Making Puppet Circuits

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Abstract. The *Prototyping Puppets* project presents a craft-based prototyping project for STEM education of early middle school level students in informal learning. The project combines crafting and performing of hybrid puppets. It was pilot tested in two expert workshops (n=6 and n=10), which focused on crafting practices and materials and two student workshops (n=8 and n=9), which included performance elements. The resulting data back the main design concept to combine craft and performance in a STEM-focused maker project. They suggest particular focus on key elements of our educational scaffolding that focus on material performance in combination with crafting. We close with an outlook toward emerging changes as references for related work.

Keywords: craft, design, performance, puppetry, STEM.

1 Introduction

Affordable microcontrollers, accessible APIs, sensors, and prototyping materials have invited a range of hybrid approaches in STEM education that combine material crafting with tangible interaction design. This combination tries to reach new students who might not identify with electronics or engineering but are interested in crafting and making. The *Prototyping Puppets* project extends these efforts as it adds Performance Art to the design of craft-inspired STEM approaches. Craft and performance are both applied as practical methods for personal engagement and expression.

The paper reports on the design stage of this project. It will sketch out the background for the craft-based design space, then it will describe core elements of the project at hand, it will discuss this design through four workshops held during the design phase of *Prototyping Puppets*, report on the workshop results, and conclude with a summary of the resulting design changes to point toward an increased awareness for and role of the adaptation of performance in making-related design.

Prototyping Puppets is centered around a workshop design to teach middle school level students basic circuit building techniques in an informal setting. Key concepts that informed this approach are educational theories on "learning-by-making" [1] and embodied interaction design [2]. In some of this work, performance and expression are already noted as active components: "as an extension of themselves [= the users']; they act *through* it rather than *on* it" [3]. Applied effectively, agency remains in the hands of the student and the embodied learning stretches from a crafted making to an actual performance setting. To achieve this, our project combines making mechanical puppets

with the construction of simple circuits included in the puppet designs. Key learning objectives were modeled after the CSTA and NGSS and touch on translation of computational thinking into collaboration with peers and design thinking. Workshops unfold over 4 stages: 1) Learn underlying technology, 2) Create a shared story, 3) Create customized puppets, 4) Rehearse and Perform. Students encounter the technology, contextualize it with their own story, and build hybrid puppets to perform them in a shared puppetry show, which also serves as a technical dissemination.

1.1 Craft

Craft and a renewed interest in materiality have evolved into key themes in interaction design and how to apply it to education. Buechley and Eisenberg built on soft circuits [4] to realize the educational potential "of new and accessible materials and programming platforms [that] permits the growth of a new educational subculture" [5]. Berzowska also focuses on wearables to potentially "convey personal identity information" [6]. The role of crafting as a personal creative practice, rooted in cultural and social context, continues in tangible design [7] leading to notions of hybrid craft [8]. This has led to initial discussions bridging HCI, making, and performance art [9] and work on "how technology and craftsmanship can be reconciled to enable diverse forms of expressive practice" [10]. This turn to craft as expressive practice led to new toolkits aimed to circumvent black-boxing of technology. These approaches emphasize "creative expression, diversity, manual skill, and individual autonomy" [11].

There are two key challenges among many existing tangible design projects in this area: first, the way interaction design has included craft in STEM education. Craft served as a means to reach new audiences through a "personal" [6] approach that attracts new "subcultures" [5] to learn STEM material. However, the danger is that craft becomes only an access point and its creative practice replaced by e.g. Computer Science or Math curricula. Second, many STEM-related projects use black-boxed technology through commercially available kits. They hide the material encounter that is central to crafting. To counter this black-boxing, Mellis et al. propose an "untoolkit" [11] and Perner-Wilson et al. introduce "a kit-of-no-parts" [12]. Both approaches combine craft materials with electronics in basic kits that emphasize novel encounters with technology. Particularly Perner-Wilson's approach does not simplify the task but focuses on a direct encounter with the technology at hand through a craft-driven approach. The concept of an open, material-based kit, thus, guided *Prototyping Puppets* to counter possible black-boxing of technology through a sharpened focus on craft.

1.2 Puppets and Tangibles

Puppetry as performance art and puppet making as crafting are directly connected creative practices that allow for personal and shared expression on both levels outlined above. *Prototyping Puppets* follows this approach, connecting the materiality of the puppet-as-crafted-object to the expression of the puppet-as-performance-object. Expression, here, is realized first through craft practice and in the encounter with mixed

materials and controllers. It manifests not only through technical skill but also individual expression of identity through the manipulation of the finished puppet.

Some hybrid crafting approaches already use puppets for educational purposes [13]. Yet, puppetry's potential still holds much more promise, providing manifold ways for personal expression through structured interaction between human and objects as it plays with the interdependency of the two. Because the art form is so old, puppets are liminal objects [14] shifting through time and technology. As cultural artifacts they are "powerful conservators of social values, but also political subversives" [15] and they take countless forms. Thus, Posner steps away from a pre-conceived notion of a puppet object and suggests the term "material performance" [16].

Through this material encounter puppets are understood as "something with which we are deeply connected, and through which we strive to express, understand, and negotiate our interrelationship with each other and with the non-human world." [23] With the notion of material performance as a bridge between making and performing, a new look at the challenges in the domain is possible. The negotiation with the material that is typical for a crafter can be expanded to a negotiation with a performative object. Design, making, puppet performance are combined in the *Prototyping Puppets* project.

2 Project

2.1 Project Goals and Motivation

Prototyping Puppets aims to attract and engage new audiences by countering black-boxing through the use of accessible materials and innovative educational design. The combination of tangibles with collaborative performance and story-making has been successful in related context [17]. In our case, it targets early middle school students to teach them basic prototyping and circuitry skills. Mirroring related projects [5, 11, 18], the method to develop this approach works through iterative workshops that explore feasible materials, practices, and modifications. In addition to this iterative approach on making and crafting, *Prototyping Puppets* also covers the creation of a story and its live performance. Participants realize, test, and ultimately evaluate their products in a concluding puppet show that combines technical validation with individual performative expression of a shared storyline.

The project is a collaboration with the Center for Puppetry Arts, which has extensive on-site and off-site educational programming. Their *build your own puppet* workshops served as an initial reference. Here, audiences are invited to build their own puppets from pre-designed kits that relate to a current show. These kits feature basic materials, such as popsicle sticks, paper, or thread, and a step-by-step explanation how to create the particular puppet. *Prototyping Puppets* mirrors this approach but integrates the construction of a simple circuit in the puppet design. This circuit is operated through the manipulation of the puppet and combines mechanical and electronic design. It shows students that if one can create a puppet, one can also create a basic circuit. The design constraints follow the limitations that the original kits at the *Center for Puppetry Arts* face: focus on easily accessible materials, on affordable supplies, avoid dangerous

components or practices such as hot glue guns or needles, and limited complexity to allow for a quick construction time.

2.2 Development

Keeping the design feasible for informal education in terms of cost, framing, technology, and scope remained defining criteria. That is why we conducted expert workshops to test different puppet designs before presenting the most suitable one to students. In the expert workshops we evaluated different components as well as teaching methodologies. They served as feasibility studies for our design and its approach.

To create feasible designs, we consulted directly with the *Center for Puppetry Arts*, their educational director, Aretta Baumgartner, and puppet designer Jeff Domke. Based on these discussions, we developed multiple hybrid puppet designs, ranging from sock puppets to marionettes to rod puppets. All puppets shared the basic design criteria of simple and affordable materials, a combination of basic circuit building with mechanical puppet construction, simple and safe assembly practices, and short assembly time.

Two *expert workshops* tested the feasibility of these designs and informed further improvements. Participants consisted of teachers, puppeteers, and informal educators. In each workshop, participants were divided into small groups (2-4) and had to follow instructors to individually build consecutively three different puppet designs each. After each build, we collected immediate feedback on the design, the teaching methodology, and the materials. In addition, each expert workshop included an initial demographic questionnaire, a final assessment questionnaire, and a concluding reflective discussion. Expert workshops lasted approximately 4 hours and were held at the *Center for Puppetry Arts* and a local charter school.

The *student workshops* tested the iterated puppet designs with the target audience of early middle school students. Unlike the design-focused expert workshops, these events featured the full educational scaffolding including story-making and final performance. Based on the feedback from the expert workshops, the format for the student workshops settled on a four-step approach:

1) *Learn Technology*; students familiarize themselves with the materials and designs at hand (~ 20 minutes)
2) *Create a shared story*; students outline a shared story they want to perform (~ 45 minutes)
3) *Create customized puppets*; based on the provided puppet designs, students build their customized puppets, props, and stages for their story (~ 60 minutes)
4) *Rehearse and Perform*; students rehearse their performance together and adjust their shared storyline (~ 30 minutes)

Each experimental student workshop also included collecting student's assent (in addition to the parent's consent) an initial demographic questionnaire, a final questionnaire, and a reflective discussion of the whole group after the workshop. Student workshops lasted 3-3.5 hours and were held at the *Georgia Institute of Technology* and a local charter school.

Data collected from all four workshops included video and sound recordings, field notes, photos, questionnaires filled out by the participants before and after the workshops, and the puppets constructed during the workshops. Video recordings were reviewed and partially transcribed before key points were identified in close reading. We will report on results that relate to our main question on how to include the performative component in the design of a craft-inspired STEM workshop. The results draw from the feedback regarding this question from both experts and students.

2.3 Piloting Puppet Designs: Expert Workshops

Workshop Design and Goals. We conducted two expert workshops in the winter 2016/17. The first (n=6; 1 female/ 5 male) included puppeteers in the *Center for Puppetry Arts*. All of them had extensive experience with puppetry (15-37 years professional experience) and the use of puppets in education. The second expert workshop (n=10; 9 female/ 1 male) included teachers of various subjects from a local charter school. Their expertise was in teaching (9-34 years professional experience) with no expertise in puppetry. In the demographic questionnaire both expert populations self-identified as knowledgeable in "making" and "performing" and reported less experience with "electronics and prototyping."

During the workshops, all participants were guided through three hybrid puppet designs which combined basic electronics with puppet types. These included a sock-puppet design using conductive thread, a LED, and a 3V battery to include a basic circuit to light up a LED (see fig. 1); a rod puppet using conductive copper tape and paper puppets; and a mixed marionette style format. The goal was to identify the most feasible design in terms of materials, technical difficulty, and puppet control. Because these workshops focused on the technical puppet designs they did not include a performance.

Workshop Observations and Feedback. The expert workshops did not include a performance condition but especially participants of the first workshop at the *Center for Puppetry Arts* "broke into play" even without being prompted.

Fig. 1. Participants of the expert workshop spontaneously break into play.

These puppet experts emphasized the role of the puppet as an active performative object in context even though no specific context was developed. The role of the puppets' expressive roles were emphasized as motivating for the construction: "it had a goal, it had a reason and that made us want to complete it even if it got hard and frustrating."

The experts approached the simple puppets as valid expressive units in themselves. This became obvious not only in their feedback and their immediate engagement but also through customization and individual adjustments. Notably, this close engagement changed once they took the puppets off to move on to the next design. Bringing the objects to life was a natural continuation of their construction process but once that purpose was fulfilled, the puppet experts did not show any further connection to the puppets. For example, they did not ask to keep them.

During the second expert workshop, teachers voiced interest in the educational approach to engage students "hands on" and across different disciplines. "To be able to create them and reenact a story, write originally to begin with." They already envisioned possible inter-subject use of the overall approach to work between different subjects (e.g. writing, math, art). Interdisciplinary connections and kinesthetic engagement stood out as indicators for a performative turn. As one noted: "My kinesthetic learners would just flip out to be able to use – at any level - anyone of these types of puppets." The design was also seen as a possible fit for at-risk students.

The experts worked with three different puppet designs to test for feasibility of materials and techniques. Based on the concluding discussion and the experts' performance during making, the clothe pin rod puppet emerged as best suited (see also fig. 2). It was favored by the experts as the best introductory level design and details for improved teaching of that design were added to strengthen the educational approach.

Workshop Impact. Both workshops included a retrospective survey to assess changes in participants' attitudes towards electronics as well as arts and craft. Participants rated questions from 0 (lowest) to 5 (highest) which cumulatively allowed assessment of six key attributes. These did not show any notable changes in the arts and craft perception but indicated improvements in the electronics assessment.

Table 1. attribute changes to electronics in workshop for teachers (left) and puppeteers (right).

Item	Before	After	Change		Before	After	Change
	Teacher WS (n=10)				Puppeteer WS (n=5)		
Confidence	2.9	3.9	1		2.4	3.6	1.2
Enjoyment	3.65	4.4	0.75		2.8	4.1	1.3
Importance and perceived Usefulness	3.4	4.3	0.9		3.4	3.6	0.2
Identity and Belonging	3	3.5	0.5		2	2.8	0.8
Intent to persist	3.25	4.15	0.9		2.5	3.3	0.8
Creativity	3.3	4.6	1.3		3	4.6	1.6

The biggest effect is an increase in the perceived "creativity" in relation to electronics (+1.3/+1.6) followed by increased "confidence" in handling them (+1/+1.2). In combination, these effects indicate a growing self-confidence of the experts to adopt this kind of electronics as they realize the creative range they provide.

2.4 Piloting Craft with Performance: Student Workshops

Workshop Design and Goals. Taking the findings of the expert workshops into consideration, the student workshops followed in spring 2017. The experts had rated a rod puppet style design as the most feasible entry level approach. It uses copper tape to

integrate the circuit to light up a LED using a clothes pin as a switch. This design was adapted for the students next to the narrative and performance components.

The first student workshop (n=8; mean age: 12.1 years) featured only female participants from seventh grade classes and two different after school clubs. The second (n=9; mean age: 12.8) was more gender balanced (5 female, 4 male) and had a wider distribution across different grades (4 six graders, 2 seven graders, 3 eight graders). In both events students were recruited from local schools. Overall, the participants represented a diverse racial background: 9 white, 5 black, 1 Hispanic, 1 multi-racial, with 1 undisclosed. Instructors from the students' schools were present in both workshops to help facilitate and their feedback was recorded but did not affect this argument.

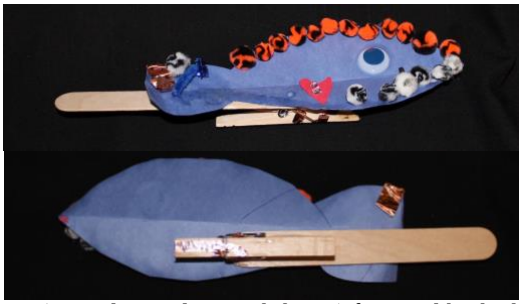

Fig. 2. Rod style puppet (created in student workshop 1) front and back; the LED is attached to the clothe pin.

Both workshops followed the 4-step structure outlined above. Unlike the expert workshops, they included shared story construction, rehearsal, and final performance. The creative process was collaborative. Students constructed a shared storyline, self-assigned work on the acting puppets, and organized the rehearsal and performance without any dedicated director or single author. Storylines differed widely. The first workshop developed a story around a fish couple wherein the male fish fell for a trickster shark and needed to be rescued by his partner. The performance and story of the second workshop was inspired by a local disaster. A hurricane had hit the city months ago and students built their piece around a storm throwing sea animals on land where they merged with land beings.

Workshop Observations and Feedback. Student participants showed the expected range of differing interests in the domains involved. This ranged from students who readily experimented with technology to students focused on the aesthetic design of their puppet. Even though the participants were not recruited from a single class or unit and had clearly differing interests, they collaborated throughout and helped each other out during the construction process. Some puppets and props had more than one student working on them from the start, others were shared during the process.

Participants of the first student workshop were recruited from a local school's robotics club and its *Odyssey of the Mind* after school program (a creative thinking and problem solving program). Before the workshop, they self-identified as interested mainly in "making and crafting" (4.38 out of 5), secondly in "performing and art" (4.25 of 5), and lastly in "electronics and prototyping" (3.56 of 5).

Participants of the second student workshop were more diverse in their grade and age groups as well as their interest: "Making and crafting" was rated 4.44; "performing and art" 3.67; "electronics and prototyping" 3.56 out of 5. All students of both workshops successfully participated in the exercise from the making of individual puppets to a shared story construction, to building customized puppets, to a final performance.

Workshop Impact. In the concluding questionnaire, students from the first workshop showed that they liked the workshop (4.75 out of 5) and they perceived the performance part as a "fun part" of the workshop. Some emphasized the teamwork aspect of it: "I wasn't really good friends with some of these people [=other participants] before this, but now I feel like we are bonded." They also noted that the multi-modal approach of the workshop appealed to their different learning styles.

All students of the second workshop appreciated the workshop (5 out of 5) but for a wider range of reasons. On the one hand, a student noted during the final discussion that "doing the play!" was the best aspect of the workshop and another stated that "I like this activity because I get to profess in my artistic skills." On the other hand, a more technical inclined participant "really liked the technology part: making things light up."

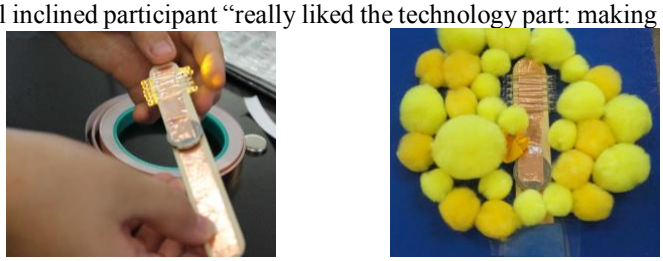

Fig. 3. Student experimenting with multiple LEDs (left) to build a "sun" object (right).

Technically inclined students' interest also reached beyond the idea of puppets as one noted that "I would not necessarily do puppets, I would do other stuff with LEDs." In practice, these students realized their interest as they experimented with the set up to add additional LED in their own version of a "sun" object for the puppet performance (see fig. 3) while the artistic expressions drove much of the storyline in the puppet play.

Table 2. Student attribute changes to electronics workshop 1 (left) and workshop 2 (right).

Item	Before	After	Change		Before	After	Change
	Student WS 1 (n=8)				Student WS 2 (n=9)		
Confidence	3.13	4.13	1		3.11	4.22	1.11
Enjoyment	3.44	4.5	1.06		3.94	4.83	0.89
Importance and perceived Usefulness	3.57	4.57	1		3.89	4.78	0.89
Motivation to Succeed	3.38	4.25	0.88		3.22	4.44	1.22
Identity and Belonging	2.63	3.88	1.25		2.89	4	1.11
Intent to persist	2.56	4	1.44		3.17	4.28	1.11
Creativity	3	4.44	1.44		3.72	4.67	0.94

All participants reported improved attitudes toward electronics with the "intent to persist" (+1.44/+1.11), "identity and belonging" (+1.25/+1.11), and "creativity"

(+1.44/+0.94) as the highest improvements. As one student noted: "[t]he best aspect of this workshop was getting to use our creativity without restrictions."

3 Discussion and Outlook

This paper reported on work during the pilot phase of the *Prototyping Puppets* project that relate the role of performance to our craft-based approach to STEM education and tested the feasibility of the material design components. The workshops were part of an iterative design process to inform two main questions: The expert workshops were conducted to assess the technical design and its feasibility; the student workshops aimed to test a 4-step educational framing in combination with those craft-hybrid designs. The pilot data are limited to tentative findings but overall supported the feasibility of the main craft designs. The increase of all participants' attitudes towards the electronic components in the workshop indicates a successful inclusion of the electronic components no matter whether the event included a performance or not. The expert workshops informed a final selection of puppet designs that was then re-tested with students and combined with the performance components in the following workshops.

The performance condition proved to support collaboration between different (and differently motivated) students. The educational scaffolding and the 4-step approach aimed to connect student to the exercise - see the improvement of their "belonging" ratings; they felt motivated to engage - see the improvement of their "intent to persist" ratings; and they noted increased "creativity" to the electronics/ making components. We argue that these effects are interconnected. Through the inclusion of the puppet performance, technical maker ingenuity stood next to performance art. Differences between students were not avoided but included along a range of material forms of expression from the typical puppetry performance (animation and voice during the performance) to the technical improvisation in making (customization and experimenting with the materials). At the same time, the collaborative work toward a shared performance allowed students to self-position themselves in a role they saw fit. We argue that it is due to this increased positioning, that students expressed a strong feeling of ownership and pride for their constructions. As one student emphasized: "If I could take it home, I would put it in a glass frame […] I would look at it every day." This indicates strong engagement and personal investment [19]. We argue that the stronger feeling of ownership in the student workshops, compared to the expert workshops which did not show this effect, is connected to the framing of a shared story and performance.

Forward going, a key challenge is to design documentation and educational material so that the workshops can be handed off to educators. The goal is to empower formal and informal educators to conduct the workshops without any help from the researchers and test them again in this condition. This first stage confirmed the focus on performative elements in the design of a craft-based prototyping workshop and *Prototyping Puppets* presents specific solutions that emerged during our project's design phase.

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