided (see Internet Resources) to assess various criteria contributing to their final design.

Figure 4: Circuit set up using a micro switch and sparkle light.
Figure 5: Circuit set up using a reed switch, magnet, and sparkle light.

Figure 6: Annotated crumble program using a switch and sparkle light.

<table>
<thead>
<tr>
<th>Start Program (required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continually run this program</td>
</tr>
<tr>
<td>If output C on the Crumble is Lo/Off (if switch is not pressed down)</td>
</tr>
<tr>
<td>Then turn the sparkle light red</td>
</tr>
<tr>
<td>Otherwise, if the switch is pressed down then,</td>
</tr>
<tr>
<td>Turn the sparkle light green</td>
</tr>
<tr>
<td>End of program</td>
</tr>
<tr>
<td>Loop back to top of program to run again</td>
</tr>
</tbody>
</table>
Figure 7: Example of a design solution using the micro-switch underneath the enclosure to signal when the weight of the orangutan has escaped.

Figure 8: Example of a design solution using the reed switch on the enclosure door to signify when it is closed or open.

Safety Considerations

With the constructing of the enclosures there are a few hazards that teachers must address. As mentioned previously, students should wear ANSI Z87.1 safety goggles or glasses when retrieving materials, during the activity, and during clean-up. Wooden skewers, popsicle sticks, coffee stirrers, and scissors can pose a hazard, which reinforces the importance of wearing safety goggles/glasses. The multi-cutter tool is relatively easy to use but can be more hazardous than a pair of scissors if not used correctly. The instructor may consider being sole
operator of the multi-cutter, or they could set up a cutting and hot gluing station where they could directly supervise students who are conducting these activities. Additionally, this design challenge could be modified to use consumables that are easier for students to work with, such as construction paper, Styrofoam plates, and tape. Weaver (2017) presents some excellent strategies for minimizing safety hazards in an elementary classroom during engineering design challenges.

**Suggestions for Instructors**

To help organize the Crumble and various small sensor components, it is recommended that inexpensive sealable plastic bins be purchased and group kits are pre-made. These can be inventoried by students using a checklist each day during clean-up to prevent lost or broken parts. Instructors will need to have any consumable materials ready for students to access. Assigning prices to each item and providing students with a fictitious budget can reinforce math skills while also reducing waste. Additionally, computers with a USB port will be needed, and the instructor must ensure the free Crumble programming software is installed.

If students have never worked with the Crumble or electronic sensors, allot time for students to independently experiment with these materials. After sufficient time to explore the materials, provide students with written directions on a handout or displayed in the front of the classroom to guide them through programming the sensors. Invite students to follow the teachers’ step-by-step directions for creating a program. For students that require additional support, the tutorial documents from the Crumble website can also be printed out for students to follow along. Next, ask students to work together to create a new program. Finally, challenge students to develop a program that will meet all the criteria specified by Rosie.
This challenge really tests students’ ability to follow directions, pay attention to detail, innovatively design, and troubleshoot. Just one minor error in the circuit or code can keep the system from operating correctly. For students that find the programming challenging, the instructor may find it helpful to create flash cards that have common terms on one side like “turn on the light”, “wait 2 seconds”, or “when the switch is pressed”. On the other side the cards may have a picture of the block command from the Crumble software that would perform the operation specified on the other side. This can help students organize their thoughts and scaffold them to proficiently use the programming commands. Students must ensure the wire from the positive power source on the Crumble is connected to the “normally open” side of the micro-switch. If the circuit does not work have students check that their alligator clips are connected securely to the metal contacts on each component, not touching any other metal contacts or alligator clips, and that their circuit matches the pictures provided. The instructor or other students may have to assist those who need help connecting the alligator clips. If students are still experiencing problems ask them to check the variables specified in their program and ensure that it matches the output where the electronic component is connected on the Crumble. If experiencing problems with the sparkle light, confirm that: 1) it is connected to output D on the Crumble, 2) the wire from Crumble output D is connected to letter D on the sparkle light and following the correct direction of the arrows, and 3) the first sparkle light is identified as number 0 in the program. Additional troubleshooting tips can be found on the Crumble website (see Internet Resources). While we provided some recommendations for modifying portions of this design challenge, we recommend instructors work with their special
education department to make the appropriate accommodations or modifications for each student.

**Extension Activities**

For students who successfully complete the design challenge quickly, they can be tasked with incorporating a buzzer or other sensors in place of the sparkle light (Figures 9 & 10). Teachers who are comfortable using various materials can create their own switch/pressure pad for the orangutan using tin foil, coffee stirrers, and index cards or card stock as demonstrated on the Crumble website (https://redfernelectronics.co.uk/projects/catch-santa/). Additionally, the Crumble could be coupled with engineering design challenges featured in other Rosie Revere books.

**Figure 9:** Circuit set up using a micro switch and buzzer.
Conclusion

Once students learn how to code these basic sensors they can easily learn how to use more advanced components in their designs via the sensor tutorials provided on the Crumble website. This also introduces them to additional programming concepts, providing a progression toward using more advanced materials and program concepts at the middle school level. Love and Bhatty (2019) presented an example of how the Crumble could be integrated with engineering design and 3D printing to help teach about data collection and prediction, as well as basic physics concepts. Additionally, they provided examples of many other design challenges in which the Crumble was integrated to teach various STEM practices, and a rubric for evaluating physical computing design challenge solutions. Instructors have access to many other types of microcontrollers and can very easily use them within the context of design challenges like the one presented in this article.

Internet Resources

- Introduction to the Crumble video - https://vimeo.com/94097687
- Crumble website with free coding software - https://redfernelectronics.co.uk/crumble/
- Tutorials for individual Crumble sensors - https://redfernelectronics.co.uk/getting-started/guide-to-using-crumbs/
- Silent Alarm Scanner Bot design challenge - https://rundontwalk.co.uk/2018/12/07/crumble-creations-continued/
- TeacherGeek® (U.S. distributor of the Crumble) - https://teachergeek.com/collections/crumble

Connecting to the Next Generation Science Standards (NGSS Lead States 2013)

Standard

3-5 ETS1 Engineering Design
https://www.nextgenscience.org/pe/3-5-ets1-3-engineering-design

- The chart below makes one set of connections between the instruction outlined in this article and the NGSS. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.

Performance Expectation

3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Classroom Connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking Questions and Defining Problems</td>
<td>Students asked questions regarding the design and function of an enclosure that could safely house an orangutan. They also asked and predicted what sensors and programming sequence were needed to create an alarm system, then changed identified variables in their Crumble program until it worked. From those questions they were able to define the problem and create an alarm system within specified constraints.</td>
</tr>
</tbody>
</table>
Students applied knowledge about basic programming commands by recognizing patterns, arranging the commands in the correct sequence or pattern, and debugging variables needed to properly operate the sensors.

Students sketched their designs in their STEM notebook, then constructed their enclosure and programmed their alarm system.

Students developed various designs and constructed an enclosure within material and size constraints to ensure the orangutan would be safe. Material constraints also applied to the sensors available and a student’s ability to successfully program them.

Students identified patterns then used loops and if/then/else statements to allow their alarm system to continually sense for a missing orangutan.

Building a mechanically functioning enclosure, integrated with electrical circuit components and a programmed microcontroller allowed students to see how science and engineering concepts contribute to the operation of a complex system.
References


Authors

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Rosie Revere’s Orangutan Dilemma Worksheet

**Design Challenge:** Uncle Fred is having a problem keeping the orangutans in their zoo enclosures overnight. The orangutans have designed strategies to escape and cause all sorts of shenanigans with other animals. Uncle Fred needs you to help Rosie design a solution that will keep the orangutans from escaping their enclosure. The enclosure can only use the materials provided by your teacher, and must not harm the orangutans. The enclosure must also incorporate the Crumble components.

**Vocabulary Terms:** Engineering Design Process, electricity, circuit, sparkle, electronic sensor, switch, buzzer, coding, and prototype.

**How could you use the Crumble to help Uncle Fred?**

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

**Provide sketches of what the enclosure could look like:**


**What problems did you encounter while building and programing your design? How did you troubleshoot these issues?**

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________


Orangutan picture retrieved from [http://pngimg.com/download/31362](http://pngimg.com/download/31362)

<table>
<thead>
<tr>
<th><strong>Crumble Evaluation Rubric</strong></th>
<th><strong>Exemplary 3 points</strong></th>
<th><strong>Proficient 2 points</strong></th>
<th><strong>Needs Improvement 1 point</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sketches/Designs</strong></td>
<td>Produced detailed sketches of possible solutions that included accurate labels for all essential components.</td>
<td>Produced sketches that had some inaccurate or missing labels.</td>
<td>Produced sketches that did not have any labels.</td>
</tr>
<tr>
<td><strong>Design Constraints</strong></td>
<td>The final solution followed all constraints of the design challenge.</td>
<td>The final solution followed most constraints of the design challenge.</td>
<td>The final solution followed a few constraints of the design challenge.</td>
</tr>
<tr>
<td><strong>Fabrication</strong></td>
<td>The final product was neatly constructed and operated effectively during testing.</td>
<td>The final product was constructed and operated during testing.</td>
<td>The final product was constructed.</td>
</tr>
<tr>
<td><strong>Programming and Electronics</strong></td>
<td>The program and circuit had no errors. The sensors successfully operated.</td>
<td>The program or circuit had a few errors that prevented the sensors from properly operating.</td>
<td>The program or circuit was incomplete.</td>
</tr>
<tr>
<td><strong>Final Solution</strong></td>
<td>When sensing the orangutan escaped, the Crumble alarm system alerts Uncle Fred.</td>
<td>The Crumble is connected and programmed but does not alert Uncle Fred.</td>
<td>The Crumble is not connected to the enclosure or is not programmed.</td>
</tr>
<tr>
<td><strong>Teamwork and Safety</strong></td>
<td>Student provided significant contributions to their group’s solution while following all safety procedures.</td>
<td>Student contributed to their group’s design solution while following all safety procedures.</td>
<td>Student provided limited contributions to their group’s design solution or had safety violations.</td>
</tr>
</tbody>
</table>