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ARTICLE

# Embedded design: engaging students as active participants in the learning of human-centered design practices

Marcela Borge, Dhvani Toprani, Shulong Yan and Yu Xia

Learning, Design, and Technology program, College of Education, The Pennsylvania State University, University Park, PA, USA

**ABSTRACT**

**Background and Context**: in this paper, we argue that integrating Human-Computer Interaction (HCI) into K-12 computing education can present learners with opportunities to develop human-centered design skills as well as higher-order thinking skills.
**Objective**: to address the issues related to the development of HCI forms of expertise, we introduce an approach, called embedded design, which extends cognitive apprenticeship methods.
**Method**: we present case studies to illustrate the embedded design approach.
**Findings**: six principles were drawn from the case studies, to inform the implementation of the embedded design approach. Three principles address learners as agents, actively participating in domain thinking processes, and three principles address facilitators as learning designers, orchestrating the co-construction of knowledge.
**Implications**: embedded design provides concrete guidance for implementation to help learners to improve their own thinking processes and succeed in computing education fields, but more research is needed to extend what is known about these complex learning contexts.

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Human-Computer Interaction (HCI) is a field dedicated to understanding how people interact with technologies, how technologies shape human activity, and how we can design technologies to best meet human needs. As we begin to develop ever more powerful digital technologies capable of changing entire cultural paradigms, it is essential that we design with human activities in mind to minimize unintended negative consequences to society. Helping students to understand HCI practices and develop HCI expertise at an early age could help to ensure that the next generation of technologies are devised in ways that prioritize human needs, culture, and critical human activities.

**CONTACT** Marcela Borge mborge@psu.edu The Pennsylvania State University, 301C Keller Building, University Park, PA 16802-6823, USA

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The problem is that HCI is a complex field that requires designers to develop abstract forms of knowledge that include an understanding of psychological principles, core methodological strategies and heuristics, and the ability to carry out sophisticated thinking processes (Carroll, 2013; Churchill, Bowser, & Preece, 2013; Rosson & Carroll, 2002). These types of knowledge are important for our increasingly connected digital world, but are also difficult to develop. What is more, traditional schooling practices may be at odds with desired HCI practices. Thus, developing expertise inherent to HCI may pose difficulty for young learners.

Our approach to developing HCI expertise in young learners is called embedded design. Embedded design is an extension of cognitive apprenticeship, a framework for designing learning environments that promotes the development of expertise through enculturation (Collins, Brown, & Holum, 1991; Collins, Brown, & Newman, 1989). Similar to cognitive apprenticeship, embedded design is intended to promote enculturation of domain knowledge. But, unlike cognitive apprenticeship, the learner is expected to be an active participant in all aspects of the learning process by assuming complimentary roles with instructors to co-model HCI practices. For example, instructors can model the role of a designer because they have more domain knowledge, but the learners can adopt the role of the user, which does not necessitate HCI knowledge. Through participation in HCI design projects and co-modeling experiences, learners get opportunities to experience what it means to be a designer and a user, to evaluate and be evaluated, all the while shaping the design process from both vantage points. In this way, learners can internalize HCI ways of thinking, and, as a result, develop underlying higher-order thinking processes associated with HCI.

We see this approach to learning HCI as a fundamentally dialogical and developmental process that advances more sophisticated ways of thinking over time. However, very little is known about the development of HCI expertise in K-12 contexts. So, it is important to ask how we design learning contexts to support the development of these forms of expertise in young learners and what roles teachers, students, and tools should play within this learning process.

Over the last four years, we have been iteratively refining our methods and practices to better understand how to create embedded design experiences to support the development of HCI expertise. In doing so, we have been examining what can be learned in these contexts and what types of problems learners face. We have used this information to iteratively revise our instructional practices to better meet learner needs. In this paper, we draw on representative cases from our studies to illustrate important problems young learners faced as they attempted to complete HCI tasks and how we addressed these problems. These cases also provide the reader with grounded experiences to understand the principles of embedded design we propose later in the paper. We end the paper by discussing the implications that such an approach could have on practice and future research.

## The promise and challenge of HCI education in K-12

HCI is a science of design that emerged from usability studies, software and cognitive psychology, and the iterative design of computing systems (Carroll, 1997; Carroll, personal communication). As computing technology evolved from desktop computing to ubiquitous, wearable, and leisure technologies, so did HCI. The field has evolved to take on more complex issues that include considerations for human culture and society, aesthetics, and emotion (Carroll, 2013; Churchill et al., 2013). Throughout this evolution, one constant has remained – the importance of a human-centered approach to design. This human-centered design approach and the many methods this field has developed to understand people, culture, and the co-evolution of these factors with technology, constitute a critical learning domain for a generation defined by the rise of digital technologies. HCI synthesizes important ideas from psychology such as theories of emotion, individual and organizational learning, empathy, cultural awareness, metacognition, and more, with the design of technologies to understand how technologies can help or hinder human activity (Carroll, 2013).

HCI is not an easy domain to teach, not even to adults, because there is a great deal of underlying expertise and cognitive complexity inherent to HCI design practices. HCI designers are expected to share, build, and negotiate their understanding of problems with their design teams and stakeholders in order to articulate their understanding of the problem through design (Carroll & Kellogg, 1989; Rosson & Carroll, 2003; Turk, Robert, & Rumpe, 2005). Unpacking HCI design problems requires designers to think about everyday problems from a human-centered, systems perspective to understand how people think, and identify important factors of the human system under study in order to design effective solutions (Preece, Rogers, & Sharp, 2015; Rosson & Carroll, 2002). Once designers and stakeholders agree upon a proposed design solution, HCI designers have to build prototypes to carry out design inquiry to test and improve their designs (Preece et al., 2015; Rosson & Carroll, 2002).

What makes the prospect of integrating HCI education into K-12 contexts so exciting is that there are many forms of higher-order thinking that are inherent to HCI. Young learners could, therefore, develop the ability to think in sophisticated ways as they learn about and practice HCI. For example, metacognitive abilities, long known to help support and extend learning (Palinscar & Brown, 1984; Schoenfeld, 1987), are an important part of design. HCI designers are taught metacognitive strategies to monitor their biases and ensure that they are analyzing a design problem in depth rather than taking a "solutions first" approach that is known to cause problems (Rosson & Carroll, 2003, p. 3). They also have to determine what they do not understand about a design problem to seek out the necessary information (Rosson & Carroll, 2002).

Socio-emotional expertise is also necessary to carry out human-centered design practices that are inherent to HCI (Brown, 2008; Carroll & Borge, 2007; Dym, Agogino, Eris, Frey, & Leifer, 2005; Luka, 2014). Designers have to collaborate well with others, develop shared understanding, and synthesize ideas from multiple stakeholders to solve complex problems (Carroll & Borge, 2007). To do so, they have to learn how to manage socio-emotional processes associated with collaboration and failure, so as to promote continued risk-taking that pushes boundaries of learning and creativity (Van der Panne, Van Beers, & Kleinknecht, 2003). HCI designers cannot fear design failure, but have to seek it, and figure out how to learn from it in order to identify design failures quickly and iteratively improve designs (Carroll & Campbell, 1989; Carroll & Rosson, 2003; Rosson & Carroll, 2002; Turk et al., 2005).

These examples are just a small part of what makes HCI contexts rich for complex forms of learning. As such, we maintain that learning HCI requires the development of knowledge and skills that are not only necessary for good design, but fundamentally important for life-long success. These types of knowledge and skills include collaborative competence; learning how to seek out, synthesize, and evaluate information; perspective taking; monitoring and regulating thinking; learning from failure; the ability to persuade others; systems thinking; the ability to empathize with others; creative problem-solving; and communicating complex ideas, simply, to different audiences. These are the types of skills that students need in our increasingly digital and complex society and yet students rarely get to develop them in formal schooling contexts (Collins, 2017; Collins & Halverson, 2018; Duschl & Bismark, 2016).

Integrating HCI education into K-12 learning contexts poses additional challenges because traditional schooling practices can promote ways of thinking that are in direct opposition to the development of HCI expertise. Traditional schooling experiences generally do not help students develop collaborative skills nor provide them with opportunities to learn socio-emotional and metacognitive processes (Borge & White, 2016; Guzdial, Ludovice, Realff, Morley, & Carroll, 2002; Kolodner et al., 2003). Failure also plays a drastically different role in the design and in traditional education. Traditional educational environments work to reduce the likelihood of failure by making it easier to successfully carry out projects and often punish failures, even though failure and difficulties experienced during learning promote richer learning experiences (Bjork, 1994, 2018). As such, learners may be averse to identifying a failure in their own work.

There is also a disconnect between the purpose of design in the real-world versus in schooling contexts. Design projects carried out in HCI contexts prioritize learning about human-centered activities so as to solve ill-structured human problems with technological solutions. In contrast, design projects carried out in formal educational contexts often prioritize the learning of scientific content in subjects such as physics or geology (Kolodner et al., 2003; Lachapelle & Cunningham, 2007) over development of knowledge and skills needed for HCI design (Brown, 2008; Carroll & Borge, 2007; Rosson & Carroll, 2002). The human element, how people think and respond to designs, how designs alter human activity, all these important considerations are often left out of design experiences in formal schooling. As a result, learners may think they know how to design and yet be ill-prepared to carry out HCI practices.

This disconnect posed significant problems for us as we first attempted to help young learners develop HCI expertise, because their everyday schooling experiences promoted routines and ways of thinking that were in direct contrast to desired HCI practices. So, we had to figure out how to help them think about their existing practices as objects of thought while also attempting to adopt new forms of expertise.

## Extending cognitive apprenticeship for the development of HCI expertise

To better meet our learners' needs, we adopted a developmental approach to the development of HCI expertise. We built on a well-known approach to instruction called cognitive apprenticeship (Collins et al., 1991, 1989). Cognitive apprenticeship recognizes that learning new domain practices requires a type of enculturation process where underlying thinking processes are made more accessible to novices (Collins et al., 1991, 1989). Cognitive apprenticeship was influenced by pedagogical practices enacted by socio-cultural and social cognitive researchers that integrated metacognitive thinking with dialogical practices for enculturation (Collins et al., 1991, 1989). The instructional cases from which cognitive apprenticeship principles emerged included Brown and Campione' (1996) Fostering Communities of Learners and Schoenfeld's (1992) expert and novice comparisons of mathematical problem-solving.

Principles of designing cognitive apprenticeship learning contexts include the promotion of diverse forms of knowledge required for expertise, instructional methods for promoting the development of expertise, proper sequencing of learning activities, and social characteristics needed for an effective learning environment. An integral part of the cognitive apprenticeship is making implicit thinking processes practiced by experts, more visible to novices during the learning process. Given the many underlying thinking processes associated with HCI, cognitive apprenticeship seemed especially appropriate to support the development of this form of HCI expertise.

Instructional methods proposed by cognitive apprenticeship include: modeling, coaching, scaffolding, articulation, reflection, and exploration (see Table 1 for definitions of these methods). Though these instructional methods seemed ideal for the development of complex forms of expertise, we nonetheless had to

**Table 1.** Methods to develop expertise in cognitive apprenticeship (Collins et al., 1991).

| Method | Ways to promote the development of expertise |
|---|---|
| Modeling | Teacher performs a task so students can observe |
| Coaching | Teacher observes and facilitates while students perform a task |
| Scaffolding | Teacher provides supports to help the student perform a task |
| Articulation | Teacher encourages students to verbalize their knowledge and thinking |
| Reflection | Teacher enables students to compare their performance with others |
| Exploration | Teacher invites students to pose and solve their own problems |

reimagine what they would look like in a design context. This was especially true for the modeling method.

In cognitive apprenticeship, modeling is an instructional method aimed at providing students with access to expert thinking processes as they occur in real-time. During modeling, the expert performs a task and verbalizes their thinking so that the learner, acting as an observer, can see how the strategies and heuristics used by the expert help the expert reach their solution. The idea behind modeling is that the learner can see an example of desired thinking processes specific to a domain task; however, the learner is not expected to take an active role in the modeling process, nor are they expected to take a participatory role in the practice that is being modeled.

A core aim in our approach is to make learners primary agents in the entire learning process, including modeling, with instructors acting as facilitators. We wanted to promote the development of cognitive and socio-emotional forms of expertise associated with HCI design, including how to interact with potential users, receive and analyze user feedback, identify failure, and regulate feelings throughout. We also wanted learners to comprehend the importance of both the roles of the designer and the user throughout the design cycle. Towards this aim, we used a common human-centered design technique, participatory design, as an instructional tool to push learners to assume different participatory roles in the learning process. We wanted to provide them with opportunities to be a designer and a user, to evaluate and be evaluated, and to ultimately be in control of their own learning experiences.

To accomplish this aim, we created a narrative that we, the facilitators, were designers and they, the learners, were users. Facilitators designed activities and tools, and learners evaluated them throughout the semester. This narrative allowed facilitators to model different aspects of the HCI design process from the perspective of the designer, while learners modeled the user's role. After such co-modeling, students practiced emulating the different forms of domain knowledge they experienced as part of their own design projects with ongoing support from facilitators. Meanwhile, facilitators promoted the articulation of thinking, reflection, and exploration of problems and solutions. Together, facilitators and learners iteratively improved the design of curriculum and tools to better meet learners' needs as learners took on design problems of their own.

This form of embedded design and practice was highly interactive, providing opportunities for rich discussions about problems learners and facilitators would face when they engaged in design. These rich discussions, in turn, provided opportunities for students to develop cognitive, metacognitive, and socio-emotional competencies.

## Examples of embedded design

To illustrate how embedded design works, we present two cases that highlight how the facilitators co-modeled design thinking and embedded the use of design language and practices into ongoing club experiences. The first case illustrates embedded design as a means to provide students with an opportunity to experience design practices of usability testing, with special emphasis on seeking and receiving feedback from the user. The second case shows embedded design as a means to guide whole class reflections upon a design failure that we, the facilitators, experienced. Both examples highlight embedded design as a highly conversational and interactive processes between the facilitators and the learners.

The two cases are drawn from one year of an afterschool club designed for students in grades four through seven, who were eight to 12 years of age. There were 16 students in the club, 37.5% female and 50% students of color. Students had a range of abilities, with gender and ethnicity represented across the performance spectrum. Four students had special needs requiring Individualized Education Programs (IEPs); three students were in advanced math and reading.

The club was structured by an evolving curriculum informed by theories of HCI design. The club introduced HCI concepts and provided ongoing design challenges that students could solve with a variety of playful technologies, i.e. art supplies, Legos, computer games such as Minecraft, and invention kits like Makey Makey. Daily club sessions ran for 80 min. The first 10–15 min and the last 10–15 min were whole-class discussions that included introductions to design challenge projects, reminders of or reflections on previous activity. During the 45–55 min in between, students worked on design challenges as part of teams. Meanwhile, facilitators observed activity and provided support when needed.

### *Case 1: extraordinary experiences with user evaluations*

In this first case, we focused on helping students understand design evaluation. We especially focused on the role of user feedback in improving designs. Giving and receiving feedback posed difficulty for learners because of negative feelings often associated with it; the students would get visibly upset when others would point out flaws and would refuse to acknowledge problems with their design. In response to this problem, we created a series of short design challenges that allowed for rapid generation and evaluation of design ideas, which we called the Persuasion Game.

As part of the game, teams had to learn about persuasion as it applied to HCI design. Each team had one hour to use clues provided about a user to identify a potential problem to overcome with design. For example, teams received an illustrated card from a design game, The Extraordinaires® Design Studio PRO. This card contained pictures of an extraordinary person – a potential "user" of a design that they would create. The card showed the extraordinary person in multiple contexts, i.e. a superhero at their day job, in the field fighting crime, and at home with their family. Once teams used the scenes to imagine a potential problem their user might face, they had to envision potential design solutions, decide on one design, and sketch it for an audience.

The team then had to devise a two-minute design pitch to persuade the audience, i.e. their fellow club members, that their design met the user's needs. Teams would present this pitch in the following club session. During this presentation, teams were expected to use the clues presented in the card as evidence to justify design features, receive feedback from club members, and discuss how they could use the feedback to improve their ideas.

The game was intended to help students improve their ability to give and receive feedback, but it failed to do so. Students were overly harsh when giving feedback, saying things like "that's a stupid idea". Teams would also get upset when receiving feedback, no matter how constructive it was, because they did not want to see flaws in their design. Students' fear of failure and lack of respect for giving and receiving feedback were problematic because they negatively impacted their ability to iterate and improve their design. So, we decided to focus on creating an embedded design experience as a means to make visible to students the desired underlying processes in giving and receiving feedback.

The lead facilitator, F1, introduced the activity by explaining that the club would get the opportunity to work with a real designer, Padmesh, the CEO of a small start-up company in London. She added that Padmesh was trying to build a system for students like them for collaborating with each other. She explained that the club was going to test his system, see how usable it was, and help Padmesh by giving him feedback so he could improve it. This, she said, was called a usability test; they would watch a short video Padmesh made for them and complete the first of the three evaluations of his system. She then played the video where Padmesh described his design goals and pointed out that he made assumptions about them, the users:

> "When I started developing this system, I wanted it to be collaborative and fun, but I made some assumptions about what you'd like and I don't really know if you'll like it or be able to use it. So today, I want to see how easy or hard it will be for you to upload your own files into the system and share them with your team. So, I'm hoping you can help me test it. So, please try it and let me know how it goes."

After watching the video, F1 described the specific task they would do to evaluate the system and stated that they would then provide Padmesh with feedback. One student expressed his disbelief that a CEO would listen to them, “Do you think he’s gonna listen to some random stranger?” The facilitator stated that they, the users, were important and shared that they were the only focus group he would talk to in the US. This helped convince the students that their feedback was valuable and excited them.

There were three usability tests, during which the facilitators modeled design methods and techniques by taking on the role of co-designers working with Padmesh. The facilitators set-up screen captures on each of the students’ laptops to record their activity. The facilitators also created plans for the user tasks and set predetermined benchmarks of how long it should take users to complete the tasks. All of these ways of capturing and measuring user activity were briefly and explicitly described to the learners. As the learners worked on user tasks, the facilitators held timers and took field notes to model careful observation of user behavior. In this way, students were able to see expert practices associated with user evaluation, the importance of the process, and how to discuss and evaluate results.

After completing the final test of the system, where students attempted to use a note-taking feature in the online system being tested, they all took part in a focus group session. The CEO Skyped into the club, in real-time, to lead the focus group, ask questions, and receive suggestions for improving his system. He began by asking for strengths of the design: “So, let’s start with the notetaking activity. And let’s start with the positive . . . How did you find this activity: was it easy, was it confusing, was it difficult? What did you like, find easy or hard?”

Students were all paying close attention, sitting up straight, not laughing at other’s comments or having side conversations. They provided Padmesh with diverse user feedback. For example, in response to Padmesh’s question, Antonio said, “It was confusing at first, but then it got easier as we continued using the notes and ah, it was easier. So, I liked the notes, ah, feature, it was very useful.” Another student, Amy, did not find the notes feature useful and provided negative feedback, “I think it was confusing the whole way through and I didn’t really get much info on how to use it”. Padmesh asked her to elaborate, “Can you specify what was confusing?” Amy clarified that she could not figure out how to use the notes, specifically how to open a note. Padmesh expressed interest and enthusiasm in understanding why this was difficult for her and wrote down her feedback. Other students provided their thoughts and the facilitators also asked questions about problems they observed.

Padmesh then asked for suggestions on how he could improve the system and multiple students provided specific suggestions. For example, Armondo said. “I would say that the site needs instructions. Like when you do something there would be instructions here to tell you what you’re doing and how to do it, and a good version of it and a bad version of it”.

Once the evaluation and feedback session ended, a facilitator asked Padmesh if he could tell the club a bit more about his design process and about what he thought it took to be a good designer. Padmesh said:

> "So, the system emerged as a result of all the frustrations I had with other collaborative platforms. I sat down to design something of my own from scratch. And I got inspirations from the way people collaborated in the real world and I kept asking for feedback from my friends and students who used it. And so, many changes have been made to it today. And so, it's with constant feedback, and questions, and challenges, that we got designers constantly improving the product … and that's it … All the best with your studies."

After saying goodbye to Padmesh, the facilitators moved on to help the club reflect on the embedded experience: "Okay so now, how was that experience? Okay, the very important thing, what did you learn about designers by working with Padmesh?" F1 called on Catherine who stated that she learned "that he spent a lot of time thinking about designing". F1 then asked them how they thought he got to be such a good designer and another student said, "With thoughts". F1 repeated the response, but then added, "how do you make your thoughts better". Armondo responded by saying, "By asking other people what they think of your thoughts."

In reflecting upon the embedded experience of usability testing with Padmesh, students were drivers of the ongoing, productive conversation, where the facilitator F1 helped students relive their experiences from the activity to reinforce desired design ways of giving and receiving feedback and improving their thinking and design. Table 2 shows a short excerpt from this conversation that highlights the facilitator's role. The facilitator pushed students to describe their observations and then worked to connect them back to core concepts and principles of design: in this case the importance of evaluating designs with real people and getting feedback to improve them (Table 2,

**Table 2.** Extraordinary experiences with user evaluations, episode 5.

| Turn | Speaker | Utterance |
|---|---|---|
| 1. | F1 | That's exactly what Padmesh was here for because you are the real-time users of this product. He wanted to make sure that he does what makes sense for you, he's doing something that helps you. So, it's very important in design to take feedback and take feedback from the people who are going to use your product. What did you see? What was he doing throughout the session? Um Amy? |
| 2. | Amy | He was typing down our answers. |
| 3. | F1 | That's, that's a good observation. So, did you all see he was, he was typing everything that you guys were saying. So, he was taking feedback, he was asking a lot of questions, to make more sense of what his product looked like to you guys. What else? What else did you observe him doing. What else is a good design practice that you can pick up from him? |
| 4. | Marcos | That when you get negative feedback, he wasn't mad, he wasn't like (making angry face), AHHH, Laaa, laa (makes excited face)! (Kids laugh). He was like (makes a relaxed face) … cool. |
| 5. | F2 | That's right. |
| 6. | F3 | And he, one time, when Yair told him about that insert function, he was actually very happy about that, that you guys figured out that that wasn't very helpful. […] Right, so exactly when he takes the negative feedback, he turns it into a very good learning opportunity for him to improve his product. |

Turn 1). She also ensured that the students noticed how the facilitators and Padmesh were all taking notes and how Padmesh responded to negative criticism (Turns 2–6). She asked, “What else is a good design practice that you can pick up from him?”, and Marcos responded:

> “That when you get negative feedback, he wasn’t mad, he wasn’t like (making angry face), AHHH, Laaa, laa! (Kids laugh). He was like (makes a relaxed face) … cool.”

Embedded design can help introduce learners to a variety of complex domain-specific methods and techniques. The experiences that occur during embedded design serve as objects of thought to develop an understanding of underlying processes that are involved in design practice, which are hard to teach through written or verbal explanations. In design contexts, critical cognitive, metacognitive, and socio-emotional processes can be developed through authentic experience and reflection.

### *Case 2: the problem with reward systems*

In the same school year, two facilitators designed a chart that kept track of all teams in the club with star stickers for each time they did well on a design challenge or were recognized for excellence in thinking or collaborating that day. Students referred to this artifact as the star chart. During club sessions, facilitators would reward those they identified as displaying desired thinking processes with stars, add the star to the chart, and discuss the desired process. Student teams also received stars for creating the best design, i.e. met the most user needs compared to others. These stars did not “win” students any prizes; it was just a form of recognition and opportunity for club members to reflect on ongoing processes and products.

In a previous club session, one student had commented that the chart made him feel bad about himself. Facilitators realized they, as designers of the club, failed to design a reflection tool that fully met the learners’ needs. So, they decided to hold a whole club reflection in the next session to model how to approach a design failure. Table 3 shows the first episode in this whole-class reflection.

F1 began by reminding students that in the previous session they had learned of an unintended consequence of the star chart, that it made Anton feel bad (Turns 1–2). In Turn 5, F1 went on to connect central design concepts to students’ concrete experiences with the star chart. She pointed out that the star chart was a design created by the facilitators to help resolve a specific problem. She unpacked the problem and explained their rationale. She then stopped to make sure all the students understood that when discussing the star chart, they were the “users” in this scenario (Turns 5–6). In this way, she helped learners to be aware of the shift in design perspectives.

**Table 3.** The problem with reward systems: episode 1.

| Turn | Speaker | Utterance |
|---|---|---|
| 1. | F1 | [. . .] Something really interesting happened last time, led by you Anton. It was so cool that you thought you could share the way this thing (holding up a star chart with students' names on it) made you feel. |
| 2. | Anton | Bad. |
| 3. | F1 | And that was a really important thing that you said that, because – |
| 4. | Eric | (Says to his team as F1 talks) That's risk-taking. |
| 5. | F1 | - we designed this thing for a particular reason. Right? This was our design (holding a star chart). We created something that we thought would solve a problem [. . .] getting you guys to collaborate, to engage in design thinking, and take creative risks, which is what you did last time Anton: you took a risk by sharing how this thing makes you feel. Those things are really hard and sometimes really uncomfortable [. . .] so, sometimes kids don't want to do it [. . .] Because it's after school. So, we thought we could solve this problem by using this reward system. [. . .] It was intended to try to encourage you to try and do some of these really difficult things and so that you guys could design better and collaborate better. [. . .] But what we found was that, as our users – in this situation, who's our users? |
| 6. | Learners | Us. |
| 7. | F1 | Good. You guys are our users – As our users tried to carry out their activities, it didn't really have the desired outcome that we wanted, right? [. . .] |
| 8. | Anton | It made me feel bad. |
| 9. | F1 | That's not what we want to do. So, we sort of failed at our attempt [. . .] We found out when we tested it [. . .] How did we test this design? |
| 10. | Learners | By testing it on us. |

F1 then highlighted that only through testing the design with real users were the facilitators able to realize that their design failed to meet the club's needs (Turns 7–9). In Turn 9, she reiterated that when facilitators created tools for the club and tried them out, they were testing them and getting feedback from real users (Turns 9–10). Through discussion, F1 highlighted the importance of examining whether designers met users' needs and how making assumptions about users could lead to a design failure. She also modeled genuine curiosity in wanting to understand why the design failed.

While F1 started the reflection session, the resulting flow of the conversation was dictated by students to ensure that they experienced their input as valuable. For example, F1 wanted to get the club to understand unintended consequences and so asked them about other types of reward systems they were familiar with and learners talked about grades. In discussing how well grades motivated students, one learner responded by saying he was not sure if grades helped to motivate him because the effort was not always rewarded: "It makes me want to try my hardest and sometimes when I try my hardest, I flunk." Another student, looking genuinely upset, added that some kids were just smarter.

F1 responded that, "it's not about being smarter. There are kids who have spent more time doing stuff than other kids. They may have read books earlier, they may have written earlier, they might have spent more time doing it; they might have more conversations about it. And so, when you are comparing yourself to other people … ", and then another student, Eric added, "It kind of lowers your self-esteem in a way". F1 asked Eric to elaborate on why he thought so. Eric explained that when someone else is constantly recognized and one is not, it feels like they are just better or smarter, even if in reality they have spent more time doing it.

Different students presented their perspectives on reward systems, while others presented counterarguments. For example, Marcos, argued that it was fair to reward those who put forth more effort. He said:

> "So, I said when, when people are born, they have the same amount of intelligence. It's what you do with that. Whether you, whether you practice or you decide to do something else. Then you spend your time doing that instead of the other thing and then you can't get mad if someone wins a reward for doing that thing that you decide not to do any more."

However, as the conversation continued and became centered on concrete examples from the club, Marcos realized that sometimes people do not get the chance to develop a skill, because they may lack opportunities or resources to do so. For example, some students stated that their parents had bought them technologies used in the club. As a result, they had developed more experience and expertise with the tools.

Marcos also realized some students had not gotten the opportunity to be in the club as long as he had, because the club filled up quickly and some parents were unable to sign up their kids in time. The parents of the students in Marcos' group knew how hard it was to get into the club and would stand by their computers the moment club registration opened (at noon on a workday). However, many parents had less flexible work schedules that did not allow them to do so. As such, this was the first time many had been able to get into the club. Recognizing this, Marcos changed his position: "I think because we have four years … well four semesters of experiences. We can't say 'we got the star' and make everyone else feel bad, because that's unfair."

During this reflection, F1 worked to moderate the conversation while modeling important dispositions. She helped students articulate their feelings, validated their perspectives, and worked to ensure that all tried to understand different shared perspectives. She pushed students to figure out a better design for accomplishing their primary aim than the existing star chart; they needed to design a better way to encourage students to reflect on their design processes and improve them over time.

She said that now that they understood the problem better, they needed to decide if the design challenges should be competitive. The students said no. She then asked them to come up with new alternative designs to better meet their needs. The students suggested different design paths but, in the end, decided on a collective reward system where they would all pool their stars to earn a day of free play. F1 thanked them for their valuable feedback and for helping her to improve the design.

In this example of embedded design, F1 modeled important design habits of mind, especially in dealing with design failures. She accepted that her design failed and worked to understand why it failed by asking users for their honest criticism. She valued the feedback as an opportunity to learn, pushed users to articulate their thinking and feelings, empathized with others, and then used what was learned to generate new, improved designs with users. Club members had opportunities to think about more than just design content. They thought about each other's experiences, how different students were affected by competitive reward systems, and how differences in opportunities could lead to differences in performance over time. Afterwards, learners moved on to design their own projects and were encouraged to discuss their own design flaws, how they felt about them, and how they pushed themselves to see failures as learning experiences.

## Principles of embedded design

The two cases demonstrate aims and practices associated with embedded design, as well as the rationale behind its use. Among these is the primary purpose of embedded design: to help novices develop interconnected knowledge of underlying processes associated with design practice by creating shared experiences that experts and novices can make sense of together. These forms of knowledge include underlying cognitive, metacognitive, and socio-emotional processes in design, how design impacts people, and desired dispositions that are necessary for effective human-centered HCI design practices. In this paper, we specifically focused on practices that our learners struggled with during this particular year: giving and receiving feedback, empathizing with the user, and managing design failures to learn from them so as to improve designs.

Embedded design provides an embodied experience within the practice that allows learners to make sense of a phenomenon by drawing on situated knowledge including how events could be felt from multiple perspectives. As the two cases demonstrated, embedded design requires students to experience a practice within a practice, to be both the subject (i.e. designers) applying the practice and the object (i.e. users) experiencing the practice. Guided reflection helps students connect the two experiences and discern underlying HCI design processes to move novices closer to experts.

When implementing embedded design experiences, we adhere to six core principles. These principles center on the roles that learners and facilitators play in the learning process. Three principles focus on the role of learners as agents, actively participating in thinking processes. Three principles focus on the role of facilitators as learning designers, responsible for orchestrating the co-construction of knowledge (see Table 4).

### *Learners as primary agents, actively participating in domain thinking processes*

Like Papert (1980), we believe that abstract forms of knowledge, like those inherent to HCI, are more difficult for children to understand because everyday

**Table 4.** Principles of embedded design and the roles and responsibilities of learners and facilitators.

| Principles | Roles and responsibilities |
|---|---|
| **Learners as Agents, Actively Participating in Domain Thinking Processes** | |
| *Learners as primary learning agents* | Learners spend most of their time in control of their own learning experiences. They work on self-directed projects with peers, making collective decisions about what they will design and how they will spend session time. |
| *Learners as central participants* | Learners are taking an active role in different aspects of design, even during expert modeling, by playing an important complementary role that the expert must interact with, i.e. user for the designer, builder for the planner, etc. |
| *Learners as anchors of the sensemaking & solution process* | Learners' perspectives/feelings during the process of design anchor collective sense-making during reflection. These concrete experiences are used as objects of thought to understand problems and devise solutions. |
| **Facilitators as Learning Designers, Orchestrating Co-Construction of Knowledge** | |
| *Facilitators as creators of perspective shifting events* | Facilitators create opportunities for learners to experience a design event from different perspectives, i.e. the learner takes on the role of designer receiving feedback from potential users and then takes on the role of a potential user providing feedback to the designer. |
| *Facilitators as orchestrators of ongoing reflection* | Facilitators lead reflective activities where the facilitator prompts learners to share their thoughts, feelings, and concrete experiences; learners' contributions are used as a means to connect the situated practice to expert practice, help learners identify important expert practices and existing problems in their own practices, and to understand why these problems occur. Facilitators also help learners to understand and develop shared goals and concrete plans for improving existing practices. |
| *Facilitators as connectors of experiences* | Facilitators observe learner activity, taking notes on important topics to discuss and analyze during community reflections. Individual and team experiences are shared with the community to develop shared understanding of important processes, dispositions, and values embodied by different experiences. These shared experiences can then be used as shared references to make sense of future events. |

life experiences rarely provide learners with opportunities to interact with abstract concepts in meaningful ways. To mitigate this problem, Papert (1980) argued for the need to provide young learners with objects-to-think-with: embodied experiences to help learners construct a deeper understanding of the complex phenomenon. For example, Papert (1980) discussed how he played with gears as a child and then drew on his previous physical experiences with gears to imagine different types of gear functions in his head. This ability helped him understand algebraic equations later on. As such, he argued that the gears served as an "object-to-think-with" (Papert, 1980, p. 11).

While Papert was interested in developing children's understanding of abstract mathematical concepts and computing systems, we are interested in developing children's understanding of abstract psychological concepts and human systems. Thus, we want to promote learners' agency to explore their own processes in the club and use these physical experiences as "objects-to-think-with" to make sense of more complex HCI concepts and improve their design processes.

Providing learners with agency does not mean they get to do whatever they want, because if it was up to them, they would not make time to reflect on their processes. For us, agency means that their experiences in the club, including the problems they face with design and with each other, drive reflective discussions and the creation of new activities. When problems emerge that impact the entire community, learners take part in guided reflection where they are given the authority to decide how to improve these problems for themselves.

Towards this end, the majority of club time is set aside for students to work on their own design projects. During this time, facilitators observe learners' activity and identify problems that learners face. In this way, learners dictate what needs will be emphasized through instructional methods like modeling, reflecting, coaching, etc., by virtue of the problems they experience. Students also actively participate in the entire instructional process, including modeling, and are encouraged to take part in core decision-making processes associated with the rules, expectations, values, and activities of the club. Facilitators try not to directly tell students what to do, but rather to create experiences to help learners understand learning goals, and identify, diagnose, and resolve problems, as a community. In this way, embedded design helps to develop technical skills and higher-order thinking skills, while providing learners with opportunities to see themselves as problem solvers.

### *Learners as primary learning agents*

It is our contention that learners need a variety of experiences to understand design. They further need to pay attention to their processes in different contexts and to be in control of them. In our cases, novice learners had opportunities to practice design skills in teams as they took on playful design challenges. They used different types of tools to create design artifacts, moving from paper representations, to physical Lego models, to a computer aided virtual design. They also shifted back and forth between being a designer and being a user.

Throughout these experiences, facilitators prioritized the process of learning over the completion of design products. Facilitators did not try to prevent learners from failing or even require them to complete projects, but rather gave learners the agency to fail without fear of punishment. Facilitators empowered learners to decide how fast the curriculum should progress, what they wanted to learn, what design activities they wanted to take on, what they needed to fix, and how to fix it.

Planned activities were often changed to meet emerging learner needs. For example, in the first case, students' fear of failing and unwillingness to accept criticism drove facilitators to design a new activity to help students learn to give and receive feedback in productive ways. In the second case, an individual's negative experience with a classroom tool pushed the entire club to unpack the intent of the tool and evaluate whether it was meeting its objective.

### *Learners as central participants*

What makes the embedded design unique is that it requires learners to take an active role in authentic design practices while learning about design. Rather than watch passively while an expert demonstrates a specific skill, learners take part in the larger systemic practices. For example, in our first case, "extraordinary experiences with user evaluations", learners' understanding of user testing and user experience was deepened by having them switch roles from being designers to being users. As novice designers tested their own designs, they were initially committed to proving their designs worked and were reluctant to identify any weaknesses in them. However, when they took on the role of users to evaluate Padmesh's design, they were able to experience how a design could impact users and were invested in improving the experience for other potential users like themselves. As part of this participatory modeling experience, they took part in an actual usability test, helping the facilitators to test a system designed for children and to provide feedback to the designer.

These different forms of participation provided learners with shifts in perspective that allowed them to "see" different aspects of HCI practices. As designers, they could understand the time and effort that went into the design, the difficulty of presenting ideas to others, and the negative feelings associated with design failures. As users working with an expert designer, they saw how the designer prioritized the users, listened to them, and valued their input. They saw how the designer regulated his emotions, had productive interactions with users, and reflected upon his own design to improve it. As users, learners also saw that the designer believed all designs were flawed and that he needed their feedback to find the flaws he missed. Through all these forms of participation, learners were able to experience why they should seek out and value negative feedback about their designs. In this way, learners got the opportunity to learn about the underlying socio-emotional aspects of human-centered design from their personal experiences and draw on their lived experiences to make sense of these processes.

### *Learners as anchors of the sense-making process*

Events that take place between learners during the club provide facilitators with concrete examples of human activity from which to help learners make sense of HCI concepts and techniques. Club experiences serve as embodied experiences. These embodied experiences are powerful learning tools because learners can think back on these events and remember what they looked like, sounded like, felt like, and use these insights to better understand HCI principles and practices. For example, when learning about emotional design and how emotions impact how people think and behave, we can talk about how learners feel when they get frustrated with a technology or experience failure in the club.

We can build on these club experiences to introduce more complex ideas, like emotional regulation. Of course, we do not use jargon, we just introduce concepts. For example, we tell them that when someone criticizes their idea, their first reaction may be to feel bad. We tell them they may have developed routines to make themselves feel better in school, like defending their idea, or dismissing the person. We then ask them to recall how they have reacted to criticism in the club. We point out that denial/avoidance routines do not work to improve the design. So, they have to reflect on their feelings, remember that the bad feeling will pass and that they should feel proud to have uncovered a flaw in their design. We tell them that only by uncovering a flaw can they work to improve it. We can then point to specific examples from the club to show how individuals improved a design or process by identifying and overcoming failure. We tell them without reflection, they will be more prone to react in ways that may not benefit them in the long term and push them to think of examples from their own experience to support this claim. These concrete experiences help them to understand abstract concepts and develop important skills in situ.

We also ensure to treat our learners as thinkers and problem-solvers, capable of figuring out how to overcome the problems they face. For example, in our second case, learners were empowered to draw on their own experiences and make sense of a design failure related to a reward system. They were also given agency to decide on how to improve upon the design in a way that would better meet their needs and improve their own learning processes. The facilitator did not tell them what to do, but rather guided learners to draw on past experiences in order to understand why the design failed. Learners listened to different perspectives for the purpose of developing understanding and not to win a debate. Then, based on what was learned, the facilitator helped the learners collectively decide how best to design future club experiences.

## *Facilitators as learning designers, orchestrating co-construction of knowledge*

The main goals of facilitators are to (1) design learning activities that provide teams with opportunities to learn about and experience human-centered design thinking processes, (2) observe teams so as to identify problems that may interfere with their ability to carry out design practices, and (3) orchestrate collective sense-making experiences to help learners recognize existing problems and make decisions about how to improve them. To achieve these goals, facilitators play three crucial roles within embedded design experiences: creators of perspective-shifting events, orchestrators of ongoing reflection, and connectors of experience.

### *Facilitators as creators of perspective shifting events*

An important aspect of embedded design is pushing learners to appreciate an event from another person's perspective. This helps learners empathize with others and appreciate problems that can result from differences in how individuals learn and understand the world. Perspective shifting events can help learners understand how previous experiences can impact how people perceive the world, without discussing abstract concepts like mental models. Showing learners how different people can see a situation differently, by drawing on their own experiences, can help them develop more sophisticated theories of mind and push learners to overcome egocentric biases in design.

During perspective shifting events, the facilitator serves as a support system to model important practices and ways of thinking, to help bring critical experiences to learners' attention, and to push learners to compare their own design thinking practices to those of experts. This type of facilitation is done in the service of helping learners decide on goals for self-improvement. This is especially evident in our first case where students shifted back and forth from being designers to users. These experiences helped them understand user testing and how it should help with the goal of improving their designs. The facilitators had to plan out this embedded experience, determine what expert practices needed to be emphasized, coordinate and prepare the guest designer, and run the activity.

### *Facilitators as orchestrators of ongoing reflection*

While situated experiences are important, they are not sufficient for all learners to improve their existing practices. It can be difficult for some novices to know what they should be paying attention to during embedded design experiences, even when it is their own thoughts and feelings. Thus, embedded design requires facilitators to identify practices and/or skills that the learners need to develop from observation and promote reflection on those practices and/or skills to help learners focus on and improve upon them. This requires that facilitators have ample time to observe learners as they work with their peers to devise meaningful reflections based on those observations.

For example, in Case 1, the facilitators carried out a reflection after the embedded activity to help learners articulate what they observed as they carried out the task and how Padmesh was interacting with them as users. The goal of reflection was to help learners understand the importance of honest user feed-back and why testing to failure is helpful. Towards this aim, facilitators pushed learners to compare their practices to expert practices and use reflection as a tool to help them identify important dispositions and articulate their thoughts and feeling around these experiences.

In Case 2, the facilitator also used reflection as an opportunity for club members to understand each other better and for those who had become better designers to appreciate the opportunities they had received. In HCI, as in all aspects of life, setting aside one's egocentric biases and listening to another person is a very valuable skill. In embedded design, facilitators have unique opportunities to help club members make sense of their experiences in ways that promote learning about human psychology, the unintended consequences of designs, and the development of empathy for those different from them, all of which can help them appreciate different perspectives and understand themselves as learners and designers. Facilitators can use reflection to develop learners' understanding of HCI strategies to help them overcome biases related to how they unpack problems, seek out feedback to evaluate designs, empathize with others, and utilize feedback to improve designs.

### *Facilitators as connectors of experiences*

There were many embedded design events and problems that learners experienced and overcame as part of the club that served as important learning benchmarks. A third important role that the facilitators play is connecting previous learning experiences with new, related ones. This way, facilitators can help learners build on their experiences and continually remind them of community values and how those values came to be. For example, the events that took place between the expert designers, i.e. Padmesh and club facilitators, and the users, i.e. the club members, provided meaningful experiences that played a critical role in developing community values. In Case 1, the club developed a shared understanding of the value of feedback and the need to be constructive when providing it. In Case 2, the club recognized potential negative consequences of competition within design contexts and the value of working together to achieve a goal.

These experiences became learning objects for making sense of design processes in future sessions. When teammates would have different competing ideas, facilitators would remind them to think about what was learned from the star chart (Case 2) or from working with Padmesh (Case 1): it is not about meeting the designer's preferences; it is about using collective brainpower to figure out how to meet the user's needs. The facilitators reminded them not to be too attached to a design, but to seek out feedback, evaluate alternative ideas, and work together to determine which aspects of the ideas are more or less helpful. By connecting the current problem to a previous experience, learners were able to draw on that previous experience to better make sense of the current one.

As these previous experiences became objects of thought to reflect upon, the facilitator made cognitive and emotional processes behind domain practices more visible and accessible to the learners. These past experiences also served as grounded examples of desired domain practices that could be referred to in future sessions. However, the facilitator had to remember to continually remind students of related experiences, often asking those who had been in the club longer to tell new students about previous events.

## Conclusion

The types of cognitive and socio-emotional expertise associated with HCI design education (i.e. collaborative skills, the ability to communicate ideas to a broad audience, give and receive feedback, empathize with others, regulate emotions and behavior, etc.) are important for design, but also essential for academic performance and life-long success (Domitrovich, Durlak, Staley, & Weissberg, 2017; Elias & Haynes, 2008; Wentzel & Watkins, 2002; Zins, Bloodworth, Weissberg, & Walberg, 2007). These forms of expertise are becoming increasingly necessary for technology development, and for thriving in society more generally, but are often missing in adults (Fiore, Graesser, & Greiff, 2018; Norman, 2004; World Economic Forum, 2016). We need to find ways to develop these types of expertise as part of engaging educational programs. Formal educational contexts are bound by a series of constraints that pose obstacles to change (Collins & Halverson, 2018), which is why we focus on developing them in informal, playful after-school contexts.

Embedded design builds on the theory and shows promise in helping young learners develop essential skills. However, more studies are needed to unpack the various forms of expertise that learners develop and how different forms of expertise develop over time. These types of studies will likely require longitudinal design-based approaches that examine the impacts of different features of embedded design practices on a variety of social, cognitive, and metacognitive learning outcomes. The types of expertise we aim to develop, like collaborative problem-solving, are not easy to measure or support because most people are not able to pay attention to complex processes like collaboration or collective sense-making as they happen (Cooke, Salas, Cannon-Bowers, & Stout, 2000). This is why self-reports of learning or perceived performance are often inaccurate (Dunning, Heath, & Suls, 2004; Kruger & Dunning, 1999). In order to see what learners are actually able to do rather than what they perceive themselves to be doing, we need to evaluate these processes in action.

Such an approach to the design and evaluation of learning contexts will not be easy to accomplish. Developing reliable ways to track changes in these processes will require that we track changes in patterns of communication and interaction between novice designers over time. To do so, we will need to unpack desired HCI processes into observable patterns of communication. We would then need to operationalize these patterns into concrete rubrics that learners and teachers can use to diagnose problems and monitor improvement.

Operationalizing these types of complex processes poses challenges to researchers, because such processes are often discussed abstractly and not easily assessed. Even processes with long histories of research, such as collaboration, are conceptualized in different ways by different researchers, though they use similar terminologies (Suthers, Lund, Rosé, & Teplovs, 2013). Nonetheless, our previous research on designing technology to help students develop collaborative expertise illustrates that it is possible to develop simple tools to support the development of complex ways of thinking (Borge, Ong Shiou, & Rosé, 2018; Borge & Shimoda, 2019).

When Collins et al. (1991) first proposed cognitive apprenticeship, they clarified that this approach was not intended for all forms of learning. Simple forms of learning would be better served by less complex approaches, but they argued that complex learning processes require complex instructional solutions. They were not proposing a simple instructional method, but rather promoting a paradigm shift in how we teach, one that recognized the importance of developing life-long thinking processes and focused on designing learning environments to adequately support them. Our society is demanding increasingly complex learning processes from future generations of students. To meet this demand, we need to develop more complex forms of instructional support.

Embedded design is an approach to teaching and learning that builds on cognitive apprenticeship. Like cognitive apprenticeship, it is not easy to learn, practice, nor evaluate. The graduate students that work as facilitators in our club, spend years, in an apprenticeship manner, learning how to take on the role of lead facilitators. Nonetheless, if we want to help a broader range of students succeed in computing education fields and develop ways of thinking that promote HCI design, we must go beyond teaching technical knowledge and skills. We must allow learners to experience HCI design practices for themselves so that they can improve their own thinking processes and see themselves as designers of their own experiences. And we must find new ways to help the next generation of teachers develop the types of knowledge and skills necessary to carry out these complex forms of instruction. In this way, we can ensure that K-12 computing education succeeds in creating authentic human-centered design experiences that not only broaden participation but also help develop the next generation of thoughtful problem-solvers and innovators.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

## Notes on contributor

***Dr. Marcela Borge*** is an assistant professor in the Learning, Design, and Technology program in the College of Education at the Pennsylvania State University. Her research interests are at the intersection of collaborative learning, cognition, and design. She examines computer supported collaborative learning processes across the lifespan. Her current research focuses on unpacking collaborative sense-making processes in technologically enhanced educational contexts in order to understand how groups learn, what problems they face, and how to design tools and interventions to enhance collective thinking processes. One of her current projects examines how children ages 8–12 collaborate on human-centered design projects in play-based contexts and how technology impacts social learning processes. Another project examines the utility of an online tool designed to help undergraduate students learn how to collectively monitor and regulate collaborative sense-making processes.

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