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Framing craft and performance in hybrid puppetry workshops

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Abstract

Prototyping Puppets combines craft and performance in a puppet making STEM workshop for informal learning. We report on its final evaluation in two events (n=10 and n=13) to show how the design addressed black boxing of technology through a craft-centric approach and successfully engaged different student populations through an educational framing that included performance practice. The informal learning workshops are aimed at 5th grade level students. First, the problem space is laid out and the approach of the project introduced. Second, the design realization is briefly covered. Third, the final evaluation of the design in two workshop conditions is presented using qualitative as well as quantitative data. Students showed self-perceived increases particularly in their attitudes toward technology. These results are discussed before we report on the adaptation of the workshop for different conditions to illustrate the flexibility of the basic set up.

Keywords

craft, informal STEM learning, puppetry, performance, making, adaptation

Designing prototyping puppets

Prototyping Puppets is an exploratory informal learning research project conducted in Georgia, US. It targets students near the end of elementary school to teach them basic skills in circuit building and electronics. The project targets informal STEM learning but to focus on its key audience, it follows Next Generation Science Standards Engineering Design guidelines (States, 2013) and aligns with Georgia's Academic Standards (Cox, 2004) of 5th grade education. Key technical elements include topics of conductivity, polarity, and simple electronic components such as switches and LEDs.

The project developed a workshop curriculum that combines methods from craft and performance in a puppet-making and -playing exercise. Students construct basic rod puppets consisting of a double-sided paper-puppet build around a craft-stick to hold and manipulate the puppet. During the process, students learn fundamental principles of circuitry and combine physical making with prototyping electronics as each puppet also includes a simple circuit that students create and operate. The workshop uses student-driven narratives and collaborative performances to motivate students of varying interests. It addresses two key challenges in

STEM education: 1) to attract and engage diverse student audiences with varying interest in STEM-topics and 2) to counter black boxing of technology. The following will outline the design criteria, development, and evaluation of the project, which saw assessment throughout its different stages. The essay will focus on the final evaluation through two afterschool workshops (n=10 and n=13), which included quantitative and qualitative feedback from instructors and students. The argument closes with a broader impact outlook, illustrating how the project was adapted by external instructors and fit into new contexts.

Problem and Motivation

Prototyping Puppets leans on craft practices and simple materials to push basic functionalities of circuit building to the forefront. A second foundation of the project was its reliance on the integration of performance practice to attract new students and keep them engaged. In combination, craft and performance were not used to necessarily lower any entry threshold but to spread engagement wider, reach different student populations, and inspire by tackling underlying circuitry logic, not hiding them.

A prevailing call to educational STEM kits is to support context for their teaching technologies and approaches (Peppler, 2013). It is “fundamentally important for any student to be able to frame any STEM topic in a personal, thoughtful and meaningful context so as to allow for open inquiry, discourse, and evidence-based reasoning” (Zeidler, 2016). But as optimized kits focus on the support of a particular technology, the origin of the operation and the cultural role of the mechanisms the students build can become secondary. STEM science labs might ask students to concoct particular solutions that will grow crystals or assemble blocks to build a specialized robot but the nature of the crystal or the robot themselves remain unexplored. This can detach students from the activity at hand. Such detachment fails to overcome a “not for me” perception especially among female students (Archer et al., 2013). Even successful STEM projects, like the iCODE project, report difficulties to attract female audiences (Martin et al., 2011) and can struggle to provide a solid cultural and engaging context – an “interconnected whole” (Katehi, Pearson, & Feder, 2009) – to attract and engage new students. A second challenge of standardized kits is that most of them attempt to simplify access to complex challenges and to achieve this they hide more complicated components. Access might be enabled but the underlying logic of a particular technology might be hidden from sight in the process. For example, LEGO Robotics offers a rich tool kit to teach STEM skills but requires careful scaffolding by teachers (Castledine & Chalmers, 2011). If this scaffolding builds onto the tool kit without critically questioning the provided functionality, the integrated functions are used as a given. This can lead to black boxing. Black boxing is caused by containing complex technical problems into prepared sub components. A designated block might specialize on a task such as receiving some input and applying it to a separate block which might specialize in applying motion via motors. But neither block would explain the underlying technologies used to achieve these effects, nor can they be re-shaped to fit personalized aesthetics (Mellis, Jacoby, Buechley, Perner-Wilson, & Qi, 2013). Such optimization can lower entry thresholds and inspire students to embrace existing tools but by definition it hides and mystifies underlying technology. Craft and DIY based approaches have been deployed as own learning approaches (Pirttimaa, Husu, & Metsärinne, 2017) and own approaches toward possible tool kits are emerging. This includes the 'kit-of-no-parts' "where electronics are crafted from raw materials" (Perner-Wilson, Buechley, & Satomi, 2011) or material-based approaches, like using conductive playdough, to reach new student populations (Peppler, Wohlwend, Thompson, Tan, & Thomas, 2019).

Craft and material culture remain useful tools in teaching STEM (Ólafsson & Thorsteinsson, 2009) and new materials and technologies have become accessible that allow for a combination of traditional craft approaches with electronics and digital media. This nexus of traditional creative practice and new technology has led to a range of successful projects. Buechley et al. even spoke of the dawn of a "a new educational subculture" (Buechley, Eisenberg, & Elumeze, 2007). It has fostered a range of formal and informal STEM learning projects in soft circuitry (Peppler & Glosson, 2013) or paper (Mellis et al., 2013), as well as educational game design approaches based on craft (Horn et al., 2016), and reaching into "maker" cultures, where a focus on craft has been effective to engage female students (Sheffield, Koul, Blackley, & Maynard, 2017).

The *Prototyping Puppets* project continues this trajectory and builds on existing work (Peppler, Tekinbas, Gresalfi, & Santo, 2014). It combines basic prototyping materials with craft and performance – not by "utilizing" one over the other but through the integration of both domains in a single activity. Its contribution is the development of a workshop design that balances crafting and performing as engaging activities to support STEM teaching in an informal workshop design centered on puppetry. Puppetry as a creative practice has a long tradition in education (Kroflin, 2012; Krögera & Nupponen, 2019), which includes its use for STEM education (Walt & Potgieter, 2018). Various practical guidelines to use puppetry in the classroom exist (e.g. (Peppler et al., 2014; Smegen, 2017). Here, we report on the iterative design and testing of our concepts up to the concluding evaluation workshops conducted by educators in an afterschool setting.

Targeting Learning Objectives through Iterative Design

Inspirations for the project's craft components were taken from the work of Perner-Wilson on constructing basic circuits out of the most fundamental crafting materials (Perner-Wilson et al., 2011). This work uses crafting as an educational and engaging process itself, combines it with materials such as conductive thread or ink, and often foregrounds the function of components through this assembly. Participants might crochet a potentiometer or stitch a switch. This combination of hands on transparent technology making counters any hiding or for blackboxing of functionality.

On the performance side, the make-your-own-puppet workshops held at the Center for Puppetry Art in Atlanta (CPA) served as a key reference. Since its opening in 1978 the CPA is a leading center for puppetry art, conservation, and education in the United States. In its workshops, visitors use everyday materials such as paper, rubber bands, and popsicle sticks to build simple puppets that relate to the puppetry show currently running at the Center. They reach wide audiences and connect the making of a puppet to professional puppet shows as well as individual artistic exploration. The core design of *Prototyping Puppets* centers around a combination of these approaches in performance and craft practice. It required an iterative design approach to optimize and simplify the initial concepts.

The final version of *Prototyping Puppets* took the shape of a 3 hour workshop activity. The underlying learning approach is based on constructionism (Papert & Harel, 1991) but combines it with storytelling and performance activities. During these workshops, students build basic hand puppets that include simple circuits. They learn key concepts of electricity such as polarity and conductivity and cover translation of computational thinking into collaboration with peers and design thinking. The students use their puppets to act out a story they developed earlier in the workshop and test their technology in the performance. The embodied learning stretches from a crafted making to the collaborative performance. Here, we will focus on the final workshop instances and their evaluation in two two-tier workshops that first taught educators our approach and secondly observed teachers and their students as those educators taught our hybrid puppetry workshops to their students (n=10; n=13).

Puppet Design

In collaboration with the CPA, we initially developed a range of different puppet designs. Each of these designs used hybrid materials such as conductive thread, tape, or basic actuators to provide a crafting exercise in building a puppet and combine the mechanical construction with basic prototyping and circuitry. Figure 1 shows four sample design, using from left to right soft circuits and conductive thread in a hand puppet; a dual-puppet design where one component holds the battery and another uses a clothes pin to close a circuit; a string puppet using conductive thread; and a rod puppet close to our final sample puppet. The authors tested these designs in two workshops with educators as well as puppet experts (n=10; n=6) for improvements in materials and procedures.

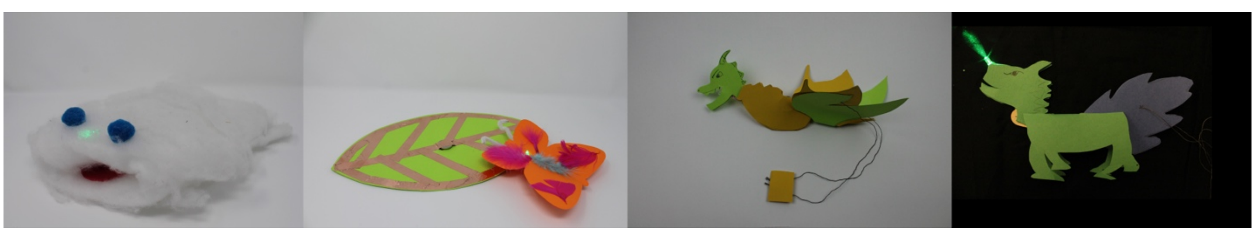

Figure 1. Samples of initial puppet designs tested with puppeteers and educators.

The designs and their documentation were optimized and tested in two additional workshops with students (n=8; n=9) to assess feasibility and inform further iteration. The puppet designs, documentation, and especially the educational framing were optimized once more. Results of these design-focused workshops have been reported elsewhere (Nitsche & Eng, 2018).

The final design of our base-puppet is realized in a double-sided rod puppet. Its body builds around a central rod which carries a simple circuit using conductive copper tape, a 3V lithium Ion battery, a LED, and a switch. This central spine is formed by a wooden rod that separates positive and negative sides of the circuit and also serves for the handling for the puppet. To allow expansion of the basic model, the full online documentation also covers other variations, including versions using Piezo speakers, small motors, or hook ups into other systems such as LEGO Mindstorms.

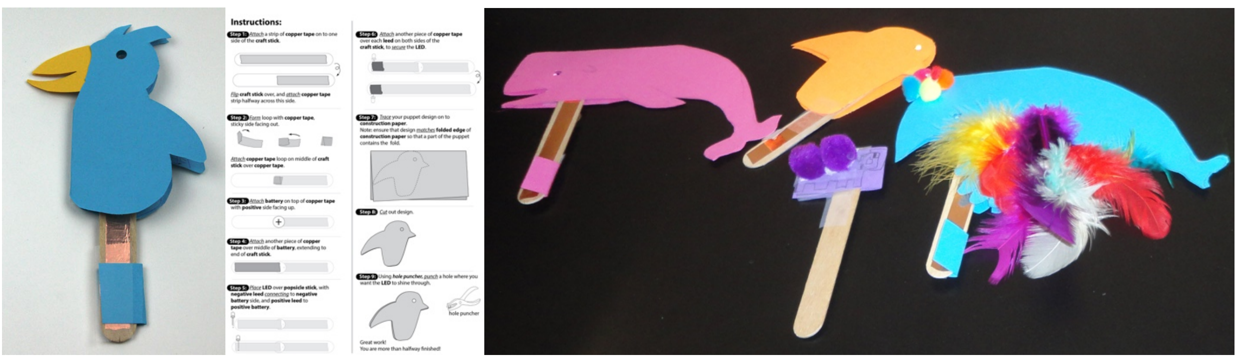

Figure 2. Default design (left); excerpt of instruction package (middle); samples of student-build customized puppets (right).

The design combines simple crafts and puppet making not unlike related projects (Peppler et al., 2014) but its focus, here, is less on the puppet design as the solution. The basic puppet serves as a blue print for further development, customization, and ultimately performance. While the material craft-based design foregrounds transparent technology (e.g. separating polarity through the rod control stick), the customization emphasizes personal context-building, collaboration, and ownership through expression and remained part of the educational framing to increase student engagement.

Educational Framing

Building the basic puppet prototype is the first part of a four-step teacher-led workshop that frames the *Prototyping Puppets* as an informal learning experience. The work-shop stages are: 1) Learn the underlying technology, 2) Create a shared story, 3) Create your customized puppets, 4) Rehearse and Perform together. Each workshop lasts about 3 hours in total. Through this structure, students encounter the technology, contextualize it with their own story, and build hybrid objects that encompass both circuitry as well as story to bring both to life in a concluding puppetry show, which also serves as a technical dissemination.

During this progression, ownership gradually shifts toward the students as they develop their own puppet concepts. Students encounter the initial puppet design, components, and circuitry as taught by an educator. But as they collaboratively develop a storyline, characters for that story, as well as props and scenery, they increasingly control the elements of the workshop until they perform as a team the concluding puppet show with the educators largely as audience to the now student-led activity. Emerging ownership in co-creative processes like these has been emphasized as individual as well as social dynamic processes that support informal learning (O'Neill, 2005).

Table 1. Workshop activities and individual stage durations

Stage	Activity	Length
	Introduction	10 minutes
Learn Technology	students familiarize themselves with the materials and designs at hand by building a default hybrid puppet	20 minutes
Create a shared story	students outline a shared story they want to perform	45 minutes
Create customized puppets	students build their customized puppets, props, and stages for their story	60 minutes
Rehearse and Perform	students rehearse their performance together and adjust their shared storyline into a final show	30 minutes
	Wrap up and reflection	15 minutes

Just as the puppet designs followed an iterative design approach, the documenting materials (video and print) were iteratively developed. This documentation included a pdf file that educators can download and print out for use with their students, but also can use as an online file with embedded links to the various steps of puppet assembly documented in a YouTube video. Instructional approaches consolidated as the supporting materials covered also story-building and put more emphasis on the rehearsal stage, which had been neglected in the first versions.

Design and Implementation of the Study

The final studies evaluated the resulting workshop designs. Each study was performed in two parts. The first consisted of a preparation session with the educators. Researchers met with them for a 45 minute session and taught them the technical steps of how to create the rod puppets, introduced the documentation, and left them with kits to explore the activity themselves. These preparatory workshops could include additional visiting teachers who were interested in the technology, but only data from actually participating educators in the whole study was collected. We tested the designs in two programs, one taught by one teacher, the other by two co-teachers. At this stage, mainly qualitative feedback was collected to test for possible shortcomings in our documentation and our educational approach.

At least one week had to pass before the second stage of the study followed. In this stage, the teachers administrated the full puppet workshops to their students. The break allowed for special preparation of material and/or modification of our approaches by the educators. Each workshop was a select group of students, based on teacher choice, and student availability. Because the student population of the first school was much larger than of the second, the recruitment there reached further to guarantee a diverse group of students. Both final student workshops happened outside of normal class operating schedules and were each 3.5 hours long. Workshops were held in school environments, a classroom and a STEM room, as informal after school club like activities. Neither student group was recruited from any single class and the events were outside usual teaching conditions. For example, they did not include any grading or teacher assessment.

The first study's (WS 1) teacher was an experienced (11 years of practice) teacher with extensive expertise in crafting and making practices, including electronics. The second workshop (WS 2) was held by two teachers. One with 10 years of practice, working as Art teacher at the school. The other, a STEM teacher with 18 years of experience in education.

Workshop 1 (WS 1) was conducted as an extra-curricular STEM workshop at a charter school Workshop 2 (WS 2) was conducted as a STEAM exercise for an after-school robotics club at an Elementary school. Neither workshop was part of any existing curriculum, neither included grading or other formal assessment from the instructor, neither used a single homeroom population but instead mixed students from either clubs or different classes. Both workshops managed to conduct the full exercise in the allotted time frame. Construction included props, such as simple cages, backdrops, and puppets. The stories were developed by students collaboratively in both events and resembled action-driven fantastical adventures.

WS 1's story was set in the future in an animal wizardry school where teachers are getting abducted by arriving aliens and need to be rescued by their students. The performance included scene changes and integrated the LEDs, for example, in the alien designs.

WS 2's story centred around a zoo, where a fire broke out and all animals escaped and broke into a fight. The worst of them ends up in a police car, while the rest extinguishes the fire and eventually return to their cages. They integrated the use of LEDs in their story at various points: as fire indicators, during the fights, as well as for the police car lights.

Data collection and results - teacher involvement

Data collected from teachers consisted of a pre- and post-questionnaire, field notes, and interviews after the workshop that followed core questions. Interviews were transcribed and analysed either by an external evaluator or three researchers through individual analysis and shared discussion. The main data presented here regards the qualitative feedback collected in the final interview.

The teacher for the first workshop (TWS1) had conducted the original puppet construction before as part of a STEAM day activity at school, led by the teacher. To prepare for the workshop, the teacher had prepared versions of the original assembly instructions in clear sleeves and showed the project introductory video to the students beforehand. The teacher valued the documentation and particularly the assembly construction: “I think just having me show it, and then having the visual to go back was very good for some of them. They’re still working on refining their listening skills and their attention.” (TWS1). The educator also noted that students were able to refer back to the instructions during the making process of their individual puppets, “so that when they went to make it on their own, they could come back and reference it.” (TWS1)

One single table was set up for the students to work on during the workshop. The teacher had referenced the provided assembly documentation but did not use the storyboards/ narrative documentation during the story generation. Instead, students assembled the story on a whiteboard under rubrics that resembled the categories provided in the documentation. This emphasized the shared story building and made the story construction itself more performative as well as accessible.

Once the shared story backbone was constructed, the students spread out to develop their puppets, props, and backgrounds. Some worked in the hall outside the main room. The final performance was conducted in a different room: a hallway where the school had stored a designated puppet theater stage.

The second workshop saw two teachers conducting the workshop together, one the designated STEM teacher of the school (TWS2), the other the art teacher (TWS3). While the documentation was deemed good, they did not use the documentation materials in the workshop. Both stated that they were “very visual” in their learning and TWS2 noted that “for me the most helpful was the visual, watching” the making processes during the preparatory teacher workshop. Instead, one (TWS2) had prepared a separate poster that explained key concepts of the workshop. After the initial construction session, students were allowed to lead most parts of the rest of the workshop (e.g. they set up a vote on the story to choose by themselves). This showed a hands-off teaching approach that encouraged self-organization among the students.

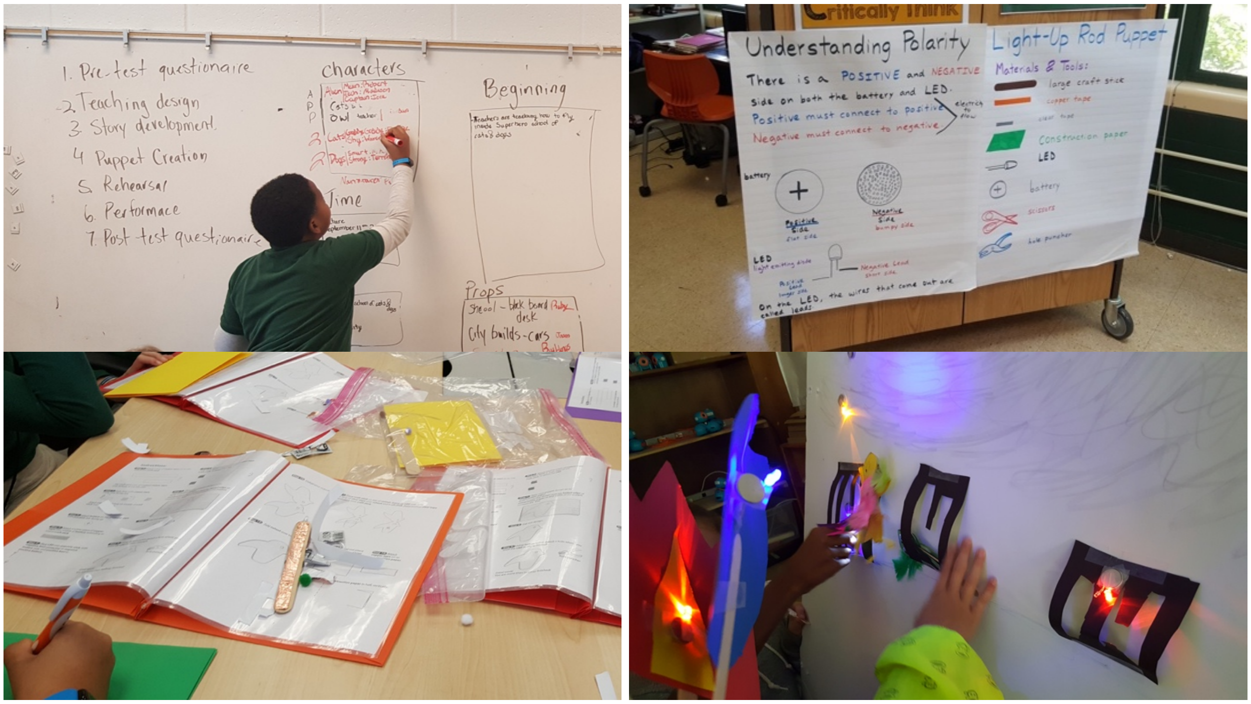

Figure 3 WS 1 (left): replacing the storyboard in the documentation with the whiteboard and re-usable instruction sheets; WS 2 (right): teacher-created poster and rehearsal of puppet scene.

In the teacher feedback for workshop 1 (TWS1) the room set up was not seen as optimal, having a too small table. The teacher also argued for a smaller group size of 5-7 students even though the group had successfully finished the workshop. The best form of teacher preparation was mentioned to be repeated assembly of puppets before the actual workshop. To that matter, TWS1 lauded the documentation and the video of the assembly. The workshop materials were seen as effective with the possible addition of pre-cut models for the blueprint first construction in stage 1) of the workshop and some more crafting and customization materials for the decorations. Notably, while some additions and simplifications to the craft-side were mentioned, none were given for the electronics side. The teacher did not note any additional changes to the circuit building instructions and materials.

TWS1 further connected the workshop to both Science and ELA standards but to fit it into a formal education plan, she called for a more gradeable rubric. A rubric would also clarify expectations among students and clarify focus point for the teacher to support further.

> “Before they even build it, I might read through the steps and let them see, ‘Here’s what I’m looking for,’ so they’ll make sure that they’re doing it a little bit more diligently. Like if they know I’m going to grade their puppet, they will not want to make silly mistakes and things like that.” (TWS1)

In its current form, the workshop was conducted in an informal setting where these rubrics did not yet apply.

A second opportunity for improvement was increasing opportunities for peer-tutoring by students. TWS1 mentioned opportunities for quick learning students to teach others during the exercise. The integration of electronics was not a problem but some students embraced them faster than others, based on their prior knowledge in the field. These students could support the workshop:

> "I think any of these kids in this group would love to go and reteach it. If you saw, I think there were 2 boys who were at my STEAM. They were moving ahead of me." (TWS1)

Thirdly, the teacher recommended a more guided rehearsal phase. TWS1 recommended that the students record a rehearsal of the performance and then review the recording to make improvements. "[T]he performance seemed a little sloppy and not as refined as I probably would have liked it. But I think that takes time. I would probably prefer to do this over a couple of days." (TWS1) For TWS1, rehearsal and performance took on a stronger role: "I would probably have preferred it to have a little bit more of a script and have them write out more of what they're saying." (TWS1) In contrast, the current set up "uses" these stages more as a technical-artistic validation but not as a graded activity itself.

The second workshop had two educators co-teaching (TWS2 and TWS3). Here, the construction of preparatory material (see table 1, upper right) was itself a learning process for TWS2:

> "I put it on the chart paper, that also helped me to be able to explain to them and also understand myself because I was only doing it the second time, because I think as a teacher the more we do it we learn more and more how to make it better, and we also, to teach better, like the next time we do it I bet we'll come up with more ideas." (TWS2)

Both teachers of the second workshop agreed that for preparation "the main thing is practicing it yourself" (TWS3) as well as making the motivation and target clear. Both noted that the visuals were the most import part of the documentation but did barely use the actual documents in their own preparation. The video was watched by one, but the other had problems with a blocking of the (YouTube) site. In addition to the existing materials, they called for more documentation on possible errors and about the "things that can go wrong" (TWS3) to allow students to make mistakes (TWS2 + 3). During the workshop itself, the teachers added halfway through the workshop a big clock that gave students a better idea of what to deliver when.

Both teachers focused on creative choice and exploration in their feedback: "So I would do that mini lesson where I would teach them how to create the circuit and how to make it work- and its up to them how they utilize it in their work." (TWS3) The circuit building was not seen as problematic and the materials and instructions were seen as sufficient, but the purpose of building circuits for one expressive object (puppets) only was seen as limited. The circuit building was suggested as a more independent part,

> "then they can use that stuff to build other things and within their own artwork and in that circuitry and it could be other things besides LED lights, anything that can have power and it could be part of their artwork because there's plenty of artwork out there that uses circuitry and power and balance." (TWS3)

But they realized that this would require more time commitment and a longer structure of the exercise. To implement this, they suggested to spread the workshop across different subjects and over multiple days of engagement.

TWS2 and TWS3 both mentioned the impact of time constrains particularly for the teacher. While the time frame was seen as a challenge, the workshop was considered a success, as "they [=students] were able to get their own ideas in" (TWS2) and "[t]hey stepped up" (TWS3). Peer tutoring was noted as an effective way of learning (TWS3) as well as a good way to provide coherence over time as student generations grow out of clubs and projects and graduate to new schools (TWS2).

Across both workshops, the existing documentation, materials, and overall structure were seen as sufficient. Wider ranges for the craft-based side were noted more than changes to the circuitry teaching but suggested improvements concerned largely time management and how to expand the condensed version of the single workshop format across longer periods of teaching. In addition to strengthening cross-curricular integration, peer-tutoring, and an opening up of the designs for other formats were suggested.

Data collection and results - student involvement

Quantitative student feedback was collected in questionnaires before and after the workshop. Questionnaires used multiple Likert scales to probe for changes in perceived attitudes towards electronics and craft/ art. They also asked for students' feedback on the workshops and their designs as such to assess efficiency and engagement. Each workshop started with an initial demographic questionnaire and closed with a comparative assessment questionnaire and a group discussion. All instruments were facilitated by the researchers.

The first questionnaire covered basic demographics (age, race, gender) but also asked for pre-existent knowledge in related STEM toolkits (such as Mindstorms, MakeyMakey).

The concluding assessment questionnaire was designed to identify effects of the workshop on students' changing attitudes toward electronics and art/craft. The assessment questionnaires included a self-assessment of students' attitudes towards these two components. This was assessed through a 10 point questionnaire designed to cover 7 main qualities through cross-referencing (Confidence, Enjoyment, Importance, Motivation to succeed, Identity, Intent to persist, Creativity). Questions directly asked for students' self-assessment of that quality (e.g. "I am confident when it comes to electronic/ arts and craft"). We tested the qualities of Enjoyment, Intent to persist, and Creativity with two questions each to make these qualities more accessible for students (e.g. Enjoyment was recorded in asking whether working with electronics/ arts and craft was "fun" as well as perceived as "comfortable"). No outliers between these two questions were recorded in either of these three qualities.

The same ten points were asked for perceived changes in attitudes to craft and to electronics and assessed as before/after Likert scales.

In addition, the assessment questionnaires included questions that explored the workshop itself and its perception. It asked on a 5 point scale whether the workshop was perceived as difficult/ easy, engaging/ boring, not useful/ useful, creative/ not creative, not satisfying/ satisfying. This questionnaire also asked whether students would recommend, repeat, and overall enjoyed the workshop itself as an exercise. Regarding the students rating of the workshop as such, Figure 4 shows the weighing for the dominant of each pair.

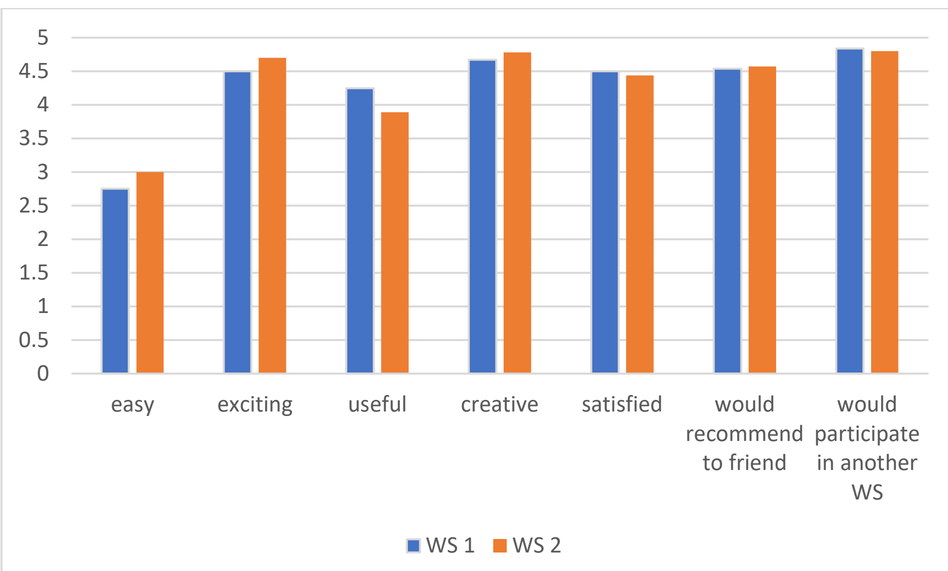

Figure 4. Students rating the workshop activities (0=negative 5=positive).

Students of both workshops rated the activities overall high (see Figure 4) with the highest ratings in agreement to participate in another workshop like this (WS 1=4.84; WS 2=4.8 with 5 being the highest possible rating). The single outlier was the rating for perceived challenge, where students assessed that the workshop was perceived as either "easy" or "challenging." Results here were balanced (WS 1=2.75; WS 2=3).

Students' perception of changes in attitude toward technology were recorded in Likert scales. Both workshops reported improvements across all seven qualities. Students in both workshops reported an increase in their perceived knowledge in electronics (see Figure 5). WS 1 reported an increase from 3.85 before to 4.25 after the workshop (increase 0.67). WS 2 reported an increase from 3.30 to 3.90 (increase of 0.60).

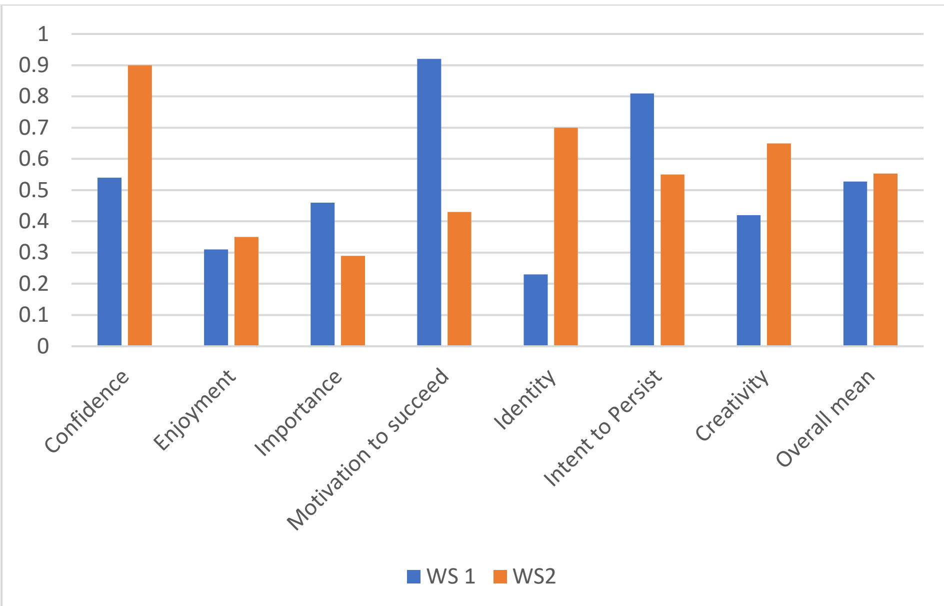

Figure 5. Changes in attitude regarding technology between WS 1 and WS 2.

The self-perceived changes in attitude regarding technology before and after the workshops vary but the overall improvements are comparable (mean WS 1=0.53; mean WS 2=0.55). Notable outliers are the increases in "motivation to succeed" (WS1=0.92; WS 2=0.43) and in the "confidence" increase (WS 1=0.54; WS 2=0.9 increases).

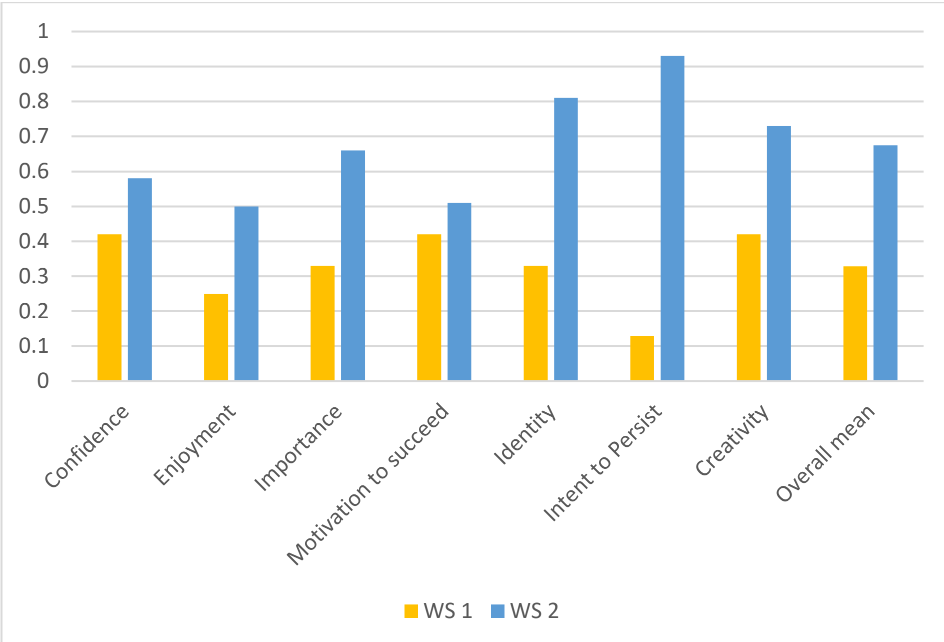

Figure 6. Changes in attitude regarding arts and craft between WS 1 and WS 2.

The self-perceived changes in attitude regarding arts and crafts differ more clearly between the two workshops (see Figure 6). All showed increases but the perceived changes were higher in WS 2 (mean WS 1=0.33; mean WS 2=0.67) with especially clear differences in the improvement of attitudes regarding "importance" (WS 1=0.33; WS 2=0.66), "identity" (WS 1=0.33; WS 2=0.81), and "intent to persist" (WS 1=0.13; WS 2=0.93).

Qualitative feedback was collected in concluding group discussions and open feedback forms on the questionnaires. Students emphasized that they appreciated the workshops overall and especially the making part but equally noted the performance part in WS 1. Time management was seen as a challenge but unlike the teachers, the students enjoyed the freestyling performance more. As one student participant in WS 1 mentioned: it was the "coming together" that seemed to keep them engaged and "how we all helped make the show." In the same session, one student lauded "The ending when we made up lines, and it was funny when we messed up a lot." Failure was not seen as a threat, as another student noted: "The best aspect of this workshop is that no idea was wrong and everyone got along." Likewise, students in WS 2 emphasized both, the "show experience" as well as the building sections that were perceived as fun activities. Students in WS 2 also noted collaboration and teamwork as positive aspects: "The best aspect was that we had to be creative and collaborate." No problems with the electronics were mentioned, yet more possible materials for their customization were called for.

Discussion

Here we present only the final evaluation data but we recognize that the same distribution was found between earlier researcher-led workshops. Whether the workshop was given by an educator, who had to be taught to deliver the workshop, or by the researchers and designers of these exercises, caused no significant difference in the students' perception of the activities. This indicates a successful documentation and material transition from the researchers to the teachers. This is supported by the fact that in both cases, the educators succeeded in conducting the whole workshop in the designated time without any specific delay or complication.

The workshop activities were rated highly by students throughout (mean WS 1=4.13; WS 2=4.16) with only the value for perceived "challenge" in a medium range. This indicates that the workshop overall balanced difficulty levels for all students involved. It was neither too challenging nor boring in its activities. This supports successful engagement overall while they still appreciated the workshop format.

In terms of self-perceived attitude changes, student participants in WS 1 reported in their demographic questionnaires an overall slightly higher initial interest in "performance/ art" than participants in WS 2 (WS 1=4.31; WS 2=4) while the picture is reversed in the higher initial interest of participants in WS 2 in "electronics" (WS 1=4.38; WS 2=4.7). The student group in WS 2 was more coherent as they were all members of an afterschool robotics club, which focuses on technological competitions, such as LEGO robotics. Students participating in WS 1 were more diverse in their interests but overall identified closer with the arts and craft side.

We read this difference in initial interest as the main factor for the differences in the perceived attitude changes in "art and craft" between the groups. WS 2 shows higher increases in this category than WS 1. With an initially lower interest in arts and performance among the robotics club students in WS 2, the opportunity for increase was larger. The data indicate that the puppet performance and story development unlocked some of the artistic interests among the more technologically inclined students of WS 2. It still spoke to the students in WS 1 but did not trigger the same change in the perceived changes of their attitudes towards arts and craft because the initial interest was already given. In comparison, the workshop's overall effect on the students' perception of their attitudes to technology and was more balanced. All attitudes showed improvement in both domains and indicate a successful integration of technology with arts and craft activities. Course populations are bound to be diverse but the differences indicate overall improving attitudes across the board as well as higher impact where the initial ceiling was higher. This supports the core goal of this study: to attract and engage diverse student audiences with varying interest in STEM-topics. Differently motivated student groups remained engaged, showed increases that reflect learning potential, and all managed to succeed in the workshop activities throughout. Krögera and Nupponen identified five key benefits for the use of puppetry in education: generating communication, supporting a positive classroom climate, enhancing creativity, fostering co-operation/ integration into a group, and changing attitudes

(Krögera & Nupponen, 2019). Our workshops confirm their summary and more specifically, we read increases in communication, creativity, and co-operation as a way toward diverse engagement through effective group work.

Educators clearly considered the STEM workshop as a success, not only in terms of sheer results but also for the student engagement. As one noted,

> "its very empowering. As a student, it's difficult cause not a lot of kids get that time to ideate and to take risks and to come up with and use their own ideas because it's usually the teacher telling them what to do." (TWS3)

The combination of crafting and artistic presentation with technical making and electronics did provide them such an opportunity and in both studies, the final performance – which was mainly seen as a form of artistic validation and engagement from the researchers – was noted as an independent teaching and learning opportunity. At the same time, they were looking for possible additional assessment methods. Although these workshops were conducted in informal learning conditions, the instructors saw them as a good fit for their more regular formal educational work.

In summary, the workshops achieved the targeted student engagement through the combination of craft and electronics in an art-based performance frame. The activities were seen as engaging by both educators and students and triggered self-perceived attitude improvements toward technology as well as arts and craft. Another indicator for the success in this regard are the signs for successful collaboration among the students, which was noted as a key quality by students themselves. While this supports our claim that the workshops engage different audiences through their combination of art and technology in performance, the claim to counter blackboxing is less easy to prove. Perceived student attitudes toward technology increase strongly in both workshops and across all categories. This indicates successful integration of basic circuit building techniques but for a full evaluation, it would be necessary to apply more formal tests to assess students' changed understanding of e.g. polarity and conductivity.

The fact that every student managed to build an own operating hybrid puppet, no matter what their initial interests were, indicates the value of the chosen craft-based pathway to teach basic circuitry. Students built individual circuits during the workshops' first phase where technology was taught without any focus on customization of the puppet objects. Notably, the instructors did build on these electronics learning objectives, for example one provided an own poster with key concepts laid out. Students also showed basic adaptation, for example students in WS 2 re-used their original circuits built in phase one of the workshop to create the lit backdrops for their stage (see fig. 3 bottom right). Based on these observations, we argue that the chosen approach to combine craft and electronics in a puppet-based performative setting does encourage some exploration of the underlying technology through re-use and that such reappropriation indicates successful understanding of the basic underlying principles. Students have to know which part of a circuit they need to re-use it when creating a prop out of a puppet built in phase one of the workshop. However, to fully evaluate a countering of the black boxing effect, additional test that would provide comparative data (e.g. between groups that learn using a craft-based approach and those that use another approach) would be needed.

Outlook

The *Prototyping Puppets* workshops were designed to be adaptable and simple to implement. This includes accessible and affordable components as well as easy-to-adjust designs and documentation. As the evaluation workshops proved, the approach did work with local students. However, one unexpected yet encouraging development was the adaptation of our material for other workshops and events. All documentation was made available online and the kits have been used in numerous informal educational settings without the researchers' participation (and often without their knowledge). In some cases, educators re-designed our original concepts and instructions to adjust puppets to their specific cultural and local conditions. They highlight the value of our designs for different circumstances as well as their adaptability. Our own adaptation includes adjustments of the designs to workshops for local STEM events as well as for workshops at leading international museums. More interesting, though, are adaptations from third parties. These include local afterschool groups as well as international and national scholars/ educators.

Figure 7. Design adaptations: workshop on African-American inventors (Paulette Richards) (far left: puppet; left: instructions) and in Medellin (Isabel Restrepo) (right: community classroom; far right: bi-lingual instructions).

To provide two examples: one is an adaptation for a workshop on African American inventors by Paulette Richards, another one a range of adaptations for underserved student populations in Medellin, Columbia by Isabel Restrepo. In both cases, our original designs needed adjustments. These included translation into Spanish, change of the puppet shape, and even some material adjustments. The main design features remained the same but the concept proved adaptable to very different conditions. Creating such individual, non-prescribed forms of expression through storytelling and performance was a driving design directive for the project next to engagement through performance and craft-based technology deployment.

The flexibility of these designs provides one direction for future work. This work would target further exploration of the value of our hybrid approach in STEM education, particularly in its value to test the value of a craft-based approach in countering black boxing of technology. Our work adds an own approach to related research (Mellis, Jacoby, Buechley, Perner-Wilson & Qi, 2013) but lacks comparative evaluation.

A second direction for future work is further exploration of the performance-driven part of the project. STEM education has embraced related strategies, such as narrative, but we see further need to include performance as an integral practice. While our project remained limited to a particular setting, the value of puppetry and performance has be noted as a way to facilitate teaching of difficult themes, providing a safety for students to speak "through their puppets" and allowing students as well as teachers to adapt a personal style (Beer, Petersen, & Brits, 2018). In our case, staging the final evaluation of the built technology as a performance by students proved to be a highly effective and engaging choice that did not detach technology from art but realized both practices in combination. Exploring this approach further poses a challenge and opportunity for future STEM scholarship.

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