

Integrating Microcontroller-Based Projects in a Human-Computer Interaction Course

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Abstract—This paper describes the design and application of a short in-class project conducted in Algoma University's Human-Computer Interaction (HCI) course taught at the Bachelor of Computer Science. The project was based on the Maker Movement (people using and reusing electronic components and everyday materials to tinker with technology and make interactive applications), where students applied low-cost and easy-to-use electronic components, the Arduino Uno microcontroller board, software tools, and everyday objects. Students collaborated in small teams by completing hands-on activities with them, making an interactive walking cane for blind people. At the end of the course, students filled out a Technology Acceptance Model version 2 (TAM2) questionnaire where they evaluated microcontroller boards' applications in HCI classes. We also asked them about applying the Maker Movement in HCI classes. Results showed overall students' positive opinions and response about using microcontroller boards in HCI classes. We strongly suggest that every HCI course should include practical activities related to tinkering with technology such as applying microcontroller boards, where students actively and constructively participate in teams for achieving learning objectives.

Keywords—Maker movement, microcontrollers, learning, projects, course, technology acceptance.

I. INTRODUCTION

THIS paper describes how the Maker Movement [1], [2] paradigm has been applied in a HCI course from Algoma University, Canada. The course has been offered for some years at undergraduate level, which includes small projects done in class by small teams composed of four students each. Until recently, the use of microcontroller boards (small self-contained computers built on single circuit boards) was incorporated in our HCI classes. The course teaches the necessary foundational and theoretical components that students apply in the short projects, having practical hands-on activities. Before each project starts, students are taught HCI topics such as requirements elicitation, participatory design, low and medium-fidelity prototyping, and usability testing, among others. In the projects, students use electronic components, microcontroller boards and everyday objects to make digital prototypes of interactive devices.

Digital prototyping conducted in HCI classes is in line with other related projects and applications where students tinker with electronics, and use physical computing in a constructionist learning environment [6]. In doing so, "digital

fabrication" happens in class as part of students' educational experiences [3]. This should in turn engage students, learning HCI topics by "making" [4]. This is also in line with the Maker Movement, a social movement in which people create interactive products using digital and analog electronics and discarded or commonly-used objects, often thinking out of the box and tinkering with inexpensive technology [8].

II. IN-CLASS PROJECT STRUCTURE

We devised a structure for each project conducted in the HCI classes (see Table I). Many classes were devoted to conducting in-class projects. Not all classes included a project; in some of them, students were taught theoretical components that supported project-based classes.

TABLE I
STRUCTURE OF EACH IN-CLASS PROJECT

Class section:	Duration (in minutes)
Brief review of previous class.	5
Instructor's description of the class' learning objectives.	5
Instructor's description of the main topic and a summary of background theory that supports the class project.	10
Instructor's explanation of the project instructions, including its objective, materials, activities and expected outcomes.	5
Completion of project's activities	55
Review of project's outcomes done by the instructor and students. Class conclusions.	10
Total:	90 min.

III. IN-CLASS PROJECT EXAMPLE

The following is one example of an in-class project completed by 40 HCI students. Its instructions are shown in Appendix A.

The project objective is to build an electronic walking cane for blind users. The circuit attached to the cane has an ultrasonic sensor and a buzzer that buzzes when objects are blocking the user's way. In this project, first, students draw a sketch on paper about the overall cane design. Then, students draw a schematic diagram of the electronic components using Fritzing, an open-source electronics diagramming software tool [21]. After that, students connect electronic components to an Arduino Uno microcontroller board [22] and to a breadboard, based on their Fritzing schematic (shown in Fig. 1). After that, students connect a battery to the circuit and test the whole prototype. The walking cane design used in this project was based on a project described in [12].

Fig. 2 shows a student holding a walking cane made of a bamboo stick holding an Arduino Uno microcontroller board. The breadboard with electronic components, an ultrasonic

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sensor and a battery were also attached to it.

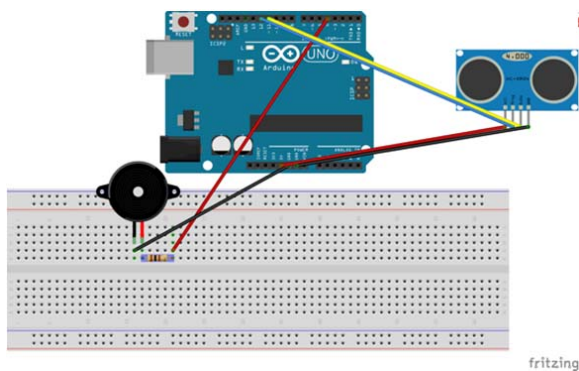


Fig. 1 Diagram made in Fritzing showing the Arduino Uno microcontroller board and other electronic components used for building the interactive walking cane

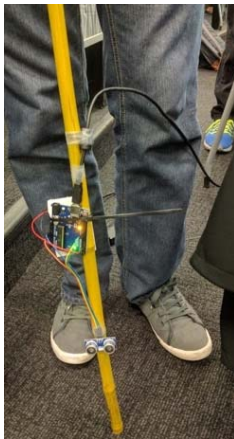


Fig. 2 Example of an interactive walking cane for blind people made by one of the teams

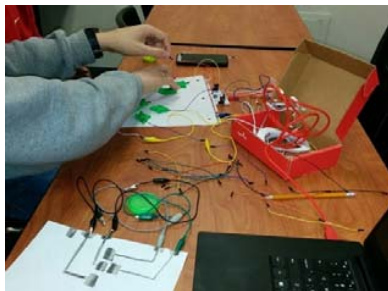


Fig. 3 A student making arrow keys and connecting them to the Makey Makey

The 40 students have also completed other types of projects in class. For example, they have used the Makey Makey Classic [23], a microcontroller board in the form of a kit that emulates a computer keyboard and a mouse, where students connect everyday objects to it using alligator clips. The Makey Makey is connected to a computer via a USB cable, and uses closed-loop electrical signals to send the computer either keyboard strokes or mouse click signals when users touch the

objects connected to the Makey Makey. Fig. 3 shows a student making simulated arrow keys using Play-doh (modeling clay) and also drawing keyboard's arrow keys on paper. The objective of that project was to make a simple video game controller with simulated arrow keys. The students tested their prototypes by playing online video games on their laptops [5].

Using the Makey Makey in HCI classes has been very successful, motivating students to keep using the Makey Makey in more applications and in other in-class projects. In addition, some of the students wanted to buy the kit [11].

IV. TECHNOLOGY ACCEPTANCE QUESTIONNAIRE AND RESULTS

Before we started to run the in-class projects, we set up two research questions:

- Do microcontroller boards (e.g. the Arduino Uno board) used in small class projects support learning of HCI concepts?
- Do microcontroller boards support Maker Movement activities such as digital prototyping conducted in class?

In order to answer those questions, we needed to see how students perceived the use of microcontroller boards and tinkering with technology in class. The TAM is a computer science theory that analyzes how people (users) come to accept and use an interactive digital product [9]. The TAM suggests that when users are presented with a new technology, some factors influence their decision about when and how they will accept and use it, including:

- Perceived ease-of-use (PEOU): "the degree to which a person believes that using a particular system would be free from effort" [9].
- Perceived usefulness (PU): "the degree to which a person believes that using a particular system would enhance his or her job performance" [9].

The TAM2 questionnaire [10] was used to measure both PEOU and PU, containing 26 questions and 7-point Likert scales, shown in Appendix B.

At the end of the course, students filled out the TAM2 questionnaire where they evaluated the Arduino Uno board used in HCI classes.

Results from the TAM2 questionnaire (see Fig. 4) indicated that most of the students perceived the Arduino Uno microcontroller board as easy to use and very useful in HCI classes. Results also shown that most of the students felt motivated to build interactive devices with the Arduino Uno board and would like to keep using it in other classes, and the board was easy to use and troubleshoot.

We verbally asked students at the end of the course their general opinion about the Maker Movement, in particular about its usefulness in HCI classes and how it relates to in-class activities and if it helped them learning about HCI. Most of the students positively answered our questions, which are related to the TAM2 questionnaire results.

The above results answered our research questions. Microcontroller boards used in small class projects are engaging and useful for supporting learning of HCI concepts and they do support Maker Movement activities in class.

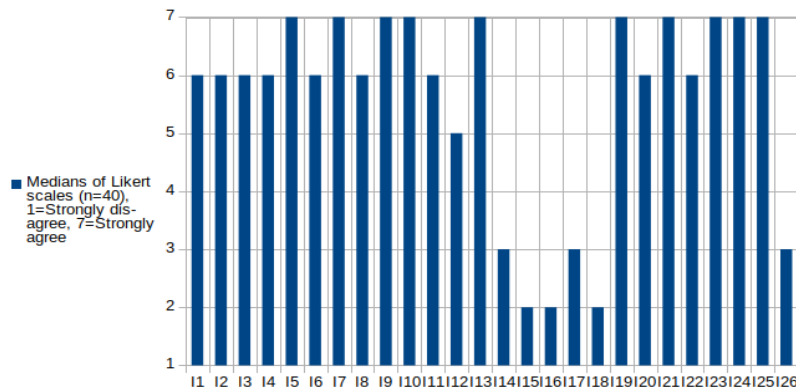


Fig. 4 Results of the TAM2 questionnaire

V. LESSONS LEARNED

The following are some lessons learned after students completed the projects in class:

- Prepare all the materials for the in-class activities well in advance, before classes start. Make sure everything works, including electronic components, batteries, etc. Make sure that the microcontroller boards work.
- Plan ahead each class. Our classes have been carefully planned and structured (see Table I).
- Make sure that all the students understand the project's main objective.
- Strive for student safety. We explain students that although the microcontroller boards and electronic components should be safe to use, it is always necessary to ensure that the electronic circuit is properly grounded and connected to the battery. The course instructor also ensured that all the electronic components and tools were properly used.
- Ensure that students wear an electrostatic discharge (ESD) wrist band when they manipulate microcontroller boards and other static-sensitive components such as CMOS electronic components.
- Allow students to fail. This is an excellent opportunity for them to learn from their mistakes. At the end of the classes, we reviewed what went wrong in the projects and how to avoid that in future projects. We had some students from areas other than computer science, and they really appreciated that mistake feedback. In addition, they were collaborating and getting support from teammates with computer science background.

VI. CONCLUSION

Many students who took the HCI course were really motivated to keep using devices such as the Arduino Uno microcontroller boards. Some of them bought the Arduino board right after the course finished, to keep learning more about it.

We believe that every HCI course should include a number of in-class activities and/or assignments related to the Maker Movement. Exposing students to low-cost and easy-to-use technology such as electronic components and microcontroller

boards in university courses is a powerful catalyst for students to use this technology in further courses and in extra-curricular activities, promoting how to tinker with technology.

Some students have suggested new and very interesting projects for further HCI courses, such as making an automated greenhouse.

We also believe that the HCI course has been popular because it seems that students recognize that the courses have practical and hands-on activities, not just theory, and they learn other topics such as an introduction to digital electronics.

Applying the Maker Movement in HCI courses has a number of educational and experiential learning benefits:

- During the course, students needed to think out of the box and work collaboratively for solving problems. For example, in one of our courses students needed to securely fix an electronic circuit and a small battery to a bamboo stick, working as a walking cane. Students tried and tested different materials, from duct tape to Velcro. The best (although not the prettiest) solution that they found was to use plastic cable ties. Students also suggested to use bamboo sticks to make the walking canes, which was proven to be a low-cost and effective solution. With these decisions and actions, we confirm that the in-class project are related to the Maker Movement.
- The in-class projects with the microcontroller boards are a great opportunity for HCI students to know about the Maker Movement, which it was also explained and practiced in our classes. Having meaningful and interesting hands-on activities with the microcontroller boards and other electronic components in class motivated students to keep participating in further Maker activities.

APPENDIX

A. Summary

Summary of in-class activity: Developing and testing an auditory UI (an "electronic" walking cane) for blind people.

Objective:

Apply fundamental concepts of participatory and iterative design, as well as usability testing of an auditory user interface.

Introduction:

Participatory design involves and encourages end users, HCI specialists and developers in the collaboration of the design, implementation and testing of user interfaces of all kind. Iterative design is the “iterative development of user interfaces involves steady refinement of the design based on user testing and other evaluation methods” [20]. It encompasses design methodologies based on a cyclic process of prototyping, developing, analyzing, testing and refining a user interface (UI) [7].

Usability testing is a systematic way to see how easy to use a UI is by testing it with real (end) users and other stakeholders such as developers, where users need to do some tasks in the UI. User feedback and usability testing data is obtained and used to improve the UI design iteratively. Usability goals address three usability components: effectiveness, efficiency and satisfaction of UI use.

Instructions:

Work in teams.

Today, you will develop and test the usability of an electronic walking cane for blind people using the Arduino Uno microcontroller board, an ultrasonic sensor and a buzzer. Blind people rely on their sense of hearing and the sense of touch (using a cane) for perceiving information about the environment and thus make decisions on where to walk to, etc.

You will use an ultrasonic sensor that will measure the distance between nearby objects and a passive buzzer (an electronic component) to make audio tones that will alert the user that an obstacle is in the user’s way.

Examples of similar projects about making an electronic walking cane are described in [13] and [14].

1. Define what are the usability goals and main task for the users and the “electronic” walking cane.
2. Develop a low-fidelity prototype of the auditory interface (a visual layout) made in Fritzing. Fritzing is an open-source computer-aided design (CAD) software that supports the design of electronic circuits and hardware, such as Arduino applications. You can download Fritzing from [21].

I’m going to explain how to use Fritzing in class. Also, a tutorial on Fritzing is shown in [24].

3. Connect the ultrasonic sensor to the breadboard using 4 wires. Connect the sensor’s “Vcc” pin to pin “5V” of the Arduino. Connect the sensor’s “Trig” pin to pin no. 12 of the Arduino. Connect the sensor’s “Echo” pin to pin no. 11 of the Arduino. Connect sensor’s “Gnd” pin to pin “GND” of the Arduino.
4. Connect the buzzer to the breadboard. Insert one leg of the 100 Ohm resistor to the breadboard’s rail where the buzzer’s positive pin (its top shows a “+” sign) is inserted in. Insert the other leg of the resistor to another rail of the breadboard. Insert a wire to that leg’s rail and to pin no. 4 of the Arduino. Now, connect a wire from the other leg of the buzzer to the pin “GND” of the Arduino.
5. Download from the University’s content management system (CMS) a file called “walkingcane.ino” and open it

in the Arduino IDE. Verify and send its source code to the Arduino, for controlling the buzzer and the sensor.

6. Attach the Arduino Uno and the circuit to the provided bamboo stick.
7. Now, do a quick test of the walking cane. Put some objects around and move the walking cane back and forth around the objects to see if the sensor can detect them. The USB cable may be short so be careful.
8. Improve the auditory UI design. Discuss how the team can improve it. Do you need to change the pitch (frequency) of the tone? Do you think adding a repetitive pattern of tones will alert the user better? Do you think the buzzer’s tone is annoying? Modify your Arduino code and test some alternatives.
9. You will conduct a usability testing method called “SUS questionnaire”. Invite members from other teams to test your electronic walking cane. The main task for them in the test is to “walk” around with your walking cane and put objects on the floor around to see if the circuit can detect them. Let the user hear the audio tones, etc. You may ask the participant to close his/her eyes while testing the cane. Be careful, the USB cable is short! After the test, ask the user to fill out the SUS questionnaire. You will be provided with copies of it. You will need to grade the questionnaire. You can download an Excel file from the CMS for that, called “Satori-SUS-Calculator.xls”. Just fill out the 10 scale positions from the questionnaire and the Excel file will give you a usability value from 50 (very bad usability) to 100 (excellent usability).

The whole electronic circuit is shown in Fig. 5.

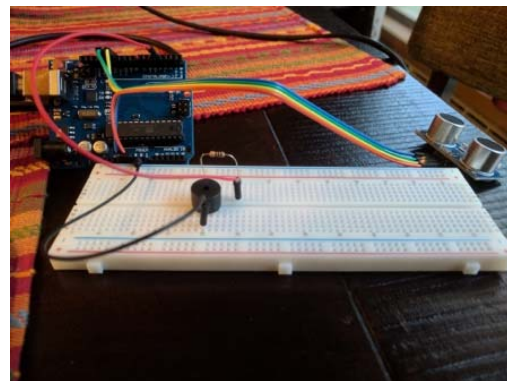


Fig. 5 Microcontroller board connections

References used in this in-class activity are shown in [15]-[19].

B. Questionnaire

The TAM2 questionnaire is shown in Fig. 6. Each item includes a 7-point Likert scale.

System=Arduino Uno microcontroller board	1=Strongly disagree 7=strongly agree
Intention to Use	
1.Assuming I have access to the system, I intend to use it.	
2.Given that I have access to the system, I predict that I would use it.	
Perceived Usefulness	
3.Using the system improves my performance in my activity as student.	
4.Using the system in my activity as student increases my productivity.	
5.Using the system enhances my effectiveness in my activity as student.	
6.I find the system to be useful in my activity as student.	
Perceived Ease of Use	
7.My interaction with the system is clear and understandable.	
8.Interacting with the system does not require a lot of my mental effort.	
9.I find the system to be easy to use.	
10.I find it easy to get the system to do what I want it to do.	
Subjective Norm	
11.People who influence my behavior think that I should use the system.	
12.People who are important to me think that I should use the system.	
Voluntariness	
13.My use of the system is voluntary.	
14.My teacher does not require me to use the system.	
15.Although it might be helpful, using the system is certainly not compulsory in my activity as student.	
Image	
16.People in my school who use the system have more prestige than those who do not.	
17.People in my school who use the system have a high profile.	
18.Having the system is a status symbol in my school activity as student	
Relevance	
19.In my activity as student, usage of the system is important.	
20.In my activity as student, usage of the system is relevant.	
Output Quality	
21.The quality of the output I get from the system is high.	
22.I have no problem with the quality of the system's output.	
Result Demonstrability	
23.I have no difficulty telling others about the results of using the system.	
24.I believe I could communicate to others the consequences of using the system.	
25.The results of using the system are apparent to me.	
26.I would have difficulty explaining why using the system may or may not be beneficial.	

Fig. 6 TAM2 questionnaire

ACKNOWLEDGMENT

Miguel Garcia-Ruiz thanks the research assistants who helped setting up and testing the equipment and electronic components used in the HCI course and also thanks Algoma University's Gaming Technology Laboratory.

REFERENCES

- [1] E. R. Halverson, and K. Sheridan, "The maker movement in education", *Harvard Educational Review*, vol. 84, no. 4, pp. 495-504, 2014.
- [2] C. Anderson, *Makers: The new industrial revolution*, New York, NY: Crown, 2012.
- [3] P. Blikstein, and D. Krannich, "The makers' movement and FabLabs in education: experiences, technologies, and research", in Proc. of the 12th International Conference on Interaction Design and Children, ACM, 2013.
- [4] D. Dougherty, "The maker movement. Innovations: Technology, governance", *Globalization*, vol. 7, number 3, pp. 11-14, 2012.
- [5] M. A. Garcia-Ruiz, P. C. Santana-Mancilla, and L. S. Gaytan-Lugo, "Measuring technology acceptance of Makey Makey as an input device in a human-computer interaction class", in Proceedings of EdMedia 2016: World Conference on Educational Media and Technology, Association for the Advancement of Computing in Education, Vancouver, BC, Canada, 2016.
- [6] E. S. Katterfeldt, N. Dittert, and H. Schelhowe, "Designing digital fabrication learning environments for Bildung: Implications from ten years of physical computing workshops", in Proc. of International Journal of Child-Computer Interaction, 5, pp. 3-10, 2015.
- [7] S. P. Overmyer, "Revolutionary vs. evolutionary rapid prototyping: balancing software productivity and HCI design concerns", in Proc. of the 4th International Conference on Human-Computer Interaction, Stuttgart, Germany, pp. 303-308, 1991.
- [8] K. Peppler, and S. Bender, "Maker movement spreads innovation one project at a time", *Phi Delta Kappan Magazine*, vol. 95, no. 3, pp.22-27, 2013.
- [9] F. D. Davis, "Perceived usefulness, perceived ease of use, and user acceptance of information technology", *MIS Quarterly*, University of Minnesota, Minneapolis, MN, vol. 13, no. 3, pp. 319-340, 1989.
- [10] V. Venkatesh, and F. D. Davis, "A theoretical extension of the technology acceptance model: Four longitudinal field studies", *Management Science*, Catonsville, MD, USA, vol. 46, number 2, pp. 186-204, 2000.
- [11] M. A. Garcia-Ruiz, P. C. Santana-Mancilla, L. S. Gaytan-Lugo, "Measuring Technology Acceptance of Makey Makey as an Input Device in a Human-Computer Interaction Class", in Proc. of EdMedia 2016: World Conference on Educational Media and Technology, Association for the Advancement of Computing in Education, Vancouver, BC, Canada, 2016.
- [12] <http://www.instructables.com/id/Smart-Arduino-Walking-Stick-for-Visually-Impaired/>. Accessed on: 25/06/2018.
- [13] <http://www.instructables.com/id/Smart-Arduino-Walking-Stick-for-Visually-Impaired/>. Accessed on: 25/06/2018.
- [14] <http://arduinoart.blogspot.ca/2015/05/project-guide-stick-for-blind-people.html>. Accessed on: 25/06/2018.
- [15] <http://www.learningaboutelectronics.com/Articles/HC-SR04-ultrasonic-distance-sensor-circuit.php>. Accessed on: 25/06/2018.
- [16] <http://www.learningaboutelectronics.com/Datasheets/HC-SR04-ultrasonic-distance-sensor-datasheet.pdf>. Accessed on: 25/06/2018.
- [17] <https://www.instructables.com/id/How-to-use-a-Buzzer-Arduino-Tutorial/>. Accessed on: 25/06/2018.
- [18] <https://www.arduino.cc/en/reference/tone>. Accessed on: 25/06/2018.
- [19] <http://www.instructables.com/id/Smart-Arduino-Walking-Stick-for-Visually-Impaired/>. Accessed on: 25/06/2018.
- [20] J. Nielsen, "Usability inspection methods." in Proc. of Conference Companion on Human Factors in Computing Systems, ACM, 1994.
- [21] <http://fritzing.org/home/>. Accessed on: 25/06/2018.
- [22] <https://store.arduino.cc/usa/arduino-uno-rev3>. Accessed on: 25/06/2018.
- [23] <https://makeymakey.com/>. Accessed on: 25/06/2018.
- [24] <https://www.youtube.com/watch?v=IJxIIfyNX0>. Accessed on: 25/06/2018.