FlowGo: An Educational Kit for Fluid Dynamics and Heat Transfer

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FlowGo: An Educational Toolkit for Fluid Mechanics and Heat Transfer

Abstract

There are many commercial toys and learning products meant to help K-12 students learn about robotics and electronics, but nothing similar exists to excite students about fluid mechanics and heat transfer. Consequently, many students who might grow up to work in these fields never even learn what they entail. In addition, while robotics and electronics are engaging for many students, water and heat design challenges may provide entry into engineering for students with different interests. With this in mind, a modular, open-ended toolkit for building fluid mechanics and heat transfer experiments is being developed for upper elementary and middle school students. The kit consists of tubes, valves, junctions, water tanks, and heaters that can be connected in any order to build flow and heat transfer devices. Preliminary tests have been conducted to evaluate the usability and functionality of the kit by asking third through seventh grade students to build plant watering and house water supplying systems. The tests indicated that the FlowGo toolset is easy to use, has a high level of engagement, and shows the potential to engage students in design challenges related to gravity-driven flow and heat loss through pipes.

Background and Motivation

K-12 students have many toys and low-cost tools available to them to explore mechanical engineering concepts related to mechanisms (Erector Sets, LEGO sets with gears and pulleys, K’nex, Tinkertoys), and robotics (LEGO Mindstorms, Arduino). These resources are all very popular and have helped to promote these aspects of engineering as exciting components of the discipline. Research on programs and interventions that use these tools has shown that they positively impact K-12 students’ achievement scores [1], conceptual learning, and attitudes toward STEM [2, 3]. Science education researchers have also explored students’ ideas about heat and temperature [4] and basic ideas about how water and flow work [5]. This work has focused on children’s mechanistic understanding of phenomena and identified areas where children have naive understandings. As engineering design challenges can teach students science concepts [6, 7], it is necessary to consider how students can engage with science ideas related to fluids and heat in a design concept. Currently, no hands-on tools exist that allow K-12 students to engage in engineering design challenges related to fluid mechanics and heat transfer.

The current research is designed to help students explore these fields and ideas in an open-ended play environment by providing them with a toolkit to build their own fluid mechanics and heat transfer experiments. The FlowGo toolkit consists of a set of tubes, valves, junctions, plugs, and heaters that can be connected in any order and filled with water to build an arbitrary flow or heat transfer experiment. The FlowGo toolkit aims to promote several outcomes. First, fluid mechanics and heat transfer could help a different demographic of students become interested in engineering. For example, research on female students’ interest in science has shown that they are motivated by projects that have personal connections or allow them to help [8]. FlowGo could support female interest as it can be used for projects to help people or animals, such as irrigation or pet water-providing systems, or artistic expression, such as fountains or water sculpture.

Second, FlowGo could serve as a classroom tool that helps teachers meet new teaching standards on engineering subjects. For example, the Next Generation Science Standards for middle school students include topics such as understanding potential, kinetic, and thermal energy transfer and applying these concepts
to construct devices that minimize or maximize thermal energy transfer (MS-PS3 Energy.) The standards also set forth that students should be able to model the inputs and outputs of a technological system and should be able to identify and describe propulsion systems (MS-ETS3 Technological Systems.) In addition, FlowGo could help students explore science concepts related to energy and heat (e.g. 4-PS3 Energy, MS-PS3 Energy).

**Toolkit Fabrication and Components**

The FlowGo toolkit was designed to be as intuitive and easy to use as possible while still allowing students creative license to build whatever they wanted. With this in mind, a simple universal connector was designed to allow connection of components in an arbitrary order. Next, a set of different toolkit components was designed such that the universal connector could be attached to both ends of each component. A section view of the universal connector is shown in Figure 1a. It consists of three components: two stationary (green and yellow) and one rotating (blue). The green and yellow parts are glued to FlowGo components, and the blue part is permanently connected to the yellow part but is free to rotate. Separate components can be joined by aligning green and yellow components and twisting the blue component until the connection is tight. The three-part connector has an advantage over standard threaded parts because it allows the user to join pieces without rotating parts downstream of that particular connection. The universal connectors were fabricated using a casting method.

Figure 1b shows flow-focused FlowGo pieces that have been prototyped and tested thus far. These parts include rigid and flexible tubes, a water tank, T-junction pieces, valves, and adjustable-height stands to hold the tubing in place. Most of the components were made from inexpensive plastic raw materials. Figure 1c shows a few heat transfer-focused components: a water heater and temperature-sensitive color-changing paper. The toolkit also includes inexpensive commercial temperature measurement devices such as thermocouples with digital displays and an infrared thermometer.
Preliminary Experiments: FlowGo Challenges

Plant Watering Challenge

To evaluate the functionality of the flow-focused FlowGo toolkit prototype parts and their potential as learning tools, eight third through fifth graders working in pairs were asked to use the kit to build a system that waters plants. The initial setup consisted of a tank of water and three plants positioned on a set of metal shelves at different heights beneath the tank. Students were allowed to shift plants horizontally but not to move them from shelf to shelf. During tests, the students were given a short introduction to the toolkit and shown how the connectors worked, then asked to draw their ideas of how to water the plants using FlowGo. Once the students had finished and explained their individual drawings, they were asked to combine their ideas into a single design and build it. Afterwards, the water was turned on to test their devices. The students were encouraged to evaluate the success of their initial prototype and make modifications if something did not work.

The tests were conducted on two different days. The groups on the first test day worked with only the tube and junction pieces shown in Figure 1b because the other pieces had not yet been prototyped. The students requested clamps and stands to hold the FlowGo parts in place during future tests. It was also determined from the first set of tests that something was needed to keep water from leaking onto the floor. In response to these observations, custom-manufactured adjustable-height stands and Velcro connectors were supplied to students on the second test day and the entire setup was in a kiddie pool. Also, whereas the first test day mainly focused on toolkit functionality, science questions were incorporated into the apparatus-building process on the second test day to explore how FlowGo could lead to student insights about fluid mechanics.

Plant Watering Solutions

Figure 2 shows two sample solutions to the plant watering challenge implemented by two different groups. The yellow lines indicate the position of the FlowGo parts, which are mostly transparent and thus difficult to see in photographs. The solution on the left uses one long, flexible tube to water all three plants, leaving the universal connectors loose so water leaks out. The solution on the right uses three separate tubes connected with T-shaped junctions to water the plants. The solution on the right was implemented at the later test date, when the valves and adjustable stands were available. The two solutions not shown in the figure were more similar to the solution on the right, although each group used a different combination of tubes and junctions to build their device. This pilot study shows that students were not only able to use the kit, but also to solve even a very simple problem using multiple different apparatus designs.

House Water Supply Challenge

To evaluate the functionality of the FlowGo heat transfer component prototypes, four fifth through seventh graders working in pairs were asked to use the kit to build a system that supplied water to a wire table modeling a house, including a miniature bathtub that needed both hot and cold water and a kitchen device that used hot water to melt chocolate. The initial setup included a tank of water on a high shelf, a model bathtub, and a chocolate melting device consisting of chocolate in a metal bowl surrounded by a larger plastic bowl. Hot water could be added to the plastic bowl, transferring heat through the metal bowl to the chocolate. Both the chocolate melter and bathtub were designed with adjustable drainage valves at the bottom to minimize water overflow. In order to successfully complete the challenge, students needed to design and construct a multi-pronged flow rig that would guide water both directly from the reservoir to the bathtub and first to the heater, then to the bathtub and chocolate melter.
The students were asked to sketch and explain their designs and then combine their ideas to build a single FlowGo device. They were also asked to predict the water temperature at the various stages of their design (in the reservoir, the heater, the bathtub, and the chocolate melter.) Once the students were finished building, the water was turned on to test their setups. An infrared thermometer was used to measure water temperature at different locations and the data were compared with the students’ predictions. Only supervisors were allowed to handle the heater so there was no risk of students burning themselves.

**House Water Supply Solutions**

Figure 3 shows a sample house water supply solution with yellow lines outlining the position of the FlowGo pieces. The solution uses a branch system with valves to control how much water travels down each tube and a funnel system to prevent leaking as water transitions between components.

**Preliminary Data**

**Student Feedback**

After both the plant watering and house water supplying exercises, students were given an exit interview in which they were questioned about the usability of FlowGo, how much they liked it, and what they would like to build in the future. When asked what they liked about FlowGo, students said it was fun to play with water, they enjoyed the puzzle-like connections, and they felt gratified when their setup finally worked. When asked what they disliked, they mentioned that the parts were sometimes hard to connect and leaky. Students were also asked what else they would like to build with FlowGo. Their suggestions included an irrigation system, a juice or milk dispenser, a water wheel, a rain system for homemade dinosaur movies, and a water-spraying device to wake up siblings on the weekend.
**Table 1: Selected science questions**

<table>
<thead>
<tr>
<th>Concept</th>
<th>Questions</th>
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<tbody>
<tr>
<td>Fluid/gravity interaction</td>
<td>What will happen if we try to water a plant that’s above the water tank?</td>
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<tr>
<td></td>
<td>Why can’t water flow up?</td>
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<tr>
<td>Effect of water pressure</td>
<td>What will happen to your design if we add water to the tank?</td>
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<td></td>
<td>Will the flow be faster or slower if we use a faucet instead of a tank?</td>
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<tr>
<td>Mass/volume conservation</td>
<td>Which weighs more, the full water tank plus dry plants or the half-empty</td>
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<td></td>
<td>tank plus the watered plants?</td>
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<tr>
<td></td>
<td>How much water should we put in the tank if we know each plant needs</td>
</tr>
<tr>
<td></td>
<td>500 ml?</td>
</tr>
<tr>
<td>Conduction</td>
<td>Why is there insulation around the water heater?</td>
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<td></td>
<td>Why is the chocolate melting even though it does not directly touch the hot water?</td>
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<tr>
<td>Thermal equilibrium</td>
<td>What happens to the temperature when we mix hot and cold water in the bathtub?</td>
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<tr>
<td></td>
<td>What would happen to the water in the heater if we left the heater on all night?</td>
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</tbody>
</table>

**Science Discussions**

One of the goals of the current research is to assess the ways in which the FlowGo toolkit helps students explore elementary fluid mechanics and heat transfer concepts. We envision FlowGo helping students to explore design ideas as well as science concepts. To do this, we are developing a set of science questions that can be answered by conducting simple experiments with FlowGo. Preliminary conversations have already shown that FlowGo has the potential to help students think about the science of fluid mechanics and heat transfer. For example, the following conversation about gravity occurred when a third grade student built an unsuccessful plant watering prototype which would have required the water to flow up.

*Researcher:* “Why isn’t the water going up?”
*Student:* “This part of the pipe is too high.”
*Researcher:* “Why can’t the water get to the high pipe?”
*Student:* “The water can’t go back up because of gravity.”
*Researcher:* “How can we fix this?”
*Student:* “Make this part of the pipe lower.”
*Several minutes later: working on a different part of the setup:*
*Student:* (to her partner, pointing at the bottom of a vertically-oriented coiled tube) “We can’t make the pipe too long because the water will just stop there.”

We envision supporting curricular resources that help teachers or informal education facilitators to engage students in discussions that use the FlowGo designs as a context to reason and discuss science. Table 1 summarizes a few such concepts and their corresponding prompts. The questions in the table are specifically tailored to the plant watering and house water supply challenges but could be adapted to explore the same concepts through different types of challenges.

**Conclusions and Future Work**

The FlowGo toolkit is still in its early stages of testing, but thus far, feedback has been positive. We have shown that students can use the toolkit to build both flow and heat transfer experiments and enjoy working with the components. This work constitutes a proof-of-concept study, and the next step is to test FlowGo in classrooms to confirm that it is practical for use with a larger number of students and can compliment
elementary or middle school science curriculum.

Long term, we hope to disseminate the FlowGo toolkit using a two-pronged approach. The parts of the kit which have already been prototyped will become part of a toolkit meant to be used with elementary and middle school-aged students in formal and informal educational settings. The parts will come with a booklet of suggested student challenges like the plant watering and house water supplying challenges, prompts to help teachers and facilitators talk about the ideas, and example videos of students using and discussing FlowGo. FlowGo will also be disseminated through existing workshops at Tufts Center for Engineering Education and Outreach and the CEEO’s online course program (okee.tufts.edu).

The second expansion goal for FlowGo is to make the toolkit into a cost-effective laboratory tool for undergraduate fluid mechanics and heat transfer classes. It is difficult for most tertiary educational institutions to offer hands-on labs in fluid mechanics and heat transfer because the majority of experiments in these fields are expensive to manufacture, difficult to calibrate, and large and heavy enough that they require permanent lab space. We hope to add quantitative flow measurement components to FlowGo such that undergraduates could use the toolkit to learn fluid mechanics and heat transfer by building and measuring their own experiments.
References


