Experiments in Self-Guided Learning with Integrated Hardware, Software, and Curriculum

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ABSTRACT

In this paper research from a National Science Foundation SBIR Phase I grant number (blank for blind review) is outlined with the relation to studying an object with embedded hardware and sensors, and integrated software and curriculum in everyday classroom use. The device built measured distance and acceleration for the purpose of experiments in physics classrooms. The success of the study depended on whether students were motivated with this device to conduct self-guided learning.

Author Keywords

Physics, data collection, PhysBUG, BUGBook, RoboBooks

ACM Classification Keywords

H5.2. User interfaces and prototyping

General Terms

Design, Experimentation, Human Factors

INTRODUCTION

This research highlights a new and improved data collection device to be used in high school physics classrooms paired with RoboBooks[1], a browser-based platform for viewing and manipulating the data within interactive digital curriculum. Feedback was collected from teachers and students regarding the look, feel, and interactions of the device in the context of existing data-collection devices in the classroom. The hardware was built using off the shelf components and the control interface is based on the RoboBook created by [left blank for review] at [left blank for review] University, for this product, the derivative was named BUGBook. In addition to building and testing the hardware, research was also collected to compare the top market competitors, Pasco and Vernier. Nine objectives were completed based on the design decisions to make PhysBUG a successful tangible device: Development of the physics based hardware must be inexpensive; hardware must be integrated with curriculum; a wireless protocol must be present; the Control Panel Interface software development must be tested by both teachers and students; development of physics classroom activities must be in-line with current curriculum; in-classroom competitor comparison tests will be completed; user experience testing/feedback will be incorporated; teacher product perspectives will be studied; and student self-guided experimentation will be observed. Several UI design decisions also came from related research about the miniBUG from Bug Labs [2].

DEVELOPMENT OF HARDWARE

The PhysBUG hardware was developed with off the shelf components. The physical prototype used an existing microcontroller called the mbed [3], coupled with an ultrasonic sensor, an accelerometer, and an RF Link to be used for data transmission, a USB for back-up data collection, AA batteries, a power switch, and a button to trigger data collection. Four versions of the board were made, including a low-fidelity mock-up and three stand alone high-fidelity devices (Figure 1).

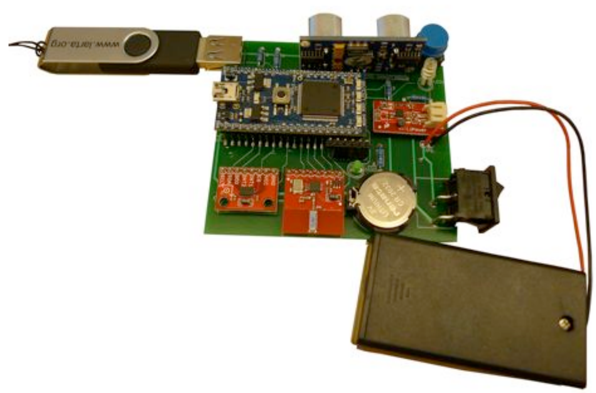

Figure 1. PhysBUG prototype in development, version 4

The challenge was to make a device that would cost $60 USD. The total BOM comes to $34.38 using off the shelf components at 1,000 part quantities. Each device was tested with users and the price point ended up having a direct effect on the creativity of students and teachers in our classroom tests. As seen in Figures 3 and 4, students used the devices to measure untraditional things that their teachers reported never teaching them about. Aside from the price point being very competitive from the most popular devices, Vernier and Pasco (each about $300 for a base unit plus $70 for each sensor tethered by USB), the number of buttons was drastically reduced on the interface. The PhysBUG device as two buttons, a power switch and a button to start and stop collecting data. All other buttons and functions are displayed in the software, which resides on a web browser – an interface that students and teachers are already familiar with. Enabling the data to go wirelessly and automatically from the device to the browser interface further connects the hardware and software together.

BUGBOOK SOFTWARE INTEGRATION

To deliver integrated curriculum (digital workbook activities that were tightly integrated with the hardware based on the sensors available) to the students, the BUGBook software was created as a derivative of the RoboBook software in development.

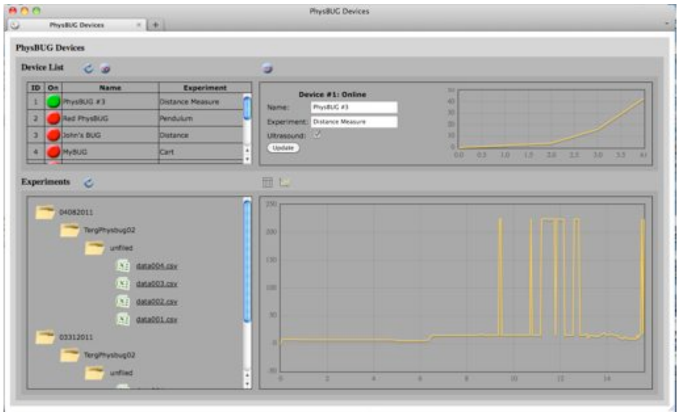

Figure 2. BUGBooks control panel

In addition to the BUGBook software integration, a RoboBook Control Panel Interface (Figure 2) was developed in order to allow easy configuration/management of the PhysBUG devices with a classroom by the teacher, as well as a method of browsing/displaying all data collected by students. Students ended up preferring this software interface than that of the BUGBook which has more of a workbook look and feel. The transparency of other student data in the control panel allows for easy collaboration between students and groups. Developed to be web/HTML5 compatible, this interface was leveraged in a variety of ways during classroom testing: on student computers, on iPad device for easy movement around room, and projected onto main whiteboard for group discussion/instruction.

OUTREACH ACTIVITIES

Research was collected in two public schools, one in New York with Timothy Jones at the Williamsburg High School of Architecture and Design and at Littleton High School in New Hampshire with William Church. Between the two teachers, three classes were volunteered. One freshman level class, one junior level, and one senior level (see Table 1). Students participated in classroom activities using PhysBUG and BUGBooks as well as the BUGBook Control Panel and completed a survey at the end of the session. Students were asked about using the PhysBUG and asked to compare the activities to other devices as well as the physicality of the PhysBUG and user experience. Data was analyzed from the survey results and observations.

DEVELOPMENT OF PHYSICS ACTIVITIES AND SELF-DIRECTED LEARNING

The prototyped versions three and four PhysBUG devices were tested within two high schools employing real physics activities in order to evaluate their effectiveness in real-world scenarios. As such, in coordination with the teachers, physics activities were developed for comparison.

The activities tested with PhysBUG and BUGBooks included the standard track and car experiment (a car gets

School	Grade Level	# of Students
Williamsburg High School of Architecture and Design	Senior	8
Littleton High School Period 1	Freshman	12
Littleton High School Period 2	Junior	5

Table 1. Student Participation Demographics

pushed down a low-friction track), which both Vernier and Pasco include in their physics kits. The students were also asked to conduct an experiment where they held the PhysBUG and walked toward a wall. The car and wall experiments were both directed by the instructors.

Once those experiments were complete, the students began spontaneously playing with the devices and self-directing other experiments, such as the two in Figure 3 and Figure 4. The activities from using the PhysBUG empowered students to come up with their own experiments. This finding contributed to the success of the device. Students were creative in their thinking and began asking questions relevant to their lives, which they reported finding enjoyable. Others wanted to test the durability and restraints of the device, but were still learning physics as they threw it, hung it from stair cases (Figure 3) and spun it on bicycle wheels (Figure 4). Self-motiving activities included using the device with basketballs and handballs. The group which hung PhysBUG down a 2-story stairwell was a pendulum experiment, however they only identified it as “throwing it over the stairwell” not realizing they had created a pendulum until after seeing the data in their BUGBook.

Figure 3. Self-directed pendulum experiment

The teachers and students reported back on aspects of the self-directed learning. For example, one student wrote in response to using the PhysBUG, "You can be up and doing things instead of sitting watching certain people or the teachings do it. It's a fun way to learn."

Figure 4. Self-directed bicycle wheel experiment

One student created plastic housings for the prototype, based on what he saw of the hardware design. He added a tripod mount to the housings after playing with the device as he saw that it would be a beneficial feature. Several other students reported needing flexible straps on the devise or for it to be wearable. The student attended the Williamsburg School of Architecture and Design, and already had CAD experience in their other classes, but the student was eager to apply that knowledge when given the chance with a real world device.

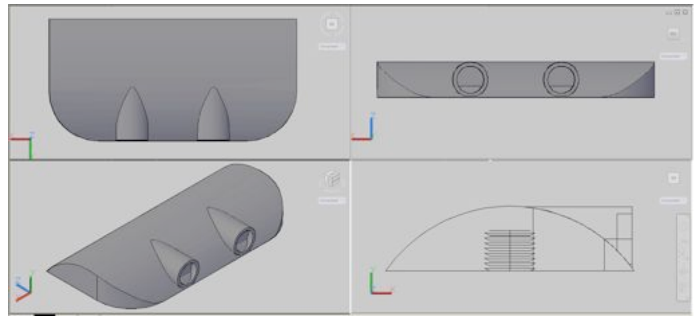

Figure 5. Self-directed housing exercise

CLASSROOM OBSERVATIONS

For any classroom device, teachers reported that the cost limits the number of devices teachers can purchase for their classroom, which in turn leads to groups of students using one device, or the instructor demonstrating the experiment in front of the class. Teachers reported observing PhysBUG used in more creative ways with self-directed experiments by the students. Overall, the students found the PhysBUG device much easier to work with, although it was still in a prototype state and had flaws. The teachers allowed students to create their own experiments and conduct multiple experiments in one class period because the data could be gathered quickly and instantly backed up on the USB as well as the automated wireless transfer to analyze the data in BUGBooks, which was different from the activities they previously demonstrated to students.

Bill Church, one of the teachers, reported on the form of the device and the collaboration derived from the PhysBUG and BUGBook integration: "Because the PhysBUG is easy to hold, students were not constrained to move in front of a stationary unit. They were more free to move naturally and in unexpected ways. This created more teachable moments in the classroom. Additionally, in just a short period of time using the PhysBUG, I can see its application in areas that other systems do not address well. A classroom outfitted with several PhysBUG units and the Bugbase/BUGBook web server would allow students to *collaborate* and run multiple experiments that replicate data sets or *collaborate* and create one large classroom wide experiment involving multiple sensors. With the "out of the box" capability of bringing data from multiple sensors to one web server and then serving it out to students through a RoboBooks platform, the PhysBUG system will allow teachers and students to create many unique full classroom *collaborative* experiments. I am truly excited about this possibility."

Finally, the students wanted to conduct multiple experiments outside of the classroom. Their teachers were excited to see the potential of learning going into their daily lives on the handball court and basketball court. Any time students take their learning journey outside the classroom, they increase their chances of seeing that what they learn in a class applies to the real world.

USER EXPERIENCE TESTING/FEEDBACK

The students reported that the PhysBUG was easier to use than the competing devices currently used in their classroom. The PhysBUG device was favored because of the single button press to collect data and the wireless integration to transfer the data. One student reported, “PhysBUG/ RoboBook is easier and faster than some of the other units we collect data. It was easier because the information was sent right to the computer. It was faster than getting the data and putting it in a computer ourselves.” Both competing devices have a graphical interface with several button options to press. The various buttons caused confusion for the students, more so on the Pasco than the Vernier platform. One student commented in a comparison of the devices that the PhysBUG was “a lot easier and quicker from the one press button and quick transfer of data.” Another wrote, “It [PhysBUG] was a lot easier to understand and was a lot more organized and on the new setup on the website it looked a whole lot better”. Tim Jones, one of the physics teachers commented in his final NSF report that “the low price point of the PhysBUG sensor unit allows for educators to purchase more of them for the same price that an alternate system would cost, this is extremely important especially with the on-going budget reductions. The ability for any browser capable platform, be it a desktop computer or laptop in the classroom, a tablet, or phone, allows for more students to directly work with the data collected from an experiment and helps to move away from instructor *demonstrated* physics labs. The overall ease of use, a simplistic design with only a few buttons, is also huge benefit of the PhysBUG.”

IMPROVEMENTS AND FUTURE RESEARCH

Improvements on the installation process and server set up need to be addressed to have a truly successful experience for the teacher. One field of research that could be coupled with the ease of setting up in the future is a method of sending binary files over flashes of light from a computer screen to a light sensor on the device translating its ID and other information, inspired by Aniomagic research [4]. Research on housing and form [5] of the object will extremely important for the next iteration. Testing for durability and improvements will continue to be made in future research.

Students continuously pushed the boundaries of the wireless configuration. The RF Link ended up being a limitation for all classes tested. Students wanted to take it everywhere, in the elevator, down the stairwell, and outside. The only potential solution to a more flexible network would be a 3G or GSM solution, however that would significantly boost the cost.

CONCLUSION

In conclusion, two products were created and tested, the PhysBUG hardware and the browser based workbook, BUGBooks. It was determined that a prototype run of 1,000 units would cost $34.38 per board and could be resold at $60 per device. The feedback from teachers and students was overall positive for the usability of the device, especially the single button interface. PhysBUG and BUGBooks together empowered activities and spurred creativity in physics experiments. Students used the device to experiment with their own questions and teachers responded positively to the creativity they could allow with the price point and durability of the PhysBUG.

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