Sketching with Hardware: A Course for Teaching Interactive Hardware Prototyping to Computer Science Students

Andreas Schmid
Andreas.Schmid@ur.de
University of Regensburg
Regensburg, Germany

Raphael Wimmer
Raphael.Wimmer@ur.de
University of Regensburg
Regensburg, Germany

ABSTRACT

Sketching with Hardware is an undergraduate university course with the goal to teach students how to build prototypes for tangible user interfaces. Goals of this course are to create awareness for tangible interaction among students and prepare them to realize advanced projects like bachelor's and master's theses in this field. In this paper, authors share their experience teaching the concepts of tangible interaction, electronics and prototyping to computer science students in a two week course. The course's content, structure and goals are explained, and needed material and infrastructure are described. The long-term effect of the course has been evaluated by conducting a survey among former participants.

KEYWORDS

tangible interaction, teaching, prototyping

Figure 1: Course participants of *Sketching with Hardware* working on their prototypes

1 INTRODUCTION

Ever since Hiroshi Ishii introduced the idea of tangible interaction to the computer science community [2] it has become an important field of research in human computer interaction. However, the process of building tangible user interfaces requires skills in electronics, low-level programming and crafting, which are usually not part of an applied computer science curriculum. To convey these skills and therefore empower students to build tangible user interfaces, we offer the elective course *Sketching with Hardware* in the media informatics curriculum of the University of Regensburg.

Sketching with Hardware is inspired by Tom Igoe's physical computing course [1] at New York University Tisch School of the Arts. While similar course concepts have been discussed in earlier publications, these focus on designing products [8] or artistic exhibits [3], while our course has a main emphasis on creating artifacts and interfaces for tangible interaction. Our course is targeted at media informatics students who already have some programming experience and a basic understanding of HCI (Human Computer Interaction) concepts. The course concept for *Sketching with Hardware* was developed by Alexander Wiethoff and Raphael Wimmer who combined a course concept targeted at interaction designers with one targeted at computer science students at LMU Munich [9] in 2009, where the course has been taught ever since. Wimmer started teaching the course from 2012 onwards together with Florian Echtler at University of Regensburg with Andreas Schmid joining in 2015. Therefore, compared to related work presenting the results of experimental courses that have been conducted only once, we can share the experience from a total of twelve iterations of *Sketching with Hardware*.

In this paper, we describe the goals and overall structure of the course, as well as the needed personnel, materials and infrastructure in order to provide tips and inspiration to others planning to start such a course.

2 COURSE GOALS AND STRUCTURE

Sketching with Hardware is a university course with the goal to teach media informatics students basic concepts of electronics, microcontrollers and interaction design. Because of the practical nature of those topics, we emphasize on

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hands-on excercises and learning by doing instead of theoretical lectures. After acquiring these skills, course participants create prototypes for tangible user interfaces. In contrast to other courses in applied computer science, *Sketching with Hardware* encourages students to approach problems from a physical and hardware-centered point of view. Even though we provide an introduction to electronics, a thorough overview of the field can not be provided within the scope of this course. Furthermore, basic programming knowledge is a prerequisite to participate in *Sketching with Hardware.*

Course Goals

Main goal of this course is to introduce the field of tangible interaction to students and teach them skills required to create tangible user interfaces. Course graduates are thereby enabled to work on further projects in electronics, prototyping, and tangible interaction, including bachelor's and master's theses with hardware-related topics.

The hardware interactive prototypes created in this course can be used as exhibits at public events to create awareness for tangible interaction and the lab among a broader audience.

Course Structure

The course is organized as a full-time block of two weeks. During the first week, basic concepts of electronics, microcontroller programming, prototyping and interaction design are taught through lectures and practical excercises.

Day	Activities
Day 1	Introduction, Electronics, Soldering
Day 2	Arduino, Microcontroller Programming
Day 3	Digital Electronics, Sensors and Actuators
Day 4	Flexible Slot, Interaction Design, Brainstorming
Day 5	Proof of Concept
Day 6 - 8	Building a hardware prototype
Day 9	Finishing the prototype, Presentation
Day 10	Polishing, Bugfixing

Table 1: Course Schedule

On the first day of the course, basic concepts and important milestones of tangible interaction are introduced to the students. The course's content is previewed, material needed for the course (Figure 3) is given to the students, and organizational topics are addressed. Thereafter, basic concepts of electronic circuits, Ohm's Law, and important components are introduced. This theoretical block is followed by an exercise where students test their knowledge of these concepts. After a lunch break, students are taught soldering and practice this technique. This is followed by another theoretical block about electronics covering Kirchhoff's circuit laws, transistors, and integrated circuits. The first day of the course is concluded after a hands-on task using the 555 timer IC to build a monostable multivibrator circuit. Main purpose of this exercise is to teach students how to read data sheets.

The second day of the course is focused on microcontroller programming. After a short introduction to the Arduino Micro, students have to solve a few simple programming tasks to get used to the platform. This is followed by a prototyping exercise where participants build a custom input device for a simple video game of their choice based on the Arduino. After a lunch break, the main differences in programming between the Arduino and Java (the programming language taught in our induction courses) are explained. The final exercise of the second day is to build a binary clock using the Arduino Micro, a shift register and several LEDs.

The third day of the course starts with an introduction of important libraries for Arduino and an exercise with *Adafruit NeoPixel*[1] LED strips. Thereafter, communication with sensors and actuators over SPI, I^2C and UART protocols is taught in a short lecture followed by a practical task. For this exercise, each group gets a pair of components (one sensor and one actuator) which they have to connect in a adequate way to the Arduino. Depending on the complexity of selected components, this task can take rather long and students are likely to need individual support. The third day is concluded with an overview on existing sensors and actuators as well as existing projects using those components.

The fourth day of the course begins with a flexible slot which can be used to teach specific skills needed for the final project. After a lunch break, concepts and workflows of interaction design based on the ideas of Bill Moggridge [4], Kevin Silver [7] and Donald Norman [5] are taught and affordances of tangible artifacts in comparison to GUIs are explained. With this hard break from the technical point of view of the former content, students are motivated to change to a mindset more focused on design. Then, the theme for the final project is revealed. We recommend selecting an abstract theme with room for creativity, as too specific themes will limit the students' possibilities while too general themes can leave them overwhelmed with the number of possibilites. As an example, a selection of past topics of our course are *"Spooky Interactions at a Distance"* (prototypes communication with each other), *"Harry Potter"* (tangible artifacts inspired by the *Harry Potter* [6] universe), and *"Tangible Games"*. Following the revelation of the theme, participants form groups of two for their final project. To find a concrete topic for the project, each group sketches three ideas on a poster and presents those to the other students who provide feedback. After this brainstorming round, each group

[1] *NeoPixel* LED strips (based on *WS2812*) on their distributor's official website: https://www.adafruit.com/category/168

Figure 2: Selection of prototypes developed during the course (environment-aware lamp, ghost detector game, unicorn tamagochi, interactive ouija board, story-telling teddy bear, interactive voodoo doll)

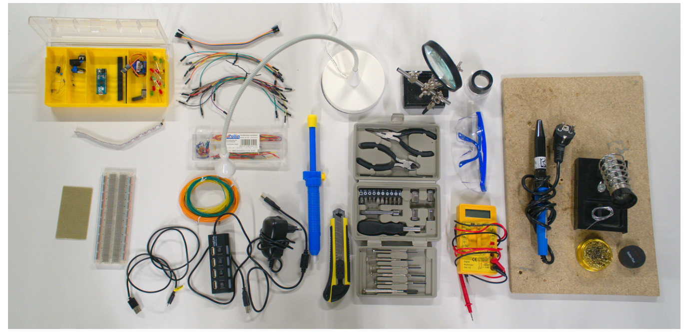

Figure 3: Tools and components for each group (see Appendix B for detailed list)

selects one of their ideas as their topic. The rest of the fourth day and the entire fifth day are used for proof of concept experiments, testing and creating low-fidelity prototypes.

Over the weekend, each group is tasked with creating a concept video for their prototype. This video has to demonstrate the interaction with the planned prototype and should not exceed one minute.

During the second week of the course, students work independently on their prototype for the final project and instructors are only present to help them solve individual problems. In case there is a need for special components, they should be ordered as soon as possible to prevent bottlenecks caused by missing material.

Presentations of the soon to be finished prototypes are scheduled for the afternoon of the penultimate day of the course. The projects have to be finished on the last day of the course and should then be in a functional and high-fidelity state. We suggest not to provide additional time to finish the projects as this has proven to have little impact on the final prototype’s quality.

In addition to the hardware artifact, participants have to hand in a written documentation of the project and a high-fidelity video demonstrating interaction with the finished prototype. Those are due one week after the end of the course.

3 ORGANISATION AND INFRASTRUCTURE

As the students have to apply newly acquired skills, intensive support has to be provided by the course’s supervisors. In addition, available space and access to tools can be a bottleneck. For this reason, we limit the number of participants to a maximum of twelve students who are selected based on a short essay in which they substantiate their motivation to join the course and specify their previous knowledge in HCI, electronics and tangible interaction.

Each group is provided with a box containing a set of tools and electrical components (Figure 3, Appendix B) required to work on the excercises during the first week. For their final project, each group gets a budget of 30€ to spend on additional components. Additionally, we recommend providing a range of often needed materials like wood, plastic boxes, screws and paint, as well as a selection of tools (Appendix B).

Due to the practical activities during the course, an appropriate room with enough space is needed. Ideally, the room is reserved for the complete duration of the course and can be locked so that tools, material, and prototypes can be left there over night. Access to tools should be uncomplicated.

A student assistant with sufficient knowledge in electronics, programming and crafting supports the instructor by helping the participants to solve problems during practical phases of the course and answer individual questions.

Sketching with Hardware has a high financial cost per student compared to other courses in computer science, as tools and material are needed and supervision is intensive. Aside from gear for shared use by all participants, each group gets a box containig tools and material which cost about 150€ altogether. In addition to this one time investment in the procurement of material that can be reused in future iterations of the course, there are recurrent costs for consumables like electrical components, building materials and the budget for each group’s project (about 250€ total per course), as well as the salary of instructor and student assistant, and the replacement of broken gear.

Design Decisions

Based on our experience teaching the course, we have made several decisions to foster participants’ creativity and ensure a smooth procedure. We strongly recommend using the Arduino Micro as a microcontroller platform because it is small enough to be included inside hardware prototypes and it can easily be plugged into a breadboard for testing. We have also tried using more advanced platforms like the *LOLIN D32*[2] but they turned out to be too complex for novice users.

As the course participants are likely to have experience in programming GUI applications, we try to get them out of their comfort zone by prohibiting the use of displays in their hardware prototype. By providing only one shared set of tools to each group of two, we encourage collaboration and planning ahead.

Exercises during the course are in form of extensive tutorial sheets. This way, each group can work in their own tempo while instructors can provide individual assistance.

4 EVALUATION

To evaluate the long-term results of *Sketching with Hardware*, we conducted a survey among graduates of the last five instances of the course (Winter 2015/16 onwards). Students participating earlier iterations have been excluded from the survey as they all have already finished studying and were hard to reach. Out of 52 eligible subjects, 38 could be reached and 22 have participated in the survey.

We asked for the participant's main motivation to join the course, the impact of the skills and knowledge contained during the course on their daily lives, the effect of the course on their interest for electronics and tangible interaction, the attitude towards writing a theses related to tangible interaction, and feedback on the course's content (Appendix A, Table 5). To determine statistical significance of the survey's results, we conducted a two-tailed paired sample t-test.

Both interest in electronics (average before the course: 3.14; present: 3.91; p=0.005) and the interest for tangible interaction (average before the course: 2.79; present: 3.55; p=0.001) have increased significantly among former course participants and knowledge obtained during the course has been *"rather relevant"* (average 4.81 out of 7) for them.

Half of the course's graduates can imagine writing a thesis with a topic from the field of tangible interaction (Table 2).

Answer	Count
Yes, I have already/Yes, am I doing currently	2
Yes, I am planning to	0
Yes, I can imagine doing so	9
I do not know	3
No, only if I have to	2
Certainly not	1
No, I do not have to write a thesis	5

Table 2: Answers to the question *"Can you imagine writing a thesis with a topic from the field of tangible interaction?"* (multiple choice)

For most participants, the course was successful in conveying skills in electronics and crafting, as well as establishing awareness for tangible interaction (Table 3).

Answer	Count
Electronics	20
Crafting	16
Tangible Interaction	15
Project Planning	14
Programming	13
Structured Working	12
Targeted Debugging	11
Interaction Design	10

Table 3: Answers to the question *"For which subjects did SWH increase your knowledge?"* (Checkboxes)

While only few former participants could make use of the skills acquired in *Sketching with Hardware* in a professional context, the course helped them in realizing private projects and passing on knowledge (Table 4).

Answer	Count
Private Projects	15
Teaching Others	13
Other University Courses	12
Thesis	6
Job	3

Table 4: Answers to the question *"Where did you profit from skills learned in SWH?"* (Checkboxes)

5 CONCLUSION

In this paper, we presented our approach to teaching computer science students hardware prototyping for tangible user interfaces. We provided an overview of our course's content and structure, as well as required material and infrastructure to conduct this course. An evaluation of past iterations of *Sketching with Hardware* has shown that we have been successful in passing on knowledge in electronics, prototyping and tangible interaction to the course's participants.

Further information on *Sketching with Hardware* and additional material, including slides and handouts, can be found at hci.ur.de/projects/swh.

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[2]https://wiki.wemos.cc/products:d32:d32

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A SURVEY

Question	Type of Answer
When did you attend SWH?	multiple choice
Why did you attend SWH?	free text
Which contents of the course have been useful to you?	free text
For which subjects did SWH increase your knowledge?	checkboxes
Where did you profit from skills learned in SWH?	checkboxes
How relevant was the knowledge obtained in SWH for you?	7-point likert scale
How high was your interest for electronics before SWH?	5-point likert scale
How high is your interest for electronics right now?	5-point likert scale
How high was your interest for tangible interaction before SWH?	5-point likert scale + "I did not know, what this is"
How high is your interest for tangible interaction right now?	5-point likert scale + "I do not know what this is"
Can you imagine writing a thesis with a topic from the field of tangible interaction?	multiple choice
If not, why?	free text
In hindsight, what would you have liked to learn in SWH?	free text
Which contents of SWH were superfluos?	free text

Table 5: Questions of the survey (translated from german, *Sketching with Hardware* abbreviated with *SWH*)

B TOOLS AND MATERIAL

Content of the Box (per group)

- Cutter
- Soldering Iron + Stand + Cleaner
- Solder Pump
- Solder
- Solder Flux
- Third Hand (optionally with magnifying glass)
- Safety Goggles
- Toolkit
- Multimeter
- Jumper Wires
- Arduino Micro + Cable
- Pin Headers (male and female)
- Servo Motor
- Potentiometer (linear, 10k Ohm)
- 555 Timer IC
- Shift Register (e.g. *74HC595*)
- Mosfet
- Resistors (220 Ohm, 10k Ohm, 10 each)
- Capacitors (100 pF, 47 uF, 5 each)
- LEDs (3 colors, 6 each)
- Misc. Buttons and Switches
- Breadboard (at least 10x60 rows, with power supply rails)
- NeoPixel Strip (10 LEDs, e.g. *WS2812*, with pin headers)
- Wire (5 m)
- USB Hub (preferrably active)
- Power Supply (adjustable, 3-9 V)
- Soldering Mat (wood or silicone)
- Magnifying Glass
- Desk Lamp

Tools for shared use

- Oscilloscope
- Lab Power Supply
- Cordless Screwdriver + Drills
- Jigsaw
- Vacuum Cleaner
- Hot Glue Gun
- Handsaw
- Screwdrivers
- Measuring Tape
- Wire Cutter
- Pliers
- Clamps

Materials and Consumables

- Alligator Clips
- Wire (thin, different colors)
- Screws
- Plywood
- Acrylic Glass
- Copper Tape
- Metal Fittings
- Duct Tape
- Electrical Tape
- Shrinking Tube
- Set of Resistors (50 to 100k Ohm)
- Capacitors (100 pF to 1 mF)
- Perfboards
- *WS2812* LED Strips (e.g. *Adafruit NeoPixel*)
- Paint
- Sand Paper
- Cardboard