Exploring the Complexities of Cultivating Adaptive Expertise in Elementary Making

Riley Jack Meehan
High Tech Elementary
San Diego, CA
U.S.A.
rmeehan@hightechhigh.org

Julia Jacobsen
High Tech Elementary
San Diego, CA
U.S.A.
jjacobsen@hightechhigh.org

Brian E. Gravel
Tufts University
Medford, MA
U.S.A.
brian.gravel@tufts.edu

ABSTRACT

This paper describes the first iteration of our three-month paper engineering project for fourth- and fifth- grade students. In a collaboration between Tufts University and High Tech Elementary, our goal was to design a classroom experience that would support students as innovators. This paper describes the project design, what we learned from a first iteration with students, and it introduces some of the challenges that emerged in supporting innovation. We present our findings and implications for future research on facilitation structures that address issues of equity in making.

Keywords: Adaptive expertise; craft; K-5; elementary; project-based learning; formal education; facilitation; discourse; innovation; makerspace; making

1. DESCRIPTION

1.1 Description of the setting

High Tech Elementary (HTe) is a socio-economically and racially diverse, full-inclusion, Title I, K-5 public charter school located in San Diego. The school opened in 2015 as the fourth elementary school in the High Tech High charter network. High Tech High is a network of project-based schools that operate on the design principles of equity, personalization, authentic work, and collaborative design. At High Tech High, projects culminate with a public exhibition of student work. In the 2018-19 school year, HTe serves 396 students, 56% of whom are eligible for free or reduced lunch, and 11% of whom have Individual Education Plans to support special learning needs.

At HTe, *Engineering & Design* is one of three exploratory classes. Students attend each exploratory class for 90 minutes twice per week for one trimester. HTe has three classes per grade, and each class rotates through all three exploratory classes during the course of a year. The paper engineering project described in this paper occurred during the first trimester of engineering with a fourth- and fifth-grade class of 25 students each.

1.2 Description of the educational experience

During the summer of 2018, we set out to design a trimester-long maker project that would support student-driven innovation. To define “innovation,” we looked to Hatanao and Iganaki’s [3] research on adaptive expertise. Hatano and Inagaki argue that students’ school experiences tend to focus on the development of routine expertise, in which students use known procedures to solve routine problems. Alternatively, they advocate for the development of adaptive expertise, which involves thinking flexibly to solve novel problems. In our research, we sought to better understand what scaffolds would support students in developing adaptive expertise.

In order for students to develop adaptive expertise, they must be able to exercise their agency to solve the problems themselves, rather than needing teachers for answers. This requires a shift of epistemic authority from the teacher to students. Toward this end, we sought to choose facilitation structures that would promote student agency and ownership.

Along with carefully choosing facilitation structures, we needed to choose a medium in which nine- to eleven-year-old students could become experts. Over the past four years at HTe, students have participated in a broad range of projects in the Engineering & Design classroom. Students have worked with digital tools ranging from laser cutters and CNC routers to Scratch programming and stop-motion animation software. In considering elementary-appropriate domains for cultivating students’ adaptive expertise, we chose to focus on low-tech media. We suspected that if we wanted students to develop richer understandings of tools and materials and begin using them in novel ways, it would benefit our students to build on their existing knowledge of a familiar material. We saw the project as an opportunity to build from the familiar to explore the unfamiliar. We decided to explore paper engineering through pop-ups in light of three appealing characteristics:

- **Students know paper.** Even though our students had limited experience making paper into movable, three-dimensional objects (save making airplanes), the familiarity of paper means students’ experiences with paper are resources.
- **Pop-ups are like DNA; a few building blocks create endless possibilities.** Pop-ups are a system with many rules –there are a limited number of folds, cuts, and pieces that can be combined. Yet, there are endless configurations. Flipping through several pop-up books indicates there is a large degree of freedom for innovation.

- **It’s only paper--try it, and then try again!** There is low-risk when prototyping with paper because the materials are cheap and the requisite tools are available to every student. Furthermore, if students are to develop complete ownership over the domain, it is beneficial that they have access to the tools and materials in spaces outside the Engineering & Design classroom.

With the aforementioned considerations around student agency and medium in mind, we designed the project and divided it across the three-month trimester into three phases: the Mini-project, Pop-up Workshop, and the Final Project.

After introducing pop-ups as paper engineering with the video featuring Peter Dahmen entitled “The Magic Moment” [2], we launched with a mini-project to familiarize students with pop-ups. In the mini-project, students interviewed their kindergarten and second grade buddies and designed cards for them based on their interests. They then learned three different pop-up techniques and applied one technique to create a design based on their buddy’s interests.

To start building students adaptive expertise and shifting epistemic authority to the students, we started Pop-up Workshop. We launched each task with a challenge to the whole group (ex: replicate a “mystery pop-up”). Students grappled with the challenge independently for five minutes before collaborating with their group. After students had successfully completed a model, we asked students to use the new technique creatively. This innovation time was an opportunity for students to test the boundaries of a known pop-up technique. At the end of Pop-up Workshop, we gathered again as a whole group so that students could share what they learned to grow the class’s collective knowledge about pop-up design.

Midway through the Pop-up Workshop phase, we introduced the final project, to give students context for their skill building work. Fourth-graders interviewed adults and were to design a custom card for their “VIP buddy”. Fifth graders were to create a pop-up spread for an informational book about Mount Everest.

In the Final Product phase, we asked students to begin with an idea of what they might show in their book or card and then identify or invent a pop-up to bring that idea alive. During this phase, students had to negotiate the tension between what they knew how to do and what they wanted to do. Near the end of the term, students exhibited their work to parents at an evening exhibition. Fourth-graders taught parents pop-up techniques, and fifth-graders presented drafts of their pop-up book for feedback. After the trimester was over, fourth-graders delivered their appreciation cards to their “VIP buddies” in their offices around campus and shared their process with their buddies.

Fifth-graders’ pop-ups were bound together in an A to Z Everest pop-up book.Given the medium and the products students were asked to make, we hoped to see the following aspects of adaptive expertise emerge as a consequence of the project design:

- Students apply foundational pop-up techniques to innovate new pop-up designs,
- Students can explain and discuss their innovative strategies,
- Students teach and learn from one another suggesting epistemic authority.

We present the results of this first iteration of the Pop-up Workshop, describing how elements of the activity structures and facilitation related to students’ innovations. And we conclude with discussions of how this first phase surfaced issues to guide a redesign for a second iteration of the curricular enactment.

2. CONCLUSION

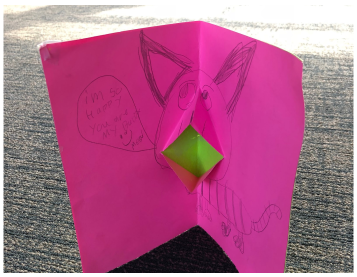
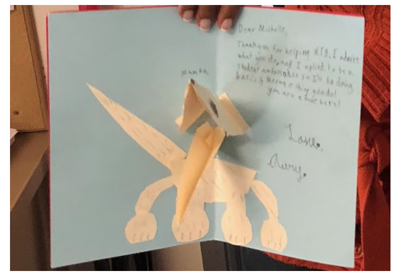
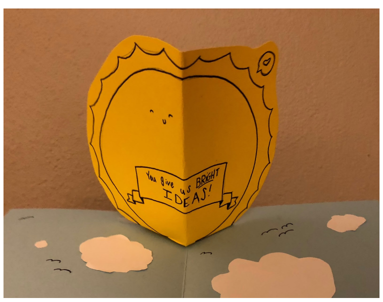
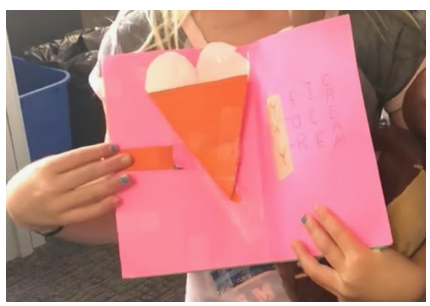
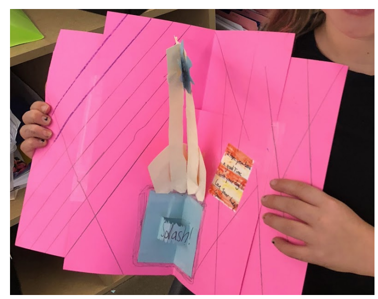
2.1 Results

We found pop-ups to be well-suited to engineering design. The vast majority of pop-ups are made using a combination of the same foundational shapes, and students can combine these shapes to create virtually infinite designs. The expressive potential of pop-ups is engaging to students. Pop-ups are also a useful entry into engineering design because of the natural constraints of pop-up techniques. The rules of pop-ups are complex, and are much easier learned by trial and error than by decoding the geometric formulas. The delight of a functioning pop-up invites frequent testing. As Peter Dahmen describes, “You have some kind of just stuff, it’s just dead material, but you grab it with your hands, and you move it a little bit, and something appears in front of your eyes. It’s always like a magical moment.” [2] Or as one 5th grade put it, “It’s so gratifying!” As students worked, we observed them frequently testing their designs by opening and closing their cards, and making frequent adjustments to get the desired effect. Students get immediate feedback about the effectiveness of their design simply by opening their card. Through this process of trial and error, students develop a better sense of the constraints of the pop-up techniques. Paper engineer Matthew Reinhart describes his design mantra as “You learn the rules, break the rules, you learn new rules, repeat” [7]. These “rules” have great potential for investigation and discourse in the classroom. Students can develop adaptive expertise by breaking novice assumptions to develop more expert understandings.

Our goal was that students would build from the known shapes to produce novel combinations, however, we found this did not necessarily develop spontaneously. The fourth graders were asked to design cards based around their buddy’s interests. We explicitly taught three different folding techniques, which could be used to make a variety of designs. When asked to produce their own designs, 7 of the 25 students replicated the design from the model. We demonstrated one technique that could be used for any symmetrical shape, and used a heart as an example. The two students that used that technique made hearts. We demonstrated another technique that could be used to make a talking mouth and made a duck as an example. Five students used that technique to make a duck. According to the students’ interview notes, their buddies did not mention ducks or hearts as their favorites. In this case, the students appeared to recreate what they had learned how to do.

Despite that pattern, the class did invent two new techniques, and 5 out of 25 students used them in their design. One student was inspired to make a peacock, which required a different structure from the known techniques. She experimented with different methods for realizing her design until she created the desired structure, then two other students used that same technique. Another two students wanted to make a tent and experimented with structures until they created the desired effect. This indicates that even without much scaffolding, some students innovated. This aligns with Hatano and Iganaki's supposition that children are innately curious about understanding the "how" and "why" of procedures they engage in, and are therefore primed to develop adaptive expertise. It also acknowledges that the development of novel techniques is not automatic, and more attention to support and facilitation may be needed to achieve this desired outcome. As students became more familiar with the techniques, we saw more instances of innovation. Below are examples of student innovations.

Table 1. Examples of different categories of innovation

Visual Innovation	**Structural Exploration**	**Structural Innovation**
 **Using a known foundational shape to represent something new.** This student used a talking mouth on a tiger instead of a duck.	 **Exploring the boundaries of known foundational shapes to see what happens.** In this example, the student used the v-fold technique to make a banner that floats off the page.	 **Combining known foundational shapes in novel ways to create a desired outcome.** After looking at a complex dinosaur mouth pop-up from a book, student created a dog's mouth by combining two v-folds.
 **Making adjustments to a known foundational shape.** Students learned the v-fold technique with a rectangular model, and this student adapted the shape to create a sun.	 **Learning a new technique from an expert or resource to create a desired outcome.** This student knew her buddy liked ice cream, and looked in an instructional book to learn how to make this cone pop-up.	 **Inventing new techniques.** After making a v-fold waterslide, this student added a slit and a tab so her character could slide down.

Talking about making is hard, but sharing ideas supports innovation. Although students became engaged in the challenge of creating a pop-up and were innovating new strategies, they were often unaware of the discoveries they were making. Hatano and Iganaki put forward three factors that influence the development of adaptive expertise – the the degree to which learners are oriented toward understanding procedures rather than simply executing them, exposure to variables influencing outcomes of the procedure, and the rewards for completing the procedure. In order to encourage students to explore variables in the procedure and center understanding rather than execution, we asked students to record their "tricks of the trade." Students were shown several examples of previous "tricks of the trade" and encouraged to think about their own or others' tricks for paper engineering throughout work time that day. Identifying novel adjustments to procedure appeared to be challenging. Although students used novel, effective techniques, by the end of the work session, only five students had identified a trick. One of those students entered into work time with a clear focus on identifying tricks of the trade. She struggled to identify any tricks that she could teach and in turn showed frustration. It was not until a classmate asked her for help and through the process of showing her peer how to do something that she exclaimed mid-teaching, "Oh! I have a trick of the trade for making a square." The act of recognizing expertise in oneself or in others was challenging for students.

We hoped for students to begin to share their discoveries with one another in class discussions, and to decenter the teacher as the technical expert. Without awareness of their own expertise, it was challenging for students to engage in discussions about new techniques. Student engagement during whole-group discussions about technique was low. During whole-group discussions, students frequently engaged in side conversations. Discussions did not produce the rich, substantive dialogue around making sense of the techniques and procedures as we had hoped.

However we did observe peer teaching came in the form of on-demand one-on-one help. We observed students asking for help from student experts in different techniques. Often the expert would do the hands-on work for their classmate, narrating their work step-by-step. This peer teaching suggests that students were developing agency and ownership of the problem-solving process.

Building a community to support the development of adaptive expertise required more attention to the structures for idea-sharing. When giving feedback about how to improve the project, one student suggested that we should "Have more partners. It's easier to do things with help." Building in more support for on-demand one-on-one peer support may be a more effective means of developing adaptive making expertise, and more enjoyable to students.

Exhibition impacts innovation. An additional conjecture we are entertaining is that authentic audience and exhibition may set the conditions to play it safe and, as a consequence, limit the development of adaptive expertise. During pop-up workshop, we observed students experimenting with pop-up structures in new ways. When learning about the v-fold technique for example, students discovered that you could cut out shapes from the v-fold (i.e. to make a rainbow or a superhero) and that the v-fold could be various dimensions (i.e. a taller v-fold turned into a tree). However, during the product-creation phase of the project, we observed students replicating techniques that they had already mastered--a problem redolent of the "keychain syndrome" [1] in which students acquire a simple and effective fabrication skill and then have difficulty transgressing into the messiness of innovation.

Creating pop-ups for an audience also generated stress for students. One fourth grader began crying because he had a vision for the card he wanted to make, but struggled to make it. One possible explanation for this was that perhaps because students had the objective of creating a product for an audience, the cost of failure was higher. One student described the challenge of making a high-quality pop-up: "What I want my buddy to know is that it's not just one draft I made, I made like 10 to make it perfect and it was very hard."

The final product phase lacked the focused and creative energy of the pop-up workshop phase. When giving feedback about how to improve the project, one student suggested that we should "Do more mystery pop-ups. They were fun and exciting and then we stopped doing them and I was sad." This student is referring to an activity where a pop-up is shared but the mechanism is a mystery that the students solve through trial, error and innovation.

2.2 Broader Value

Through both its successes and its failures, this project offers insights into designs that foster innovation. We set out to develop adaptive expertise by giving students time to experiment with new techniques before applying them to a novel design for a client. We did not observe as much innovation as we expected. Our results suggest that three factors are in tension with student innovation--our task design, discourse facilitation and student exhibitions. Revisions to our project in the second iteration have yielded promising initial results that warrant further research.

Collaboration in support of student agency and understanding may foster innovation. Tasks that explicitly require students to experiment with variables and discuss their findings might be more effective than simply allowing space to apply new skills to creative design. In the second iteration of our project, we have designed tasks that integrate discussion of variables into the regular routine before building. We have also designed tasks that require students to build structures that combine techniques.

Whole-group discourse may not be an effective method of sharing skills in making. Whole-class discussions and idea-sharing proved unsuccessful in supporting the kind of discourse we hoped to see. Hendrix [4] outlines three competencies for craft learning: knowledge, skill, and appreciation. Hendrix explains that "skills are acquired by actual practice of the craft," so discussion a means of developing skill was a mismatch. However, we did observe students sharing ideas and techniques in the moment, when working alongside peers. In the second iteration of this project, we are structuring collaboration with roles to encourage sharing ideas and techniques, and to make sense-making a clear expectation of the process of designing and making pop-ups.

The relationship between exhibition and innovation is worth investigating further. While an authentic audience can motivate students to create high quality work, the audience can also increase the risk for failure and decrease risk-taking and innovation. Since exhibitions are central to project-based learning, there is value in better understanding how exhibitions influence student work. How might we adapt student exhibitions to encourage risk-taking and experimentation? One idea is student exhibitions could feature student strategies, rather than sharing final products. Students might also teach audience members routines for creative design and collaboration that they use in class to support their innovation, so that the audience learns about the process of experimentation itself.

2.3 Relevance to Theme

The growing social and environmental challenges that our world currently faces are not the routine challenges that can be solved by applying known procedures. These are complex challenges that require new ways of thinking, and novel solutions. If we are to make solutions to these problems, as we educate the next generation of makers, we must learn how we can best foster the next generation of innovators.

In his introduction to FabLearn 2017's panel for sustainable change in education, Roy Pea spoke to his concerns for education in a world with increasingly novel challenges:

> The same tools of education will come to break over time when rigidly applied to very different situations; with a hammer in hand, everything appears to be a nail. But creating a level surface by repeatedly hammering down every 'nail' you see may well erase the lumpy boundaries where innovation lives, the fringes where new insights for adaptivity may be discerned and developed for the future if only they are given due attention. [6]

Pea suggests that these challenges are so pressing that the development of adaptive expertise should be the primary focus of our educational system.

The work presented here responds to the call to create and understand routines and classroom culture that support adaptive expertise. The theoretical framework of adaptive expertise to guide thinking around making is not new [5], though most existing research is drawn from out-of-school contexts. Through this work, we hope to contribute insights into how teacher might foster adaptive expertise within formal schooling environments where accountability structures may value procedural efficiency and external reward structures rather than open-ended discourse and experimentation.

3. BIOS

Julia Jacobsen is a project-based elementary teacher. This year she an Engineering Scholar in Residence at High Tech Elementary in San Diego, investigating structures to support student engagement in engineering.

Riley Meehan is a researcher-practitioner working with K-5 students on engineering and design. His research focuses on making in formal education, primarily in elementary schools.

Brian Gravel is an Assistant Professor and Director of Elementary Education in the Department of Education. His research focuses on students' representational practices in science and engineering studied using design-based research on learning technologies and socio-technical learning environments.

4. REFERENCES

[1] Blikstein, P. 2013. Digital fabrication and "making" in education: The democratization of invention. *FabLabs: Of Machines, Makers and Inventors*. (2013), 1–21.

[2] Dahmen, P. 2015. "The Magic Moment" - Peter Dahmen the Amazing Paper Engineer. Helkey Media.

[3] Hatano, G. and Inagaki, K. 1984. Two courses of expertise. *乳幼児発達臨床センター年報= RESEARCH AND CLINICAL CENTER FOR CHILD DEVELOPMENT Annual Report*. 6, (1984), 27–36.

[4] Hendrix, S.L. 2008. *Popup Workshop: Computationally enhanced paper engineering for children*. University of Colorado at Boulder.

[5] Martin, L. and Dixon, C. 2016. Making as a Pathway to Engineering and Design. *Makeology*. K. Peppler et al., eds. Routledge. 183–195.

[6] Pea, R. 2017. Sustainable Change in Education for What?

[7] Tech Insider 2016. *How a pop-up book is made*. Youtube.