Tools with Histories: Exploring NFC-Tagging to Support Hybrid Documentation Practices and Knowledge Discovery in Makerspaces

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Abstract. We present the design research process towards a novel learning technology to improve instructional documentation in makerspaces. Our focus is on the ways in which smart tools can better support learning practices, with a particular emphasis on role of documentation plays. We first describe a co-design process with educational stakeholder that generated concepts for NFC-enabled forms of hybrid documentation. This solution developed offers a process for coupling physical tools, parts and materials to online resources in order to help make documentation ready-at-hand for learners. Findings from a subsequent focus group led to a refined implementation. Our preliminary evaluation in a high school settings highlighted the value of integrating online documentation formats to support youth navigating a broad array of fabrication tools and parts. Educators valued the solutions ability to support self-directed learning and to increase student access and agency with instructional resources.

Keywords: Makerspace · Education · Learning technology · NFC · Smart tools

1 Introduction and Background

Much work has explored the role of documentation in making learners' thinking visible [3, 5, 24] and revealing process and accomplishments [3, 29]. By externalizing and sharing concepts and craft [26], documentation prepared by others also plays a significant role in learning [7, 22], particularly in maker-based contexts; as evidenced by the popularity of digital guides like Instructables and Hackster.

Makerspaces contain a wide array of tools, materials and components visible and ready-to-use for learners [17]. While the tools are ready-at-hand, the knowledge and practices needed to use them is not. This is particularly challenging for novices who need to successfully navigate many choices to identify appropriate tools for their projects [11, 13]. Each tool often requires safety, training and imposes a large number of practical, logistical and instructional overheads on facilities and staff [4]. Recent studies have noted the many complexities present for learner and practitioner alike: the

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tools in makerspaces require much training and guidance; they are often not suited to youth learners without training and guidance; they require alignment with instructional methods and outcomes to be successful; and they require learners to successfully and regularly transition from physical work spaces to virtual spaces to manage documentation and knowledge discovery [21, 23].

In this paper, we address these challenge and present a mechanism for distributing knowledge into the makerspace: to more closely integrate tools, components and physical assets with supportive digital instructional resources. Recognizing the same problem, Knibble et al. [13] created an augmented workbench to overlay contextually-relevant instructional guides and augment project-work in makerspaces. Schoop et al. [25] similarly proposed a mixed physical-digital environment to build confidence with tools and technical skills. These two approaches highlight how technology augmentation can positively enhance the practices within a makerspace. Both examples, however, employing expensive and technically intensive strategies that are unlikely to be replicable or affordable for most makerspaces. We instead use NFC technology to offer a low-cost, scalable solution.

We outline the design research process behind this solution. We first describe a multisite co-design process to generate concepts for technology-enhanced making. This process is used to closely with educators and identify technology-driven concepts that aligns with the cultures, values and practices of educational stakeholders. We discuss how this process was leveraged to synthesize and identify solution for hybrid documentation - the coupling of a physical object to online digital content like a blog-post, portfolio or Instructable. We describe the system prepared, its operation and how it offers a low cost, scalable alternative to existing and emerging approaches. Finally, this system is evaluated both through an early stage focus group with two experts and through a preliminary evaluation with seven participants at a high school makerspace. In so doing, we illustrate an effective approach to introducing NFC technology within educational contexts and additionally demonstrate the value and applicability of NFC in creative and technical documentation to support learning within a makerspace.

2 Design Research and Concept Development

In this section, we describe our design process for documentation in educational makerspaces.

2.1 Co-design Workshops

We emphasize a design research and participatory approach in how we examine new technology supports for maker- and project-based learning. In so doing, we seek to include educational stakeholders in identifying and responding to instructional practices, learning goals and outcomes, and cultures of documentation valued in their spaces. To do this, we developed a series of co-design workshops to solicit concepts and possible design enactments. This four-hour workshop was conducted with stakeholders at across three contexts which emphasize maker based learning: an undergraduate degree program (four participants), a high school (eleven participants) and a youth summer program (six participants). The curricula at all three sites was organized around hands-on project-based learning and the instructors all explicitly included documentation activities within their instructional practice. Participants included instructors, program coordinators and staff. Initial activities in the workshop encouraged educators to develop a shared understanding of documentation, how it benefits their curricular programming and the pain-points encountered when facilitating documentation in educational settings. Pain points were actively discussed and prioritized as they related to each program. This elicitation of challenges was central to supporting generative design activities later. The workshop then transitioned to introduce technologies and emerging approaches that could be used to scaffold documentation practices. After which, the remainder of the workshop was dedicated to a series of participatory design activities. These encouraged educators to speculate on the ways in which technology (e.g. cameras and timelapse/video capture, live-scribe pens, smart home products, etc.) could be deployed to augment existing or foster new documentation practices in their classroom. In this, we encouraged participants to consider technologies that are situated in learning activities and routines, would improve documentation skills and outcomes, would be valued by educators and learners and would address the pain points and challenges identified by the group. At the end of the activity, participants reported out on their concepts and as a group prioritized concepts for supporting learning in technology enhanced makerspaces (Fig. 1).

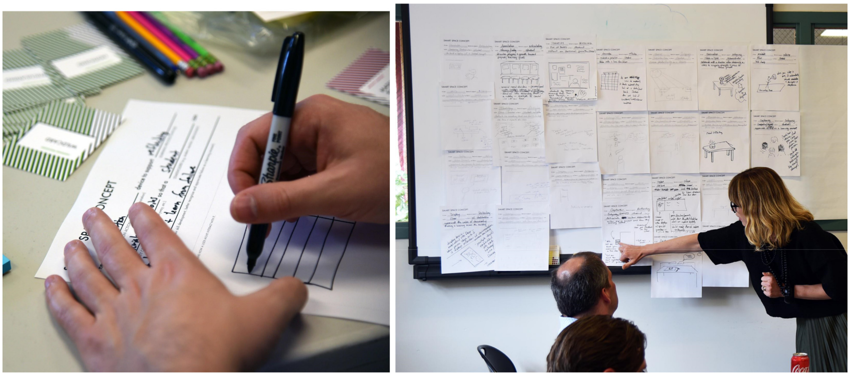

Fig. 1. Participants brainstorm, discuss and prioritize concepts.

Across all sites, participants converged on a cluster of related concepts that identified the need to trace the history of interactions, and to support peer-to-peer learning and knowledge discovery with the objects, tools and parts that are typically found in a makerspace. Several related concepts suggested that tracking patterns of use would encourage students to explore new materials and tools. Another set of concepts valued augmenting tools with digital instructional guides through spoken audio or projection; while others considered how the tools themselves could gather feedback and reflections from students while in use.

For example, at the high school, participants prioritized three concepts relating to material and tool usage, and ways in which the tools and materials themselves could enable students to learn how to use them effectively by their documenting past interactions with (other) learners. A concept from one participant imagined an augmented parts bin where "[a]s a user comes to materials, [the device] tracks materials they look at and take/put back. Students then "get a list of considered/used/returned materials" to help them develop a bill of materials, identify relevant online tutorials and guides, and to support the creative exploration of parts as they apply to assigned project work. A second, and similar, concept saw a design of a materials or parts bin that would help students to "understand the purpose of complex parts and their effectiveness". It would do this by allowing a student to place materials or parts in front of a camera, and then it would begin "displaying text and describing use of parts and materials through video and images". This notional concept also included the idea that students could add to these descriptions based on how they had used the tool, giving richer resources to the next student to use the same material or part. In the same vein, the third use case, imagined a storage area or cubby that would actively track tool use and encourage a student to "articulate how they used tools to support their learning". During use or on returning a tool to the storage area, this solution might prompt them with messages like "How did you use this tool today?" to verbally record their experience with a tool, encourage reflection on skills and project development and provide knowledge resources to other students. These tools were organized and described by the group as *"tools with histories."* They are illustrated in Fig. 2.

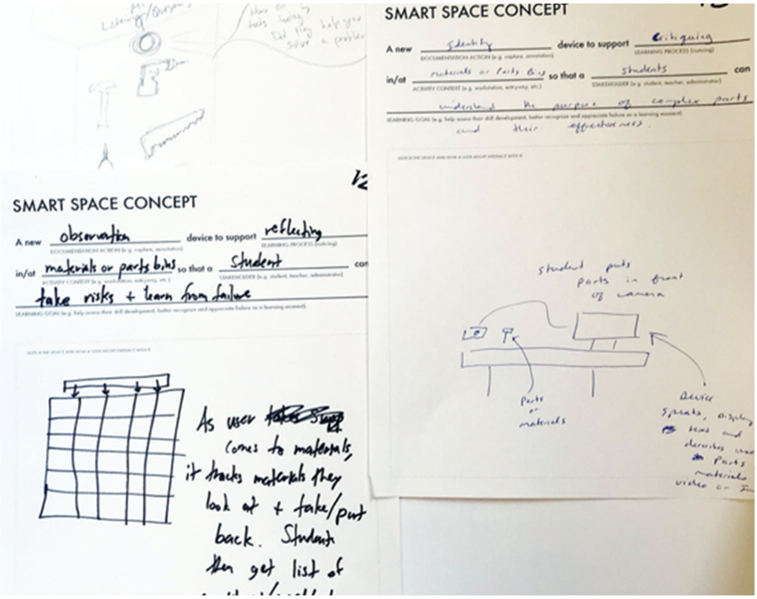

Fig. 2. Concepts for 'Tools with Histories' generated by participants.

2.2 Concept Development and Iterative Prototyping

Concepts were analyzed and key features elicited by participants drawn out. This was synthesized and conceptualized into an underlying solution for enabling hybrid documentation – the coupling of a physical object to online digital content like a blog-post, portfolio or instructable, brief surveys and reflective prompts. At the core of the concept was the need to enable proximity-based interactions with a wide variety of tools, materials and components that were of an array of shapes, sizes, arrangements, etc. Additional constraints on scalability, deployment and use were set: namely it must create the least amount of effort to infrastructure a space for a resource bound educator, it must be a broadly accessible solution to students with the least amount of overhead to adopt/participate with the solution, and it must provide agency to educators and students alike in developing knowledge resources.

These requirements guided our survey of ubiquitous proximity-based technologies for a suitable solution including include printed markers (barcodes and QR codes), RFID/NFC, BLE or indoor localization strategies, and computer vision techniques; all of which could be used in our approach. Computer vision (object detection and recognition) has been used in identifying parts in electronics [12] and tools within spaces, however it requires extensive visual examplars to be collected for training purposes making it impractical as a broadly scalable solution. Furthermore and as Gong et al. [9] note: "While these computer vision based methods are powerful, we deliberately excluded cameras in this work since the spaces that fabrication can take place in can be large, transitory and dynamic, the issue of occlusion can cause loss of information from camera streams." As an alternative, Bluetooth LE beacons could be applied to tools, but they are more costly than other solutions (e.g. QR codes, RFID/NFC), require power and are generally more bulky making them impractical to apply to varied surfaces and small components. Indoor localization strategies could be used to detect where a learner is in the makerspace and operating in tandem with a virtual model of the space could allow a learner to be presented with relevant (augmented) information. As parts, tools and materials are regularly moved in active makerspaces and not reliably returned to designated locations, this was also deemed impractical. In addition, both BLE and indoor localization would require the development and installation of a custom mobile application(s), adding overhead to deployment and immediate use by students. This left printed markers and NFC technologies as candidate technologies. Both were low-cost, and scalable mechanisms that had seen recent integration into modern smartphones (QR codes can be automatically detected in camera applications [30] while background tag reading for NFC is included in latest Android and Apple models [1]), removing the need for installed applications. QR codes offers a more adopted and ubiquitous technology, and one that shows past success in educational settings [8, 19]. In assessing the technology two issues were presented: readability issues could present [28], especially for small tools, or tools with irregular surfaces and while it would provide a visual signal to augmented content, it would also require extensive relabeling in established educational makerspaces – such makerspaces typically are well labeled, especially parts bins, componentry and storage. Relabeling to accommodate the inclusion of a QR code would be a resource intensive effort. While, NFC is less widely used in educational makerspaces, its potential has been suggested as an avenue for future exploration [16]. Making it an interesting technology to study further in this context. It has, however, has been extensively used in industry (e.g. payments, logistics, healthcare) [2, 14, 15, 18, 27], is proven reliable and recent iterations of smartphones have incorporated background NFC-tag scanning capabilities making it more broadly accessible [1]. In addition, as a flexible sticker, it can be widely applied to a variety of surfaces and can be placed on or behind existing labeling.

As such we identified and adopted NFC tags as a low-cost, easy-to-use and scalable mechanism to enable hybrid documentation. Thus, and by using NFC, in our scenario a learner would tap their phone on a soldering iron, for example, to reveal step-by-step guides curated by their instructor, prompts on past students experiences with the device and the opportunity for students to contribute and evolve the documentation. This would make learning guides ready-at-hand and contextually relevant to a student's activities.

2.3 Focus Group and Concept Validation

An initial prototype of a NFC-device was prepared. Two representatives from the co-design workshops were invited to take part in a short, 2-h focus group. This was intended to validate the conceptual design, assess relevance to their makerspaces and solicit further requirements and needs. The participants included one lead for a physical computing educationally-focused makerspace and a program coordinator for a youth summer program that focused on making and entrepreneurship. During the focus group, the prototype was introduced and the two participants were asked to consider scenarios and uses cases, share feedback on the initial implementation, discuss refinements necessary and consider its relevance and applicability at their sites.

During the session, participants immediately drew comparisons to QR codes but P2 noted "my experience has been that they've been kind of a little bit cumbersome for users in that they depending on the angle and the lighting and like how close you get and the camera resolution, it can be a little bit difficult" and "one of the things that I like about NFC is that with the latest of phones that they're passively scanning for NFC, that it's in the background and it's really easy to tap and get it." They also noted the drawbacks of QR codes: "I don't have to open the camera app." "I don't have to then tell it what to do when it gets a URL" and "it's like a four step process."

Both participants noted potential accessibility issues with an NFC based solution. They stressed it was "absolutely essential for some kind of other way of accessing [the resources]" as "we want to have everyone to be able to use" any solution deployed at their site. Participants suggested "having [another dedicated] device that's local, that we're not dependent on people's individual phones". Similarly they noted providing an additional device would allow students who did not have access to a smartphone to still benefit from the platform and gain access to its content easily. They recommended a tablet with NFC capabilities would be ideal as "[t]here's something nice about a tablet size for scrolling through."

The educators also voiced concern at the level of effort it might take to completely outfit an existing makerspace. They offered suggestions as to how the system might practically manage and minimize this effort: "bulk labeling could be super interesting" and linking with or supporting import from existing inventory spreadsheets or database software was seen as advantageous. Both recommendations were later incorporated into the platform.

Both participants saw immediate opportunities for any analytics of student interaction with NFC-tags as being beneficial. These comments centered on the potential of usage data to help instructors monitor and better support student progression through analytics of documentation (and material/part) use: “It would be an easy way at a glance to see if they needed help or resources in a certain area.” P2 illustrated this further: “if I could see students as they scan one thing, and I knew what their next steps would be and they stopped or they started over or they got the wrong thing next…I could easily touch base with them and say, Oh, you seem like you’re stuck on this one part or you’re continually revisiting this.” It was also noted that these analytics would be equally valuable to the learners themselves: “they’re creating their own interactive history of learning.”

Reflecting on this further, P2 remarked “I like the idea of the history, but I also like the idea *of them* creating the history (P2).” Both participants noted analytics would beneficial but fostering an active community that contributed to the continued development of associated tool documentation would be much more advantageous; they also suggested the system should become “a commons for technical components.” P1 noted that the system currently repeated the existing model: “[w]hat I have to do now is either point students towards a resources that I wrote… or I point them to another tutorial I found on the internet that I think is a good tutorial.” However, P1 preferred if the system could give more agency to the students in building knowledge resources: “I want a user editable page, for every single thing in our inventory, which is akin to a Wikipedia page” as it would be “great to be able to say here’s a resource developed mainly in part by faculty and teachers of the space, and maybe in part by other students who’s project used this part… and other student can build on it.

The participants concluded the session by considering additional ways this system could be deployed in their space beyond documentation. Tags could be added “in each cubby where students leave their work behind having a link to their process work”, as a way of “the door having a feedback survey, that they can scan on the way out, on what they learned that day”, and suggested it should allow “these tags to connect to any other network device in the space”, for example “we can have a tag that sends a signal to the printer and it prints a recipe for parts and everything that they should go through.”

To recap, we validated the “tools with history” concept with two educational stakeholders in a short focus group. They emphasized the needs for: supporting alternative means of accessing the documentation linked to a NFC tag; providing dedicated NFC-enabled devices in the classroom to allow students without access to a smartphone to participate with the platform; revealing analytics to enable learners to trace their tool use and development, in tandem with providing visibility of their learning experience so that instructors can better support them; to enable wiki-like editing of the documentation to give voice and agency to students in supporting their peers and in decentralizing the process of documentation development; and finally, enable tag activations to trigger actions with networked devices and resources. These requirements informed the development of a refined version of the platform described next.

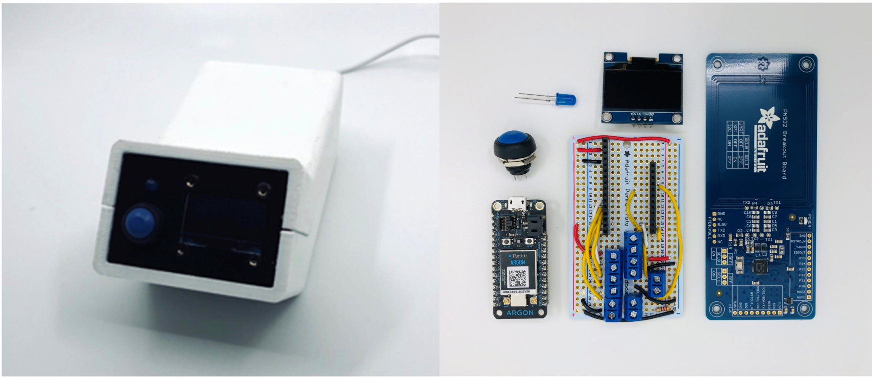

Fig. 3. *Left:* final prototype of NFC tag writer for hybrid documentation. *Right*: depiction of components used.

3 Implementation and System Description

The underlying framework for hybrid documentation comprises a custom NFC-writer device and a cloud platform. The NFC writer is a key component of the infrastructure (see Fig. 3); as it is used to write information to an NFC tag before it is applied to a tool, component or asset within the space. It is designed to be replicable with hardware and components commonly available in makerspaces. It contains a wifi-connected microcontroller, a PN532 NFC board, an OLED screen, a pushbutton, a LED and a 3D printed enclosure.

Figure 4 depicts the relationship of the NFC-writer to the larger framework. The NFC-tag writer is responsible for encoding a URL to each NFC tag. When a new tag is placed on the tag writer, it will be detected and prompt the user to set it up. During the setup process, the device connects with our middleware, which generates a unique URL per tag; comprised of middleware's domain and a tag specific shortcode. Thus, each time the tag is scanned, it first visits our server and is then redirected to the resource, allowing analytics to be gathered.

Once configured, the tag can be scanned with a recent model smartphone. The first time the tag is scanned, it will prompt the user to specify how it is mapped to documentation. Each tag can be set to either redirect to a web resource (e.g. an instructable or guide), or to a wiki-like webpage that can be collaboratively edited by the learning community. This process is illustrated in Fig. 5.

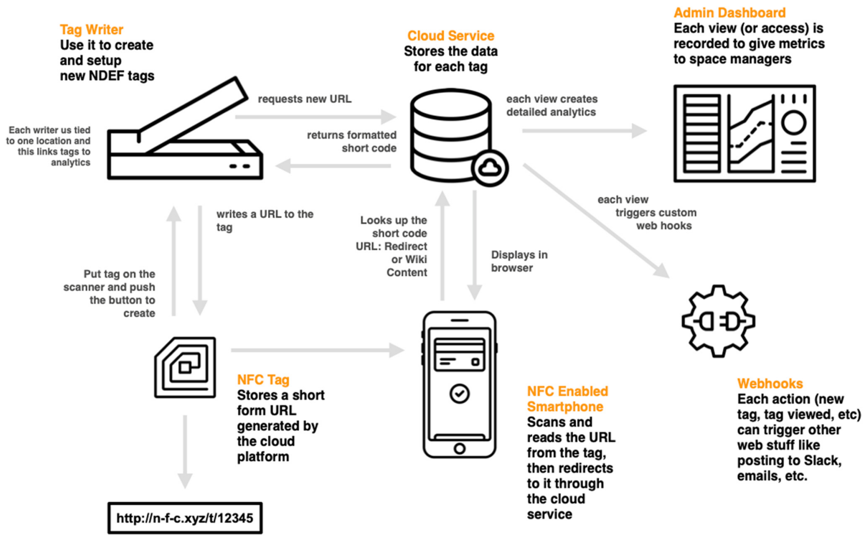

Fig. 4. An overview of the hybrid documentation framework.

The server provides a full featured web application for makerspace managers and authorized users. The user interface provides a dashboard to view analytics, manage tags, and connect webhooks. Webhooks are triggered when a tag is scanned, modified or setup.

Modern smartphones passively scan for NFC tags, so once the phone is proximal to a NFC tag it will immediately load the associated URL. Thereby making documentation ready-at-hand and convenient to access.

This approach is flexible, allowing multiple forms of documentation to be associated with a variety of tools and components. For example, a soldering iron might be linked to an Instructable to guide novices on its use and through a webhook activate its outlet connected with a smart socket. Similarly, and as suggested by focus group participants, storage areas or student project work might be linked to their online portfolio or process blog, while a component bin could be linked to a wiki that distributes the work to the community of describing how to use the resource in their projects and example use cases.

The novelty of this approach is threefold. Firstly, it provides a low-cost, easy-to-adopt, scalable framework that can be overlaid in existing makerspaces without requiring significant technical knowledge, redesign of labeling, signage or componentry’s organization. Secondly, this solution offers an integrated platform to support learning in an educational makerspace. While RFID/NFC is already widely used in makerspaces for access control, here, it deployed to solves two common key challenges for learners in makerspaces: identifying and distributing instruction in-situ and ready-at-hand while providing agency to the learning community to continually gather and evolve learning resources through collaborative editing. Thirdly, and by gathering analytics of the documentation accessed by learners, it provides educators and instructors increased visibility on what knowledge resources are being frequently accessed and how this changes over the course of a semester. This can enable them to direct effort to digital documentation and make curricular moves to better support novices.

There are some limitations to this approach. Most notably, it is reliant on smartphones that support NFC technology, and this may limit the number of students who can adopt and interact with such an approach. As noted previously, this can be overcome by providing a dedicated NFC-enabled tablet or smartphone for students without access to a NFC-enabled device to access the content conveniently. In addition, the documentation resources can be accessed via a web frontpage for the makerspaces to provide another accessible mode of access.

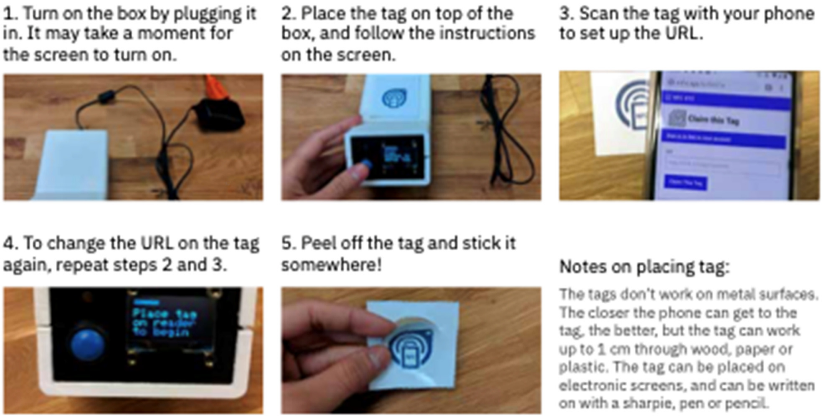

Fig. 5. A step-by-step guide to set-up of a NFC-tag with the custom tag reader

4 Evaluation

As a formative evaluation of the hybrid documentation framework, we conducted a two-hour workshop at a high school with five educators and two administrators. The high school, and participants, had previously taken part in the previously described co-design workshop. As such, all participants were familiar with the concepts generated from this work and valued documentation in supporting student learning. The workshop was held in the school's makerspace, a large dedicated room situated in the school's library.

Table 1. A summary of concepts generated by the educators.

Physical item	Digital content	Learning goal or purpose
Wire stripper	Tool information and demo- how is it used and named; Pictures and video of students using the tool	Help familiarize students with tools and skill development
Computer project kit	Dis/assembly guide through rich media (text and video)	Set stage for students to understand what's inside the box and how to use the components
Soldering area	Tutorial on soldering, safety video, tools associated with soldering	Use of equipment; safe use of equipment
Roland mill	Tutorial on how the tool is used, a safety tutorial, student work produced on the tool	To help student to know how to use a piece of equipment
VR googles	Video introducing VR equipment and how to use google earth; guidance on setting it up for use in the classroom	Introduce students to the concepts of VR equipment for a project
Past project (Game Console)	Video of student work; reflections on construction; highlights video	Provide reflections on the creation of a product; highlights student contributions

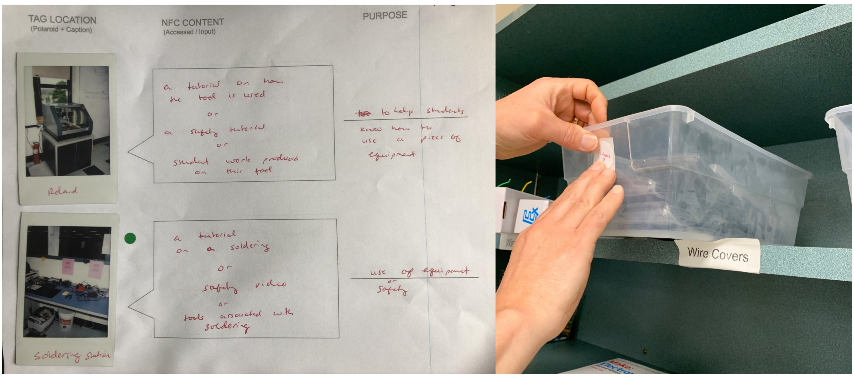

Fig. 6. *Left*: NFC tag brainstorming. *Right*: Instructors deploying tags in the makerspace

4.1 Procedure

The workshop began by reviewing the co-design process outcomes and discussing the 'tools with histories' concepts generated. The hybrid documentation framework was then introduced and demonstrated using a series of staged artifacts including linking a multimeter to a tutorial on its use and a clipboard linked to an online collaboratively editable to-do list.

After introducing the system, participants toured the makerspace using Polaroid photo elicitation activity to help identify scenarios that could be supported by the system [4]. As part of this process, individuals were asked to capture a polaroid photo of an object, tool, part, material or area in the space that could be augmented with NFC-enabled documentation. Using the worksheet (see Fig. 6), they recorded what content they would like to associate with it and the educational goal or purpose that it would serve. This exercise lasted 15 min, after which participants gathered to share out their use-cases. A total of unique 14 objects and areas were marked-up. This included an interactive white board and digital signage, equipment (green screen, thermal printer, Roland mill, 3D printer), tools (wire stripper, 3D Pen), storage bins and areas (soldering station, entry way), a project kit (a computer to be disassembled/reassembled) as well as one past student project (a gaming console). While more creative applications were covered (attendance tracking, gathering documentation), these initial scenarios emphasized providing introductory content to "introduce students to makerspace and equipment" and increase their recognition of the type and use of tools. They favored being able to help students name specific tools, increase understanding of tool affordances, encouraging safe tool and equipment use, providing curated introductory guides, and revealing procedures and setup processes for proper use. A subset of participant-generated scenarios is provided in Table 1. Working with the educators, they were then invited to use the framework to enact these scenarios within the makerspace, as illustrated in Fig. 6. This was followed by open-ended discussion with the stakeholders. The discussion was audio recorded, transcribed and synthesized. Findings are next described.

4.2 Discussion and Findings

Flexibility: Participants appreciated the system's potential to increase familiarity and contextual know-how with tools without instructor support, remarking that this approach to instructional resources is about "making it more accessible. It's more direct." They also valued its adaptability to a variety of uses including administering surveys, linking portfolios, and gathering documentation. Of most importance to the participants was the fact that it builds on, rather than replacing, existing digital content at their disposal. This school uses Google products (Drive and Sites to gather project documentation) so it would be convenient for both educators and students to work with: "Google drive is something that we're comfortable using", "we could write step-by-step guides for some of these scenarios…using Google drive", "probably that would [link to] a separate webpage of the student would build." By linking to online resources, they felt it could easily integrate with existing digital platforms in the school and layer on instructional practices already used in their curricula. This could save time and effort in deploying the system.

Effort and Coordination: However, educators shared that they did not have enough suitable content to begin building the use cases they envisioned. One teacher noted "I'd love to do [this] but I don't have the student reflections. I don't have the videos and that content created yet." Another agreed but noted "the real goal is getting the students to get content in there." Stakeholders further discussed that getting students to cooperatively prepare documentation and resources for the makerspace would be helpful but would need to be situated within a curricular process to be most effective. Coupling a class project with developing documentation for tools and part, would be most beneficial to students as "its a really nice use beyond just content or information… but if we're looking for students create content. By the end of this term, [a student] will have created two tutorials. The creating of the tutorial is kind of a bonus. Somebody else gets to learn from viewing the tutorial, but…there's a lot of evidence of learning in the process of creating the tutorial." As such, the suggestion was to have students document outcomes that contribute to the situated knowledge of the makerspace; this would allow the effort in developing resources to be shared, and mutually benefit student by creating shared resources for others in the space, while being a vehicle to evidence their own learning on projects.

Issues Surfaced: In considering a curricular framework where students cooperatively develop content, educators raised concern over broad access to edit the linked content. Instructors wanted greater oversight over content to avoid digital vandalism or misuse. Additionally, the group was cautious about the analytics, not wanting to be "too heavy handed with tracking" as that could have "raised other kinds of concerns about how the data is being used and that kind of thing" for students. Finally, they suggested the need to "develop some sort of visual convention, like a sticker, an icon or something. So that students start to recognize this as an NFC tag." This led to a discussion comparing the approach to QR codes, which have a more prominent visual signifier.

Knowledge Discovery and Credibility: During this comparison of the two approaches, one participant raised the question "why shouldn't they [the students] just Google?" to find the resources they need. This led to a productive conversation. One participant responded: "You can Google anything and we don't really want to test kids on things that they can Google. So if they can Google how to use this tool, why should we not just make it accessible for them?" Another noted that by making the content available in-situ and "on demand, that changes instructionally what can happen and what you can do because [the teacher]'s gained back that time" from formally introducing each tool in class. Discussion also noted that by curating recommended resources, "[t]he teacher is directing to where you're going. So it's a credible source. It's what you've selected as the training" It was noted that students who are newer to projects involving tools and technology, often don't know how independently identify suitable sources of knowledge for their project work. This solution overcomes those challenges.

Value in Learning: Throughout the discussion, the educators noted several opportunities to create value in their educational experiences, specifically in personalizing the experience, supporting reflection and inquiry, in leaving knowledge behind for others and in helping to gather multiple forms of evidence of learning.

First, this framework, the analytics gathered and the ability for students to contribute knowledge resources to the makerspace were all seen as new and interesting mechanisms to evidence student learning: by accessing the guidance and by tracking activity students are indirectly "documenting their ability to be able to use the tool." In offering ways for students to contribute to the documentation too, this could be more actively demonstrated. Discussing the soldering station, one educator remarked ”I would love to have students literally sit here and take a 30-second video of the evidence” that they have practiced soldering and add it to the associated tag’s documentation. In so doing, it was seen as a way for students to “start to learn how to articulate what they know and learn”

Second, in making details about tools, components and materials accessible in-situ and in the context of hands-on project work, it would “have a role in helping [students] reflect on what’s possible for their projects” This was seen to be of benefit not only to increase familiarity with tools but to allow students to reflect on the forms of inquiry that the tools support.

Third, it was seen as an opportunity to enhance personalized learning and self-directed discovery within their makerspace: “the tools themselves, they provide training and guidance” and by virtue of this it would “be personalized to the students as well”; they can find the knowledge they need to work with a tool in the context of the activity. This was further elaborated: “some of the time that you spend in class explaining [tools] such as a hammer. This now becomes on demand learning…It’s almost like the flipped classroom concept where you give them the basics ahead of time for them to view, or when they need to know how to do it.” Educators noted that this is creates a means for students “to *own their learning*. And that helps them… It’s not an easy shift but that’s a very valuable and a meaningful shift”

Summary of Findings: The workshop yielded the following findings. The advantage of the hybrid documentation approach is to make existing guides, tutorials and resources more accessible and physically colocated with the tools, materials and parts they relate to. Educators noted that this has the additional advantages of being able to work within existing educational technology and platforms and the content they house. Educators recognized that by curating digital content within this framework, they were both reducing the friction for novice makers to identify knowledge and resources but also explicitly guiding students to credible, educator-validated resources. Finally, educators noted the approach to create multiple educational values, and importantly, the potential to increase student agency for self directed learning in a makerspace and to gather new forms of evidence of learning. These preliminary findings will be the subject of future investigation and validation.

5 Future Work

We have discussed NFC-enabled tags as a low-cost strategy for improving learning and present a framework to guide rapidly augmenting maker-based educational contexts. Initial evaluations demonstrated this approach as an accessible, ready-at-hand solution. There remains much further work to conduct to improve and validate this approach with students. An immediate next step for this project will be to conduct a longitudinal analysis where the tool is deployed in educational makerspace and coordinated with a curriculum over a full semester experience.

In addition, we plan to platform's support for hybrid documentation. Specifically, we plan to improve the features for knowledge discovery and organization. As the platform intends to provide agency to learners in iterating and gathering documentation relevant to their needs, we intend to explore user-centered mechanisms to incentivize peer-to-peer, collaborative documentation authoring and maintenance.

6 Conclusion

With growing interest in the maker movement and project-based learning in education, there has been much recent research on this space. This has largely coordinated around studying educational benefits, fostering documentation and portfolio practices, and identifying technological augmentations the tools offered to support novice learners and skilled work. In this work, we bridge all three areas. Towards this, we describe a co-design process with educators involved in maker- and project-based settings. This process identifies high value technological concepts to enhance education and support educator's learning goals. Outcomes were synthesized into concept for hybrid documentation and delivered a prototype that leverages NFC technology in educational makerspaces. This solution provides a low-cost, scalable alternative to recent research in augmented tools and spaces for making. We conducted a preliminary evaluation with educators to demonstrate the value of adapting NFC to educational contexts, as well as, the applicability of NFC in maker- and project-based learning documentation.

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References

1. Apple. What's New in Core NFC (2018). https://developer.apple.com/videos/play/tech-talks/702/. Accessed 10 Mar 2019
2. Benyo, B., Vilmos, A., Kovacs, K., Kutor, L.: NFC applications and business model of the ecosystem. In: 2007 16th IST Mobile and Wireless Communications Summit, pp. 1–5. IEEE, July 2007
3. Brown, J.O.: Know thyself: the impact of portfolio development on adult learning. Adult Educ. Q. **52**(3), 228–245 (2002)
4. Byrne, D., et al.: MakeSchools higher education alliance state of making report (2015). http://makeschools.org/week_of_making/report. Accessed Jun 2015
5. Chang, S., Keune, A., Peppler, K., Maltese, A., McKay, C., Regalla, L.: Open portfolio project, phase 1: research brief series (2015). http://makered.org/opp/publications/
6. Collins, A., Brown, J.S., Holum, A.: Cognitive apprenticeship: making thinking visible. Am. Educ. **15**(3), 6–11 (1991)
7. Cross, N.: Designerly Ways of Knowing. Birkhäuser, Basel (2007)

8. Durak, G., Özkeskin, E., Ataizi, M.: QR codes in education and communication. Turk. Online J. Distance Educ. **17**, 42–58 (2016)
9. Gong, J., Anderson, F., Fitzmaurice, G., Grossman, T.: Instrumenting and analyzing fabrication activities, users, and expertise. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, pp. 1–14, May 2019
10. Hall, L., Jones, S., Hall, M., Richardson, J., Hodgson, J.: Inspiring design: the use of photo elicitation and Lomography in gaining the child's perspective. In: Proceedings of the 21st British HCI Group Annual Conference on People and Computers: HCI… but not as we know it, vol. 1, pp. 227–236. British Computer Society, September 2007
11. Hira, A., Joslyn, C.H., Hynes, M.M.: Classroom makerspaces: identifying the opportunities and challenges. In: 2014 IEEE Frontiers in Education Conference (FIE) Proceedings, pp. 1–5. IEEE, October 2014
12. Huang, R., Gu, J., Sun, X., Hou, Y., Uddin, S.: A rapid recognition method for electronic components based on the improved YOLO-V3 network. Electronics **8**(8), 825 (2019)
13. Knibbe, J., Grossman, T., Fitzmaurice, G.: Smart makerspace: an immersive instructional space for physical tasks. In: Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces, pp. 83–92, November 2015
14. Islam, S.R., Kwak, D., Kabir, M.H., Hossain, M., Kwak, K.S.: The internet of things for health care: a comprehensive survey. IEEE Access **3**, 678–708 (2015)
15. Lazaro, A., Villarino, R., Girbau, D.: A survey of NFC sensors based on energy harvesting for IoT applications. Sensors **18**(11), 3746 (2018)
16. Lensing, K., Schwuchow, B., Oehlandt, S., Haertel, T.: How Makerspaces help to participate in technology: results of a survey to gain data about learners' activities in makerspaces. In: 2018 World Engineering Education Forum-Global Engineering Deans Council (WEEF-GEDC), pp. 1–5. IEEE, November 2018
17. Litts, B.K.: Resources, facilitation, and partnerships: three design considerations for youth makerspaces. In: Proceedings of the 14th International Conference on Interaction Design and Children, pp. 347–350, June 2015
18. Madakam, S., Lake, V., Lake, V., Lake, V.: Internet of Things (IoT): a literature review. J. Comput. Commun. **3**(05), 164 (2015)
19. Massis, B.E.: QR codes in the library. New Libr. World **112**(9/10), 466–469 (2011). https://doi.org/10.1108/03074801111182058
20. McHugh, S., Yarmey, K.: Near Field Communication: Recent Developments and Library Implications. Morgan & Claypool Publishers, San Rafael (2014)
21. Peppler, K., Maltese, A., Keune, A., Chang, S., Regalla, L.: The maker ed open portfolio project: survey of makerspaces, part II. In: Open Portfolios: Maker Education Initiative Research Brief Series, pp. 47–53 (2015)
22. Peppler, K., Keune, P.: "It helps create and enhance a community": Youth motivations for making portfolios. Mind Cult. Act. **26**(3), 234–248 (2019). https://doi.org/10.1080/10749039.2019.1647546
23. Open portfolios maker education initiative. Research Brief Series (2015). http://makered.org/opp/research-briefs/
24. Ritchhart, R., Perkins, D.: Making thinking visible. Educ. Leadersh. **65**(5), 57–61 (2008)
25. Schoop, E., Nguyen, M., Lim, D., Savage, V., Follmer, S., Hartmann, B.: Drill sergeant: supporting physical construction projects through an ecosystem of augmented tools. In: Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, pp. 1607–1614. ACM, May 2016
26. Schön, D.A.: The Design Studio: An Exploration of its Traditions and Potentials. RIBA Publications Limited, London (1985)

27. Shobha, N.S.S., Aruna, K.S.P., Bhagyashree, M.D.P., Sarita, K.S.J.: NFC and NFC payments: a review. In: 2016 International Conference on ICT in Business Industry & Government (ICTBIG), pp. 1–7. IEEE, November 2016
28. Tarjan, L., Šenk, I., Tegeltija, S., Stankovski, S., Ostojic, G.: A readability analysis for QR code application in a traceability system. Comput. Electron. Agric. **109**, 1–11 (2014)
29. Tseng, T., Yang, M., Ruthmann, S.: Documentation in progress: challenges with representing design process online. In: ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, pp. V003T04A027–V003T04A027. American Society of Mechanical Engineers, August 2014
30. Wired. The Curious Comeback of the Dreaded QR Code (2017). https://www.wired.com/story/the-curious-comeback-of-the-dreaded-qr-code/. Accessed 18th June 2020