Design Considerations for Capturing Computational Thinking Practices in High School Students' Electronic Textile Portfolios

Debora Lui, University of Pennsylvania, deblui@upenn.edu
Gayithri Jayathirtha, University of Pennsylvania, gayithri@gse.upenn.edu,
Deborah A. Fields, Utah State University, deborah.fields@usu.edu
Mia Shaw, University of Pennsylvania, mshaw12@gse.upenn.edu
Yasmin Kafai, University of Pennsylvania, kafai@upenn.edu

Abstract: Assessing computational thinking in making has proven a challenge, in part because student creations are innately diverse and unique. In this paper we consider portfolios as a way to document and assess students' learning processes in the context of designing electronic textile (e-textile) projects. We describe students' use of portfolios at the end of an introductory computing course, Exploring Computer Science, during which 33 students created a series of electronic textile (e-textile) projects as part of a new curricular unit. Our analysis not only illuminates the capability of portfolios to capture computational practices and certain concepts, but also reveals students' lack of effective use of non-textual evidence in their narrations. We consider the affordances and limitations of portfolios for supporting student reflection and metacognition of their own learning as well improvements that could be made to scaffold students' communication and use of visual evidence in more effective ways.

Introduction

Assessing student learning in computationally-rich maker activities has been a challenge for practitioners and researchers alike. While early discussion about educational making assumed the creation of an artifact could demonstrate the acquisition of skills, content and even a 'maker mindset' (Honey & Kanter, 2013; Dougherty, 2013), continued spread of these activities into formal educational settings has made researchers interested in not only asking what students learn, but also how to appropriately assess learning (e.g., Papavlasopoulou, Giannakos, & Jaccheri, 2017). Recent efforts in this arena include the development of traditional evaluative tools such as written tests or surveys (e.g., Litts, Kafai, Lui, Walker & Widman, 2017; Chu et al., 2015) and more novel approaches such as hands-on engineering performance tasks and eye tracking (e.g. Davis, Schneider & Blikstein, 2017). However, these assessments do not capture the *process* of making or the kinds of learning that students gain while working through mistakes, errors, and changes in their project. For this we turn to portfolios.

Portfolios have long been used as an assessment tool in disciplines such as art, design, writing and more recently in STEM fields (Chang et al., 2015; Býrgýn & Adnan, 2007). Not only can portfolios provide more holistic measures of learning, capturing process and growth over time (Paulson, Paulson & Meyer, 1991), they can also be situated within students' everyday work and context (Býrgýn & Adnan, 2007). Within computer science education portfolios have recently gained more traction through the newly launched Advanced Placement Computer Science Principles (AP CSP) course (College Board, 2017), where they have supplemented the standard multiple-choice exam. Beyond assessment, however, portfolios can be powerful learning tools in and of themselves, allowing students to reflect upon their own experiences and regulate their own pathways of learning—in other words, develop metacognition skills, something that can support more equitable learning (Darling-Hammond, 2008). However, though portfolios are acknowledged as a powerful channel for both assessment and reflection within a wide range of established disciplines, less is known about how well they are able to capture and support student learning of *computational thinking,* or skills involved in "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (Wing, 2006, p. 33), such as abstractions, iterations, and algorithms.

In this paper, we report on a study focused on the design and implementation of a portfolio assignment that aims to capture students' computational thinking. We worked with a high school computer science instructor teaching electronic textiles where students sew and program sewable microcontrollers, actuators, and sensors attached to fabric based artifacts such as clothing and toys (Buechley, Eisenberg, Catchen, & Crockett, 2008). Based on previous research looking at the effectiveness of teacher-designed portfolios in capturing students' processes of working with electronic textiles (Lui, et al., under review), we designed a portfolio assignment that was given to (and adapted by) the high school teacher for the purpose of capturing his students' learning, practices and reflections. Students were provided prompts regarding content and media use, with a specific focus on capturing students' computational thinking *practices* (Brennan & Resnick, 2012) including revision and iteration as well as debugging and troubleshooting, and *concepts* including coding, circuitry, design, and crafting (Kafai, Fields, & Searle, 2014). Analyzing the text, images and videos of the students' portfolios, we addressed two research questions: (1) How did this portfolio implementation support students in documenting and sharing their processes of making a computational artifact? (2) What are the affordances of the portfolios for revealing students' computational thinking and concepts learned? In our discussion, we address affordances and challenges of using portfolios and report on recommendations which include more defined scaffolds, as well as models of effective computational communication. We also discuss avenues for future research in these areas.

Background

Though portfolios have been used across many disciplines and fields for assessment, their actual formats and contents vary widely, providing different models for measuring and supporting computational thinking. In art and design, the predominant form promotes the curation of one's best projects over time, allowing a 'showcase' of overall competency and skill (Býrgýn & Adnan, 2007). STEM portfolios tend to follow another format derived from writing (Williams, 2002), which focuses more on continuous documentation of students' learning and growth (Paulson et al., 1991), sometimes through progression of just a *single* project (Chang et al., 2015). These 'process-folios' often focus on collection of different kinds of in-progress evidence compiled over a student's trajectory. This includes a range of often non-textual forms such as initial prototype ideas for engineering projects (Eris, 2007), code throughout the development process (Higgs & Sabin, 2005), or photos of projects in process (Chang et al., 2015). Rather than merely presenting their artifacts, students provide textual explanations for this evidence, whether explanatory captions and annotations (Býrgýn & Adnan, 2007), articulation of underlying concepts (Phelps, LaPorte and Mahood, 1997), or narrations of growth and learning (Paulson et al., 1991). For this reason, these types of portfolios highlight the actual aspects of creation and reasoning around production that are normally hidden when only relying on final products as a form of assessment (Chang et al., 2015).

Little is known about how well portfolios are able to capture novice students' computational thinking through the creation of an artifact, digital or not. As highlighted by Brennan and Resnick (2012), opportunities for youth to describe their experiences while creating computational artifacts can provide a window into their understanding of their computational thinking skills, something that can encompass knowledge of particular concepts, practices, and perspectives. Much of this depends on students' communicative abilities, a skill that is not often stressed in the context of computer science, let alone other STEM fields (Michael, 2000; Williams, 2002). In CS education, this is not just a factor of knowing the "vocabulary of computing" (Grover, Cooper & Pea, 2014), but also being able to use these terms in context, something that has been proven to foster "deeper computational learning" and nurture students' abilities to think about "computational ideas more effectively" (p. 58). This lack of emphasis on communication in computational contexts seems especially problematic, considering that it has recently been highlighted as a key computational practice within the AP CSP (College Board, 2017). There, it is described as a student's ability to report on one's own computational choices and justifications, well as describe the results or behaviors of computational artifacts (p. 10). Notably, the way that students are expected to accomplish this includes leveraging "accurate and precise language, notations, or visualizations" (p. 10)— in other words, focusing on both text *and* images. However, as noted by Williams (2002), expecting that students can effectively communicate about technical issues without assistance is not practical; not only does this require more careful scaffolding, but also actually defining what 'counts' as effective communication within this realm and explicitly sharing this with students.

The difficulty of using portfolios to promote student communication about computation was highlighted within a previous study (Lui et al., under review), where we also analyzed the use of a teacher-designed portfolio assignment for assessing computational thinking. There, students created portfolios to reflect their process of making an electronic-textile sign. The format of that portfolio was based primarily on the four established domains of e-textiles work: *design*—the planning of the aesthetics of a project, *circuitry*—the creation of electrical connections between components, *coding*—the programming of students' projects, and *crafting*—the physical sewing and construction of the project. Students were asked to describe their experiences within each of these domains, with recommendations to discuss challenges and include non-textual evidence such as photographs, diagrams, and code excerpts. While this portfolio format was successful at capturing the general nature of students' processes and practices in making their artifacts, it was not as successful in capturing the actual details of these experiences or the students' understanding of underlying computational concepts, whether in coding or circuitry. Furthermore, students' use of images and code as evidence varied greatly; most students primarily used them as a part of their aesthetics, offering little explanation or contextualization. Based on these findings as well as research on how process-folios can be structured, we designed a portfolio assignment to address these potential weaknesses in capturing students' computational thinking. This included an initial focus on computational practices rather than concepts and requiring the use of non-textual process evidence such as photos and diagrams. Our goals were to look at how well the portfolios were able to capture students' experiences and reflections for the purposes of student learning as well as assessment.

Methods

Context and participants

The Exploring Computer Science (ECS) initiative comprises a one-year introductory high school computing curriculum with a two-year professional development sequence (Margolis & Goode, 2016) to increase diversity. We co-developed an e-textiles curricular unit (Fields, Kafai, Nakajima & Goode, 2017) that takes place over eight weeks and consists of a series of four projects, with the final project incorporating a handmade human sensor created from two aluminum foil conductive patches that when squeezed generate a range of data.

In this study we focus on one high school teacher's implementation of portfolios in the e-textiles unit during Spring 2017. An experienced ECS teacher and leader, Ben taught at an independent charter high school located in the suburbs of a large metropolitan city on the U.S. West Coast. He had many years of experience teaching ECS and one prior year of teaching the e-textile unit in his class. His class included 35 students, 16 girls and 19 boys, mostly from 9th grade (14-15 years old) as students were encouraged to take ECS in their first year of high school. The school enrolls about 4,600 students: 4% African American, 18% Asian, 10% Filipino, 40% Hispanic or Latino, 25% White, 1% two or more races, and 2% race not reported. Fifty-four percent of the students come from socioeconomically disadvantaged families.

Design of portfolio assignment

The portfolio assignment was designed to capture students' descriptions of their final projects and discussions of their process, through the use of both textual (written) and non-textual (photos, diagrams, code) evidence. Refining the format of the assignment to accommodate his needs, Ben provided a Google Slides template for students, which included the following prompts: 1) Describe their final human sensor project (in a video or using pictures and text, one slide); 2) Discuss their process for making the human sensor project, including their initial design and any revisions made, and at least one challenge that they dealt with (in written form, two slides), (see Figure 1 for example) and 3) Reflect on their experience and identity as a computer scientist across the entire e-textiles unit (in written form, one slide).

For both of the written sections, students were required to provide non-textual evidence for their learning whether drawings of their designs, circuit diagrams, code snippets, or excerpts and photos from their engineering design notebooks and journals. Some of these journal prompts included questions about their design processes such as "What were some modifications you had to make in your design?" and occasionally the teacher would prompt students to take a picture of their projects so that they could track changes. Students only had a few days at the end of the unit to work on their portfolios, partly by design (because of the need to limit the unit to a certain number of weeks in line with the other ECS units) and partly by necessity (because it was the end of the school year and priority was placed on finishing projects). During these days in Ben's class, most students chose to focus their time on putting finishing touches on their human sensor projects and therefore, worked on their portfolios at home. This means that we have little observational data to draw on regarding how students put their portfolios together.

Data collection and analysis

At the end of the class, we collected the digital portfolios from 33 students (two students did not turn in portfolios), which consisted of a combination of text, photos, and videos embedded in Google Slide presentations. Data from the broader study included weekly observations of classes documented in field notes, short interviews with six students (including a brief question on their thoughts about the portfolios), and pre/post interviews with the teacher (also including some reflection on the portfolios). The portfolios themselves were the focus of analysis, though we also triangulated some of the findings with the teacher post-interview. Across the portfolios, we analyzed the two written sections of the portfolios, which included: *discussion of process* and *reflections on learning*.

Within each of these sections we analyzed: 1) <u>Computational practices</u>**—**The process-related activities referenced, whether *revising their projects*—making changes to their design based on interest or requirements, or *dealing with challenges*—diagnosing and solving problems. These draw from existing research on computational practices that identify being incremental and iterative, and debugging and testing as key activities when creating computational artifacts (Brennan & Resnick, 2012). We also looked for if students referenced additional practices (e.g., planning their projects, remixing); 2) Computational concepts—The e-textiles domains referenced (e.g., design, circuitry, coding, crafting), and level of detail included, such as allusions to related *sub-concepts* (e.g., polarity, conditionals, mechanics of sewing). Given the interdisciplinary nature of e-textiles, multiple concepts often emerged in the sections; 3) Language—The level of detail and specificity included in their narration. We looked to see if students provided 'full explanations,' which meant discussions of *both* their problems and solutions for challenges, their before and after-state for revisions, or their justifications for their learning and reflections; and 4) Non-textual supporting evidence—What forms of evidence were provided (e.g., drawings, diagrams, code, other), as well as how effectively it was presented as part of their argument (i.e., without any explanation at all; referred to in text/prose; included extra annotation or a captions). After analyzing these portfolios, identified trends within students' communication of their process and reflections on their learning. We not only highlight *what* they said about these topics (e.g., concepts addressed), but also *how* these areas were communicated through the different media forms and language styles.

Findings

Revisions, challenges, and reflections in student portfolios

Overall, the portfolio assignment was successful in getting students to document and share aspects of how they created their projects and some of the difficulties that arose as they created them. However, students completed the portfolios with a high degree of variance, both in meeting the requirements for each section that Ben required and in the quality of the descriptions and evidence they shared. One major area of difference we found related to revisions (changes made from the initial design of the project) and challenges (an issue that came up in making the project). Though both were required with dedicated slides assigned in the template, 85% of the students included challenges in their portfolios, while only 45% of students wrote about revisions (36% completed both parts).

There are several possibilities for why students completed the challenges section more than the revisions section. First, the prompt for revisions asked students to think about their initial design and how it changed. This required thinking back to the beginning of the project of what would normally be a 2-3 week period. However, this was extended even farther for these students because of the two weeks of paternity leave that Ben took, something that likely further hindered their memory. Second, students might not have been diligent in recording changes or taking pictures of early stages of the project, which would have allowed them to think about how their project had changed from beginning to end. In his post-interview, Ben commented that, while he encouraged students to document progress, students' records were very disorganized with "papers all over the place like a fifth grader's exploded backpack." One proposed change he made for the future was to "be a little bit more conscious of referring to the design notebook, that when you make [design] changes [to] make the changes in your notebook." Ben's reflection as a teacher that students needed to keep track of and document changes therefore highlights the potential reason for the lackluster record of revisions in the portfolios. Finally, the assigned journal questions that students answered during the project and Ben's discussion on the portfolio assignment featured challenges, bugs, and fixes far more than ideas about revisions. Thus, the curriculum and teaching likely emphasized working through challenges and mistakes more than thinking about revisions independent of those issues.

Along with discussing challenges and revisions, portfolios provided opportunities for students to reflect on their learning, not only in the human sensor project but also in the overall electronic textiles unit. A mandatory part of the portfolio, all 33 students reflected on their learning in this overarching way and in doing so mentioned at least two of the four domains on average. In their reflections, 38% explicitly mentioned acquiring debugging and testing skills through the experience of making e-textiles projects. Additionally, 30% of students believed that planning was a practice they developed, while 18% even mentioned some soft skills such as "being patient," or "not … procrastinat[ing]" which helped them with the process of making the e-textiles projects. These types of comments suggest that the portfolios were a place where students could reflect metacognitively about their learning across the many weeks of the e-textiles unit.

Content and detail (or lack thereof) in student portfolios

Across each of the areas where students reflected on their processes of making and learning, there was a predominant lack of detail in student reporting. Only 46% of challenges, 35% of revisions, and 27% of reflections provided detailed explanations about with explicit references to specific areas of design, craft, circuitry, or code. As an example, compare the slides on the left and right in Figure 1. On the left, Leon wrote vaguely that having a plan was important as was working through mistakes, but without explaining what any of the specific mistakes were or why a plan would have been helpful. In contrast, Aditya's slide on the right provides a very clear explanation an error that arose in coding. He had mislabeled one of the variables naming his pins and this resulted in abnormal readings from the sensor (since he named the same pin, #9, both as an LED—an output, and as the sensor—an input). These types of details were lacking in many students' portfolios overall, making it difficult to understand in what areas students struggled and learned.

Figure 1. Leon's portfolio page (left) and one of Aditya's portfolio pages (right) on the human sensor project.

In addition to the general lack of specificity in students' portfolios, differences appeared within conceptual *domains* in terms of how specific students were in their descriptions. Most discussions around crafting (83%) and circuitry (84%) explicated specific areas that needed fixing or revising. For example, Alejandra's description of challenges in making her stuffed cookie pillow project provided relatively detailed reports of where she had issues in circuitry and designing:

> …[W]hen 2 of my LEDs were not lighting up. I was really confused on what was wrong, but then I noticed that conductive thread from both a positive and negative were touched when I put the ends of my project together and that was what was wrong. To fix this problem when sewing my project shut, I put some stuffing between those two ends so they wouldn't touch. (Alejandra, portfolio)

Here, she explained a circuitry design issue that was complicated by the circuitry going across the front and back of her cookie pillow. When the pillow was closed together, those two sides touched in the middle, creating a short circuit. Adding stuffing separated the two sides and resolved the issue. More often than not, students were relatively specific about issues related to design, craft, and circuitry.

In contrast to design, circuitry, and crafting, only half of the mentions of coding (54%) provided detail. For example, Vivian described her challenge with coding in only one sentence: "Earlier into the project i had difficulties on coding [sic] and understanding the light sensors." Her explanation makes it impossible to deduce what specifically she struggled to understand, though we might expect it to relate to sensors through conditionals or mathematical expressions. Other students were even more vague, saying things like "I know that coding is pretty fun" (Amy) or "In the begginign [sic] I had no idea what to call a LED, but know I can code my own code that can feel pressure" (Kevin). In contrast to these more generic statements, the descriptions of students like Aditya (above, see Figure 1) and Lien stand out. Lien explained some complex coding issues that came up in her handbag creation:

> [T]rying to get the computer to read information from both the light sensor and the human sensors like in the code on the slide caused to computer to not be able to read either of them. I decided to use the switches on the playground to use for coding more light patterns instead…Despite both sets are fine [sic], the computer could not read and work the code made up of both sets. (Lien, portfolio)

Here Lien described problems with her ambitious effort to use readings from two sensors. Though she knew how to independently code each sensor and link it with lighting patterns, "Trying to mix two sets of working code together does not automatically make a working set of new code" (Lien, Portfolio). The contrast between Vivian's and Lien's descriptions of their coding issues shows the importance of using specific language to clarify a challenge faced or a revision made. Overall, this difference in use of detailed language within the different domains highlights the need to consider not only what prompts students are given within portfolios, but also how to support students to more effectively communicate technical details through specific language.

Students' use of non-textual supporting evidence

The portfolio also allowed students to employ non-textual evidence in form of photos, diagrams, and sketches to support their narratives about their process and their reflections. As seen in the examples previously (see Figures 1, 3), portfolios were helpful in eliciting a range of non-textual information about the process of making these artifacts. Out of the 33 portfolios, 25 students provided some form of evidence. Of these students, most used pictures (48%) or diagrams (45%) of their projects (see Figure 1, left), while much fewer (33%) included excerpts of code (see Figure 1, right). Interestingly, although a majority of students referred to coding as the most challenging domain, code emerged as the least prevalent artifact used as evidence throughout the portfolios. The lack of coding evidence furthers the points mentioned above about students needing support in explicating their coding problems and learning.

Further, across all types of non-textual evidence, many students provided no explanation, annotations, or references within the text while discussing their challenges (62%), revisions (45%) or reflections (62%). Only a few made direct reference to this non-textual evidence within their text (e.g., "in the picture below...," "the diagram illustrates…"), and even fewer included relevant visual annotations or notations (e.g., arrows, labels, color-coding). As an example consider Leon's portfolio page (Figure 1, left) where he included two pictures of his project. There were no arrows or explanations as to what these pictures showed, or how they related to his statements that he learned the importance of planning or working through mistakes. Aditya's use of evidence (Figure 1, right) is comparatively better in that he uses and labels two examples of code so that viewers know which came first. A viewer with experience in Arduino could match his writing with the examples to identify the issue (i.e., labeling both variables "led1" and "aluminumfoil" as pin 9), though additional annotation such as arrows pointing to the problematic line (top line of the upper code image) would make that more clear. The predominant lack of explanation and annotation amongst students suggests that more effective scaffolds, examples, and modelling may be needed to help them utilize non-textual evidence effectively.

Discussion

This study is part of a larger effort to test the feasibility of and develop appropriate formats for the use of portfolios (or process-folios) for measuring and supporting students' computational thinking within the ECS e-textile unit. We observed different affordances and challenges in the portfolio design in getting students to document and share their processes, as well as assessing their computational thinking. These, along with recommendations for improving the utility of the portfolio as both a learning and assessment tool, are further described below.

Portfolios as tools to support student learning

In contrast to performance-based testing, the portfolios that Ben implemented provided opportunities for students to articulate their design processes (design, crafting, circuitry or coding) and reflections and support them with evidence. They were successful at getting students to document, share, and reflect upon their overall experience and learning trajectory. Most students provided at least some documentation (and others quite rich explication) of their learning in ways that demonstrated some metacognitive awareness (Darling-Hammond, 2008). Students would often conclude with mentions of being proud of their project or their growth, an important aspect of identity and motivation in learning with implication for their future trajectories in the field (e.g., Pinkard et al, 2007). Further, the simple act of documenting their project along the way and choosing which pieces of evidence to include is inherently a form of reflection since it requires students to conceptualize and produce a narrative of learning and process (Paulson, Paulson & Meyer, 1991). The types of portfolios used in this curriculum clearly had some potential benefits for students' learning and reflection in CS.

However, there was great variance in the quality and quantity of descriptions. Some students moved past the initial requirements and mentioned several challenges and learning gains, describing their learning in great depth, while others stayed at very low levels of description. Yet most students neglected to describe the revisions they made within their project, something that is surprising considering that Ben specifically asked students to address changes made to their initial designs within his slide template. In addition, many students' descriptions lacked details that allowed readers to fully understand the problems they dealt with and failed to explain what they actually learned outside of generic statements about improvements in sewing and especially coding and design. In other words, even though all students did provide narrations of their process, these were often opaque because of the lack of detailed language and included inefficient use of non-textual evidence. Clearly we need to equip students better so that they can articular their learning more effectively.

Portfolios as tools to assess computational thinking

While the teacher did scaffold the portfolio process in several ways—through journal questions, reminders to take photographs of projects, and the template for the portfolio—we need to explore additional scaffolds to assist students in improving their computational communication skills. One potential change is to focus on what Grover, Cooper and Pea (2014) call the "vocabulary of computing," which moves beyond word choice toward giving students actual communicative tools through which to articulate and concretize abstract computational knowledge. This is particularly needed since, as noted earlier, students mentioned coding often as a challenge, yet were unable to describe their issues in precise ways. In practice, an emphasis on the vocabulary of computing would involve being more explicit about developing shared classroom discourse around computational thinking. By giving students access to this language, teachers would not only have more opportunities to assess what is actually occurring, but also help increase student understanding of these concepts and practices. Another possible change would involve collecting and sharing exemplars of good computational communication with students. Following Williams (2002), teachers cannot just expect that students become effective communicators if this has not been defined for them beforehand.

In future implementations of the curriculum we will provide different models of portfolios, recommend that teachers discuss these with students early in the process, and study whether this helps students develop better communicative competence about their computational learning. There is also an opportunity to use whole class peer critique sessions, already used in the design of the e-textiles projects in the unit, on the portfolios. We also hope to explore with teachers like Ben how to better integrate active reflection and documentation throughout the e-textiles unit (not just in the final project) in an effort to support communication as a computational practice that is fully integrated into the curriculum, rather than something engaged at distinct timepoints apart from the process. However, time is a very explicit limitation on all of these efforts. There is no room to expand the units in light of the other material that must be covered as a part of the ECS curriculum. How can we balance the importance of creating these projects with the benefits of reflecting on the process of creation?

Portfolios and computational communication beyond classrooms

Portfolios are becoming more significant options within STEM disciplines for academic and professional assessment. Not only are they being used for college admissions and the AP CSP course, but also for career advancement (Chang et al., 2015). Introducing students to portfolios within the ECS classroom gives them opportunities to practice this new format of explaining STEM knowledge and skills in addition to the personal learning awareness they offer. Further, portfolios can also be used within personal contexts. Recognizing the potential short lives of student-made artifacts, portfolios can serve as a vehicle to keep the learning and making experience alive when a fully functional artifact may long be gone. Finally, portfolios can also serve a social purpose, enabling students to connect to the larger maker culture that exists beyond classroom. Sharing has been promoted as key tenet of the Maker Movement (Dougherty, 2013), wherein makers of all backgrounds and ages share their projects and expertise with others in various formats. Research indicates that learning to become a maker is as much about creating artifacts as it is about learning to participate in communities (Pinkard et al., 2017). Thus, students' engagement with the practice of computational communication can promote participation at-large, following the idea that computation is an essentially social practice (Kafai & Burke, 2014). For all these reasons, more research is needed to explore the affordances of different types of portfolios in supporting and assessing computational thinking, classroom supports for encouraging deeper reflection and communication, and students' own perceptions about the benefits of creating these personalized narratives around their learning and process.

Endnotes

(1) All participant names are pseudonyms to protect confidentiality.

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