Makers with a Cause: Fabrication, Reflection and Community Collaboration

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Abstract. The potential of using maker and DIY approaches for collaborative learning is widely recognized. Maker techniques such as rapid prototyping are being increasingly adopted by schools, universities and colleges in order to effectively teach core design and science concepts. We describe our approach to facilitating a series of "MakeShops", maker workshops, for undergraduate engineering students, in which we used a *maker atelier* model to facilitate the design and implementation of self-directed maker projects that combined making and tinkering with reflection and community collaboration.

Keywords: Maker movement · Design facilitation · Pedagogy · Interdisciplinary collaboration · Self-directed learning

1 Introduction

In his seminal 1980 book on the potential of using computers for children's education, *Mindstorms*, Seymour Papert described the similarities he felt between Brazilian samba schools and his vision of a technological culture that "helps us not only to learn but to learn about learning" [1]. He envisioned a mode of learning that is "fully participatory" and is achieved through "real activity that can be shared by novices and experts" [1]. More than 30 years have passed since *Mindstorms* and, in recent years, the Maker Movement (or Do-It-Yourself (DIY) Movement) has emerged as a body of amateur and professional designers who often combine high-tech tools (e.g., 3D printers and embedded computers) with traditional manufacturing methods (e.g., glassblowing and woodworking) to create customized, small-batch designs [2]. The potential of this movement, especially in the light of the potentials of collaborative, self-directed and technology-mediated learning, is enormous [3, 4]. We believe the culture growing around the Maker Movement is serving in the technological/cultural role that Papert envisioned in his book and creates the conditions in which digital design and making can lead to genuine self-expression and empowerment.

Making is, of course, not new; the use of tools is associated with human evolution itself. A significant shift occurred in the Industrial Revolution, as modes of production,

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transitioning from industrial workshops into factory and assembly line contexts, became more complex and inaccessible; in the aftermath of this shift, consumers became increasingly distanced from modes of production. Making and tinkering, of course, continued, but the Maker Movement offers consumers the new possibilities for (taking up an active role in) the design of products that they use. We believe that the reason the Maker Movement is different from previous forms of making and tinkering are as follows: (a) a significant increase in the expressive potential of emerging technologies, at the same time as, a decrease in barriers to entry (in term of both affordability and expertise); and (b) a high degree of global and local community connectivity through the Internet, Maker Faires and emerging maker spaces. Making holds great potential for democratizing technology and provides valuable opportunities for learning and empowerment [5, 6]. However, for this to become reality, we believe that further critical reflection and socially aware motivation needs to be combined with prototyping and fabricating.

To explore the possibilities of making for education and empowerment, we designed and conducted a series of maker workshops, or “MakeShops”, for undergraduate engineering students at our school. In these workshops, we combined the use of so-called “maker” tools and techniques, such as 3D printing, embedded electronics and wearable computers, and pedagogical elements, such as the facilitation, collaboration, and an “atelier” mode of engagement. We believe this approach has several aspects of potential use in similar, future workshops. First, we conducted the workshops through a facilitation model in which the workshop facilitator (first author of this paper) was also a participating maker (i.e., an *experienced* or *proficient maker*) working on a project simultaneously as the other participants. The sessions were conducted in what we term as a “maker atelier” approach, in which small teams worked on self-selected projects under the supervision of an *experienced maker*, rather than an instructor, and elements of performance and creative dialogue were encouraged. Second, we developed the workshop to elicit reflection around the values embedded in the design ideas that each team was working on and their social, political and economical implications. In this way, we aimed to combine the practice of making with reflection, aiming for more *informed action*, or *praxis,* which strives for a balance between theory and action [7]. Third, we encouraged the participants to collaborate with each other and other makers, both through face-to-face meeting and working sessions and through the making available of documentation and designs online. We describe these choices and their outcomes in more detail in the following sections.

2 MakeShops: Facilitating Creativity

We designed and conducted a series of maker workshops, MakeShops, to explore the possibilities of the maker approach in an experiential learning setting. We developed outreach and advertising materials, and an intake mechanism to receive applications from interested students. The workshops were offered as an extra-curricular activity (which would not result in additional academic credit). We applied for and received financial support for the workshop from the Technology Enhanced Active Learning

(TEAL) initiative, a special project that was launched in 2013 by the Lassonde School of Engineering at York University in Toronto. The venue for the workshop was the GaMaY research lab, which is a dedicated space for the research activities led by two faculty members and their graduate students in the department of Electrical Engineering and Computer Science. Due to the competing needs of multiple other projects, the lab space could only be used one day a week and all workshop materials would be stowed away in the interim. Of more than 30 applications, we accepted 10 undergraduate engineering student participants into the workshop, representing all levels of study (first-year to final-year). The workshop consisted of 10 3 h sessions, which took place every weekend over a 10 week-period. The first author (referred to as the *workshop facilitator* in the rest of the paper) facilitated the sessions.

In the first workshop meeting, we presented the participants with an overview of maker and DIY approaches, including a discussion of the tools and techniques available and a presentation of a series of maker projects curated for their creativity and thoughtfulness including, among others, the *Banana Piano* [9], *Botanicalls* [10] and 3D printed prosthetics [11]. This introduction was crucial, given our group of learners, who were engineering students. The participants were familiar with engineering design and requirements-based problem solving, and were not attuned to a mode of practice that is not centrally concerned with 'solving' a problem but rather is focused on creative expression, inventiveness, and exploration. The second session took the form of a "field trip", and was a visit to the Toronto Mini Maker Faire. In this session, the participants interacted with many example maker projects and met and spoke with local makers. In the third session, the participants divided into smaller teams (five teams of two members each) and undertook brainstorming sessions, which culminated in a project proposal (including budgets) for each team. These proposals were shared with fellow participants, who then provided critique and feedback. Once the project proposals were refined and approved by the workshop facilitator, the participants received material needed for their projects and started working on them. For sessions four onwards, project teams would discuss the work completed, the current state of their projects, and what they planned to accomplish in the next week. During these sessions, participants were encouraged to provide constructive feedback and help to one another. Additionally, a listing of student design competitions and showcases was created and shared with the participants, and each team was encouraged to submit their projects.

At the end of the workshops, in a collective brainstorming session, the participants discussed the learning and challenges around their projects and described steps forward. Additionally, the participants provided feedback about the workshops in a survey. Finally, we conducted free form interviews with eight of the participants, six months following the workshops to assess the efficacy and retention of the material learned during their projects.

In the rest of this section, we discuss our approach to the design and facilitation of the workshops.

2.1 Creating a Maker Atelier

The concept of "artist atelier"—as a shared work space in which novice artists work under the supervision of a master artist—has been a central notion in the artistic traditions of Western Europe [11]. When designing the workshops, we were inspired by this concept and incorporated elements of it in the instruction design. The following are some of the ideas we incorporated into the workshops:

Facilitation Rather than Teaching: In accord with recent research that shows great potential in self-directed and project-based learning [3, 4] the majority of the participants' time at the workshops were dedicated to the discussion and implementation of projects that they designed and conducted themselves. The workshop facilitator adopted an *experienced maker* role rather than an instructor. This role entails facilitation of collaboration and creativity through the creation of an atmosphere of trust and goodwill, where constructive feedback can be generated and exchanged between the participants. The workshop facilitator drew on his previous knowledge of existing maker projects, as well as hands-on previous experience with making to curate relevant and inspiring examples and ideas from the research literature and maker community. Another important role for the workshop facilitator was to provide structure (e.g., in terms of time and budget) on the projects, this was crucial so that the projects would be logistical constrained and feasible. As well, the set of constraints often fostered creativity in the participants; the importance of constraints is previously recognized, as they can structure creativity without being stifling [12].

The Use of Horizontal Teaching and Peer Support: During the workshops, the workshop facilitator also initiated and conducted a project with the same time and budget constraints as the participant projects. By doing so, he was also participating in the workshops directly by discussing and researching a project himself, asking for feedback and support from the other workshop participants. He purposely chose a project (i.e., wearable computing) in which he had a genuine interest, in order to engage in a genuine learning process at the same time with the other workshop participants. This approach helped foster a more horizontal teaching approach where participants engaged in more dialogue with the workshop facilitator and each other.

2.2 Making and Reflection

In recent years, the importance of exercising reflection and critical thinking when making is emphasized [6, 14, 15]. Reflection is a rather broad term; here we focus on value-oriented reflection, contextualization, and life-cycle thinking. Researchers have argued that maker methods have the potential to address social and economical problems if engaged with purposefully [16]. Value-sensitive design approaches, in combination with maker methods, provide a means to realize this potential. These approaches include Reflective Design [17] and Thoughtful Interaction Design [17], which emphasize the examination of unconscious values hidden in design decisions, and encourage the identification of side effects of a realized design, both positive and negative. In the workshops, we explicitly provisioned for the activity of reflection across multiple sessions, in which the participants considered and discussed the social, ethical and political implications of their projects. We strongly believed that the aim of the workshop should go beyond making projects that were merely "cool."

Reflection also includes contextualization, which requires knowledge and analysis of prior relevant work. For this, we pointed the teams to the research literature, and assisted them by recommending specific readings, both in terms of prior relevant projects and also in terms of relevant methodologies and theoretical approaches. For instance, we encouraged the team engaged in the Magic Wand project (described later), to read certain papers on tangible interfaces and embodied cognition.

Another aspect of design that we explicitly asked our participants to consider was to plan for the entire cycle of design, from ideation to deployment and disposal. For each project, the participants were required to come up with a detailed budget, to source their components by researching and investigating potential vendors and outlets, and to identify cost-benefit tradeoffs in their design. Additionally, they had to describe next steps for their project and investigate potential ways to turn their prototypes into products. This included a discussion of alternative deployment strategies, such as the open-source and creative commons approaches. Finally, they had to consider the recycling and reuse potential of their designs. Previous research has emphasized the importance of exploring these issues in maker initiatives [5].

2.3 Community Collaboration

An attractive and essential characteristic of the maker movement is the vibrant and diverse community of makers who are connected through a shared interest in creativity, inventiveness and the sharing of knowledge. This worldwide community is connected both through face-to-face meetings and events, such as various Maker Faires, and in online forums and virtual spaces, such as special interest Facebook groups, forums, etc. In the workshop sessions, we encouraged participants to get in contact with other makers and also to present their projects at maker events and design competitions. To support this goal, we organized a field trip to a local maker faire and introduced some of our maker community contacts to the participants.

As Dale Dougherty, the founder of both Make Magazine and Maker Faire, noted in a 2014 panel [19], a key motivation for makers is "to interact with other people" and have an audience that shares their interest in creativity and hands-on skills. This element of performance is apparent in the enthusiasm and range of presentation techniques manifest at Maker Faires worldwide. We built in possibilities for performance into the workshop via the weekly presentations, which required the teams to present their projects to one another every week. This provided a chance for them to get feedback and additionally acquire experience in presenting their ideas in a supportive environment.

3 Workshop Outcomes

Over the course of the workshops, five project teams emerged (five teams of two members each). One team opted out of the workshop after the 4th session, and the other four teams continued and worked on their projects to varying degrees of completion. The four project ideas were: an interactive 'Magic Wand', an open-source laptop, an affective wristband, and a voice-activated alarm clock. Of these four projects, the first two resulted in working prototypes and the other two projects were partially completed. Given the limited time and resources allocated to the projects, we believe the workshops were successful in motivating original projects and introducing participants to making in a hands-on experiential manner.

In the post-workshop brainstorming sessions and survey, the participants stated that they found the workshops useful and engaging. They identified the field trip to Mini Maker Faire as inspiring and they found the maker atelier approach useful in fostering creativity. They identified a lack of dedicated space and the short length of the workshops as elements that could be improved in the future. Three of the participants suggested that more hands-on programming and implementation instruction could be provided initially. Six of the participants identified the benefit of getting feedback from their peers during the design and implementation process. Two participants described the feedback as 'intimidating' and two described the feedback as unnecessary. All participants stated that they would recommend the workshops to friends and that they themselves would be interested in participating again.

Follow up interviews were conducted six months after the completion of the workshops with eight of the participants. In these interviews, participants still felt the workshops were useful and that they learned new concepts and techniques in them. One participant described it as "the best workshops I have attended". Several participants applied specific knowledge in coursework: one participant, who had learned how to analyze results from embedded accelerometers in the design of a customized controller and then applied this knowledge in order to incorporate an accelerometer into an e-health wearable course project. A second participant learned 3D modeling and fabrication and then consequently developed a customized 3D printed case for a course project; a third participant had learned how to use embedded speech recognition with the Raspberry Pi and then applied this knowledge to implement speech commands for a custom-made robot. These examples demonstrate the efficacy and retention of the learning acquired during the workshops. Beyond the learning of technical skills, participants also became motivated beyond coursework: two participants decided to start their own prototyping-based businesses using 3D printers as a main technology.

In the following subsections, we describe 3 projects connected to the workshop.

3.1 The Magic Wand

The Magic Wand is the outcome of a participant team project. The Magic Wand is a tangible, 3D printed, motion-detecting device that emits a laser light when moved in pre-defined patterns, simulating the casting of a spell. Inspired by the Harry Potter fantasy book and movie series, two of the workshop participants (Chitiiran Krishna

Moorthy and Sonal Ranjit, with subsequent participation by Kajendra Seevananthan) decided to develop their own customized, open-source version of the wand. The Magic Wand consists of a 3D printed shell that houses an Arduino microcontroller, motion detecting modules, a laser-emitting module and a battery. Figure 1 shows Magic Wand.

Fig. 1. The Magic Wand in the dark (top), with instructions (bottom left) and in use (bottom right).

The Magic Wand can be used individually to practice different movement patterns that correspond to spells or in pairs where two users, each with a wand, compete in a “light duel”, to cast spells on each other. Currently, there are 4 movement patterns loaded into the wand’s “firmware” (i.e., the Arduino software). After coming up with the design idea, the team investigated different approaches to embedded computing and examined code for motion detection components and laser emitting modules. This initial investigation included an examination of safety concerns of using lasers. Additionally, the team used 3D modeling to come up with several iterations of the wand design. Each week, the team presented their ongoing work at the workshop and got feedback from the other participants.

Members of the design team were also associated with a student Fantasy Fan Club at the university that regularly hosts events and gatherings. Throughout the time when the workshops were running, they consulted members of the Fan Club regularly about their ideas and got feedback from them on early prototypes. At the conclusion of the workshops they presented the wand at the Fan Club’s annual show and tell. Thus, they engaged a community of potential users in their design process. Following the workshops, the participants submitted the Magic Wand to the Student Design Competition at the 2013 ACM Conference on Tangible, Embedded and Embodied Interaction (TEI), where it was accepted and showcased. The team also presented their project at the 2014 Toronto Mini Maker Faire. The team made the 3D model of their design available for download at the Thingiverse online 3D model repository, where, to date, it has been downloaded more than four hundred times (http://www.thingiverse.com/thing:248254).

3.2 HugBug

It consists of a large hat that is augmented with LED lights and a speaker system that plays music. The hat is activated by a microcontroller that detects touch (and thereby hugs). Figure 2 shows HugBug. It was designed in collaboration with a community partner (Natalie Comeau) who was experienced with designing clothing. Throughout the design process the workshop facilitator worked closely with her, as well as, with potential users at maker and wearable computing events.

Fig. 2. HugBug consists of a large hat augmented with lights and sound. It can be used as a performance or a teaching tool.

The idea behind HugBug is twofold: it is a wearable interface that augments hugs with digital media, and, it is an example of applying a simple Input-Output-Process model [21] to the design of a system to augment human capabilities (the sensors provide input, the lights and music provide output, and the microcontroller controls the process). In the latter context HugBug becomes a compelling teaching tool for children and adolescents. We used HugBug as a teaching tool in workshops for different populations, including marginalized children in Mexico, as well as, high school students in Canada [20].

3.3 TalkBox

TalkBox is a project that was initiated as a collaborative project between one of the workshop participants and a community partner. While not a participant project at the workshops, it serves as a demonstration of the benefits of supporting community collaboration. During the field trip to the local Mini Maker Faire participants met many makers. After the event, they reported their favorite projects and reflected on why they found them interesting. Several of the participants found a particular project presented by a local special education teacher and maker (Ray Feraday) most interesting. This project, an open-source communication board for non-verbal children, was made from a Makey Makey sensor board connected to a computer and a custom made chassis made from foam core and conductive tape that was connected to the sensor board, turning them, in effect, into touch sensitive keys. When the keys were touched, sound files were played back on the computer, making the system a low-cost, customizable communication board. The system was made to address the needs of children with disabilities who either could not use conventional assistive technology solutions or who were waiting for the delivery of new communication devices. The local maker and inventor had drawn on his first-hand experience of many years as a special education teacher to come up with the design.

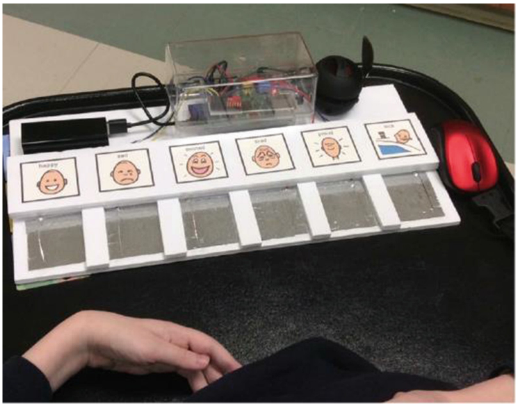

Fig. 3. TalkBox is an open-source customizable communication board for non-verbal children and adults.

Following the event, we contacted the inventor of the system and discussed possibilities of collaboration with him. One of the workshop participants in particular (Toni Kunic) became very interested in collaborating on the project. In the weeks that followed, we formed a team comprising of the inventor of the system, the interested workshop participant and both authors of this paper, to work on a new version of the system that was called TalkBox (Fig. 3). The new version of the system used the credit-card-sized Raspberry Pi computer (Model B+) and embedded touch sensors (MPR121 touch capacitive sensor) to make the system completely portable (e.g., so that it could be placed on a wheelchair tray). Additionally, new software was developed that allowed the easy loading of sound files and the customization of the system functionality [22].

The TalkBox project supported both the collaboration with community encouraged in the workshops (i.e., through collaboration with the local maker), and reflection on the social aspects of the design that aims to make technology more accessible to users who need it most. The system's design, along with all the software, was made open-source and placed on an online repository (https://github.com/tkunic/TalkBox). Since the workshops, the system has been further developed and a pilot user study is currently being planned to assess its usability. Additionally, the design has been presented at the International Conference on Computers Helping People with Special Needs [22] and has won the 2014 "Bridging the Gap" award, a design awarded at the 2014 Toronto Mini Maker Faire.

4 Discussion and Lessons Learned

In the introduction, we articulated the conjecture that maker culture is an instance of Papert's vision of a technological culture that is conductive to learning and to the emergence of creativity and inventiveness. We also fore fronted the key issue of value-sensitive design: how to raise awareness around social, political and economic issues in makers. We designed our workshops to provide not only a learning context for maker methods, but also a context for critical reflection. On the basis of evidence gathered from the workshop participants, we believe that our workshop design was successful, both in terms of fostering meaningful learning and in terms of supporting design outcomes that are community-based and community-oriented. Several teams deployed their results via open-source publishing and several maker projects, such as Magic Wand, HugBug, and TalkBox, focused on empowerment and expression. We believe explicit discussions around implications of design are important, and that such discourse is needed within the maker movement in order to move beyond the aim of merely making "cool" projects. There are myriad opportunities to develop projects that can potentially bring about positive change.

A key observation from the workshops was that making, in addition to being a method and an approach, is also a way of looking at the world that stands in contrast with 'canonical' problem-solving. The workshop participants were engineering students who were familiar with engineering design, specific computational technologies, and requirements-based problem solving. In contradistinction, maker projects are, oftentimes, not actually concerned with 'solving' a problem as opposed to being focused on creative expression, inventiveness, and exploration. Therefore, a first step in our approach was to introduce the workshop participants to this approach towards design. Presenting a series of seminal maker projects from around the world and organizing a field trip to the local Mini Maker Faire supported this introduction. In retrospect, we saw that some of the more junior participants would have benefited with a longer and more structured overview of maker methods and tools.

An important part of the workshops was creating opportunities for participants to meet makers outside of the workshops. This was achieved both through meeting local makers and, also, through presenting participant projects at maker events and design competitions. Thus, a second observation of the workshops was that getting involved in the external maker community, provided the participants with opportunities to experience maker culture first hand, and also to become participants and members of the community, rather than stay part of a passive audience.

A challenge was the limited time that was assigned to the workshops and a lack of dedicated space where more connections and meetings between the participants could happen in a less structured manner. As described previously, the venue for the workshop was a research lab, which could only be used one day a week. Workshop materials needed to be stowed away after each workshop session. This created barriers and inconvenience for the lab participants, and did not support very well our goal to foster serendipitous discovery. We affirm the importance of creating dedicated shared workspaces, similar to Fab Labs [23] and Maker Spaces [24].

5 Conclusion

We have presented results from a series of maker workshops, or MakeShops, conducted with undergraduate engineering students. During the workshops, we created a friendly, collaborative space for learning and sharing and encouraged the participants to provide feedback on each other's projects and present their work to one another. Additionally, we focused on the goal of fostering critical reflection by the participants, so that they would reflect on the impact of their design decisions and would recognize the importance of collaboration within their community. To facilitate the workshops, we used a maker atelier approach in which the workshop facilitator was developing a maker project simultaneously with the rest of the participant teams, taking on the role of experienced maker as opposed to instructor. The workshops were successful in teaching maker techniques to the participants, in building skills of critical reflection, and resulted in a series of working prototypes, several of which were presented at external venues outside of the workshops. What is particularly relevant is that participants were highly motivated to dedicate substantial amounts of their personal time to engage with this type of learning, even though they did not receive any type of formal credit for their project work. We believe in such projects, it is up to us, as facilitators and potential facilitators, to ensure that their learning is firmly rooted in critical reflection.

We believe our approach can be improved in the future by running the workshops over a longer period of time and organizing a dedicated workspace. Additionally, a more structured overview of maker methods and tools can provide scaffolding for participants with less experience.

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