The Reflective Make-AR In-Action: Using Augmented Reality for Reflection-based Learning of Makerskills

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Dishita Turakhia
MIT CSAIL
Cambridge, USA

Peiling Jiang
University of California San Diego
La Jolla, USA

Stefanie Mueller
MIT CSAIL
Cambridge, USA

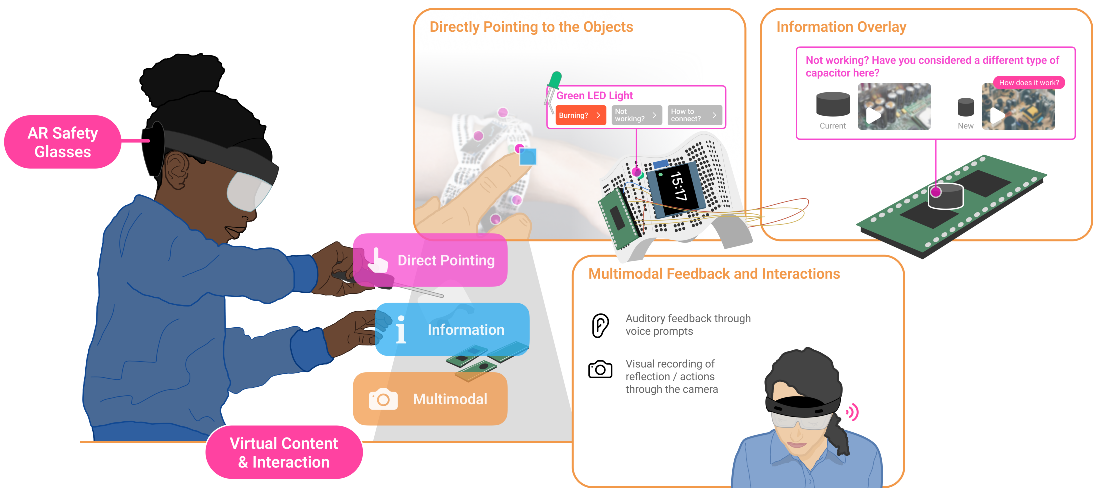

Figure 1: To support learners of makerskills with reflection exercises during their activities, we propose using augmented reality (AR). In this work, we propose a framework to design reflective exercises in AR, and illustrate a system to use an AR head-mounted device (HMD) to monitor, prompt, and record reflections while the maker activity is in progress, and use AR affordances to directly point at the real-world objects for contextualization, overlay information related to the maker activities, and provide multimodal feedback to the learners for self-reflection exercises.

ABSTRACT

Recent work on reflective learning supports self-paced learning of skills like breadboarding and using power tools in makerspaces through a reflection exercise toolkit. This toolkit monitors the learners' performances in real-time and prompts them to reflect both in-action and on-action i.e., during and after their maker activities. In this paper, we build on this prior work and use an augmented reality system to monitor, prompt, and record *in-action reflections*, i.e., while the maker activity is in progress. In particular, we propose a framework to design multi-modal reflective prompts for self-learning exercises using augmented reality with three specific goals - (1) adding real-world contextualization, (2) overlaying personalized multimodal contextual information for supporting *in-action reflections*, and (3) maintaining an immersive experience during the reflection exercises. We conclude with a discussion of three application case studies for reflective AR maker exercises.

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CCS CONCEPTS

• **Human-centered Computing → User interface toolkits**.

KEYWORDS

reflective learning, augmented reality, makerskills, makerspaces

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1 INTRODUCTION

Reflection is described as *"a conscious, purposeful thought directed at a problem"* with the goal to gain a deeper understanding of the problem [8]. A reflective exercise typically consists of sequential thoughts aimed at problem inquiry [5] and is often elicited through self-dialogue, social discourse (for example, with an instructor), or human-computer interaction (for example, with a system). The impact of the reflective exercises is generally an increase in knowledge, improvement in performance, or reduction of errors.

The role of reflective exercises in skill-learning is studied widely [5, 26] with applications in learning music [11], and professional development [22], and recently in learning makerskills [31]. Reflection is critical in learning makerskills, like breadboarding, using power tools, and digital fabrication, and has several benefits. Reflection allows learners to identify and correct errors in their work, critically analyze their outputs, identify areas for improvement, and thus, produce higher-quality work. A reflective exercise involves learners intentionally recapturing their experience of making, evaluating it, and identifying correct and incorrect aspects of the performance. For example, learners reflecting on their maker activities may realize that they misaligned a piece of equipment, or used the wrong type of material. Alternatively, they may realize that they need to improve their soldering technique or learn more about a particular type of material. Furthermore, by reflecting on their work, learners can identify the underlying principles that govern the fabrication processes. For example, they may realize that they need to develop a better understanding of the properties of different materials or the principles of soldering. Reflecting on performance and identifying areas for improvement can also help learners become more self-aware and to take more responsibility for their learning. Finally, reflection-based learning can also develop communication and critical thinking skills, as learners explain their thought processes and findings to others.

In recent work, researchers have developed a toolkit to design reflective exercises for maker skills learning, prompt the learners to reflect in multimodal ways, and record their reflections[31]. The reflection exercises prompted the learners to reflect-in-action, i.e., during the maker activities, and reflect-on-action, i.e., after completing the maker activities. The toolkit also consisted of embedded fabrication tools to sense the learner's performance and a multimodal interface to prompt the learners through text and voice. However, the on-screen prompts had limitations that they missed the real-world contextualization and diverted the learners' attention from their task.

We address this limitation through this work by using Augmented Reality (AR) for reflective exercises during maker activities. Augmented reality (AR) can enhance learning makerskills by allowing them to reflect on their work in a more contextual, immersive, and multimodal interactive way. AR can provide learners with real-world context for reflection as they work on fabrication projects by overlaying digital information onto the physical world. For example, instead of simply asking the learners to reflect on their errors, AR overlay can provide a real-world context to identify any errors or inconsistencies in the design, and thus provide a contextual and nuanced reflective exercise. Similarly, virtual simulations of fabrication processes and materials, such as soldering or 3D printing, and reflecting on virtual-in-action before learners perform real-world actions can increase efficacy and confidence among learners. This way of learning can help learners grasp the principles of maker activities, the interconnectedness between different aspects of making, and develop their problem-solving skills.

In this work, we build on the prior research and use augmented reality to monitor, prompt, and record reflections in real-time during the maker activities. We propose a framework to design multi-modal reflective prompts for self-learning exercises using augmented reality with three specific goals - (1) adding real-world contextualization, (2) overlaying personalized multimodal contextual information for supporting reflection, and (3) maintaining an immersive experience during reflection exercises. We present an end-to-end pipeline to design the reflection prompts using Optitrack to sense the performance and an AR app built using Unity3D and deployed on the HoloLens head-mounted AR device. We demonstrate three cases of reflective exercises in art and design, engineering, and remote learning applications. We then detail our plans for future work on evaluating the impact of our AR-based reflection approach on learning makerskills through three user studies.

Contributions: In this work-in-progress project, we contribute:

- A strategy to leverage the use of Augmented Reality (AR) for reflection-based learning of maker skills.
- A framework to design reflective exercises in AR for adding real-world contextualization, overlaying personalized multimodal contextual information, and maintaining an immersive experience during reflection exercises.

2 RELATED WORK

This work builds upon existing research in HCI on reflective learning, systems for reflection, systems to support skill learning in makerspaces, and AR-based skill-learning.

2.1 Background on Reflection

Fleck et al. define reflection as "a conscious, purposeful thought directed at a problem" [8]. Baumer et al. build on this idea and define reflection as "a process in which people recapture their experience, think about it, and evaluate it" [2]. Schon characterizes the reflective process as a form of conversation that occurs either in-action, i.e. during an activity, and on-action, i.e., after completing the activity [26]. Such reflective exercises, consisting of sequential thoughts and prompts [5], can be engaged in through dialogue in multiple ways: a dialogue with self, with another person (for example, an instructor or a friend), or with a human-computer-interaction system.

2.2 Reflection-based Skill-learning

To leverage the potential of reflection in educational and skill-learning applications, particularly to improve knowledge and performance, researchers have developed various technologies and systems in HCI [1, 21]. For example, Johnston et al. proposed a system for amplifying reflective thinking in musical performance [12]. Similarly, Nakakoji et al. use the two-dimensional positioning of objects as a means for reflection in the early phases of a design task [23]. Similar systems for leveraging reflection for learning skills include critical computing [27], critical design [28, 29], and brainstorming ideas in creative workflows. *Prolog-Tutor* presented a framework and a system to facilitate implicit reflection for open learner modeling for problem-solving [38]. Researchers have also used reflection to facilitate learning physical prototyping through integrated design, test, and analysis [10]. However, research on applying the approach of reflective learning for learning fabrication and makerskills remains limited.

2.3 Learning of Makerskills

To support novices with skill learning in makerspaces and to lower the entry barrier for maker skills like breadboarding, prototyping, and tool usage, researchers have developed several systems. For example, ToastBoard [6] helps with the correct placement of components by visualizing connectivity between components and also shows the voltage at each point in the circuit. HeyTeddy [14] helps with circuit wiring by providing voice assistance to the user and also requests the user to confirm that they finished a certain step. Similarly, CircuitStack [35], and VirtualWire [18] support users with wiring or re-configuring circuit wiring. Recently, the concept of smart makerspaces has also been proposed by researchers where the learners are provided with guidance during their maker tasks [16]. Similarly FabO toolkit support designing game-based activities for learning fabrication skills while playing video games [30, 32, 33]. Recently, the *ReflectiveMaker* toolkit has demonstrated the approach of reflective learning to support the design of reflection exercises within makerspaces [31, 34]. Our work contributes to this research by exploring the approach of using reflection in augmented reality (AR) to support learning several maker skills.

2.4 AR for Skill-learning

Several HCI systems have utilized augmented reality (AR) applications for educational purposes and researched its opportunities and challenges in skill-learning [3, 9, 13, 36]. For example, Radu et al. highlight the positive effects of introducing AR in the classroom, including increased content understanding, memory retention, and motivation, and improved peer collaboration [24]. They also mention some drawbacks given the current technology, such as attention tunneling and limited usability.

Prior work has also leveraged AR affordances for learning through information visualization [15], for remote instruction, and for collaboration [20, 37]. For example, SensorViz provides different visualization types for sensor specifications and data to support prototyping at different stages in the makerspace [15]. Radu et al. facilitate physics learning by visually overlaying invisible physics phenomena and attributes, like magnetic fields around coils and magnets, and their interaction potentials, onto the physical objects as the instructor demonstrates [25]. When learning happens remotely, Virtual Makerspaces introduces ways to instruct for maker projects and communication for collaborations through real-time augmented visualizations. Maddali et al. investigate the potential to use AR to instruct for skilled hobby activities by prototyping and evaluating a system that supports learning gardening [20]. To support designers with authoring instructions in AR, Kong et al. developed *TutorialLens*, a system for authoring interactive AR tutorials through narration and demonstration [17]. Similarly, *ExposAR* is an AR authoring tools for designing collaborative AR tutorials and expanding the design space of AR educational tools [19].

While these systems support learning through augmented instruction and visualization, learners' in-action and in-context reflective activities were largely ignored. Ezzaouia et al's review on existing AR authoring tools indicated that there is no systematic analysis of these emerging tools regarding what AR features and modalities they offer and how they explore the design space of AR authoring tools [7]. In our work, we build on the work on reflective learning and explore the design of AR-based reflection activities.

3 THE REFLECTIVE MAKE-AR IN-ACTION

In this section, we describe our framework and the design space of our approach. We scope our work to reflection-in-action [4] reflection exercises because we posit that AR affordances can particularly impact learning *during* maker activities.

3.1 Framework

We propose a framework to explore and scope the design space of AR-based reflection-in-action exercises for maker activities in a structured way (Figure 2). In this framework, we list the aspects of designing reflective exercises across three dimensions: the learning goals, the reflection strategies, and the AR affordances. This framework and the mapping of the dimensions provide a structured way of designing the reflection-in-action exercises illustrated above.

Learning goals: The first axis in our framework is the learning goals. Makerspaces are learning environments where individuals can come together to create, collaborate, and learn new skills. These spaces often include tools and equipment for a variety of different projects, such as 3D printing, woodworking, and electronics. However, simply providing access to tools is not enough. We focus on the key goal of makerspaces is to support learners to improve their skills and knowledge in a hands-on, experiential way. In particular, we focus on the three goals within makerspaces:

(1) *For Tool and Material Knowledge:* This includes knowing which tools and materials to use for which purposes.
(2) *For Errors Detection:* This includes identifying errors in progress, debugging the errors, and learning to anticipate errors.
(3) *For Processes Execution:* This includes knowing how different tools and components within the makerspace interconnect in the execution of a maker activity, knowing the sequence of tool usage (for example, refining a CAD drawing before lasercutting the file).

Reflection strategies: The second axis of our framework for designing reflective exercises is reflection strategies. Reflection is an important aspect of learning, as it allows individuals to analyze their experiences and gain new insights. While several different reflection strategies can be used to support learning maker skills, in this work we focus on three specific strategies that we consider most aligned with reflection and maker skill-learning.

(1) *Contextualization:* Contextualization involves reflecting on the different aspects related to the project, maker processes, and design goals, and how they might impact their design decisions. Examples can include thinking about the choice of materials to align with the design requirement, thinking about the sequence of fabrication processes based on the material chosen, or thinking about the form of one component of design with respect to another. Reflecting on the real-world context can help learners understand how their work fits into the larger picture and identify areas and opportunities for future improvement.

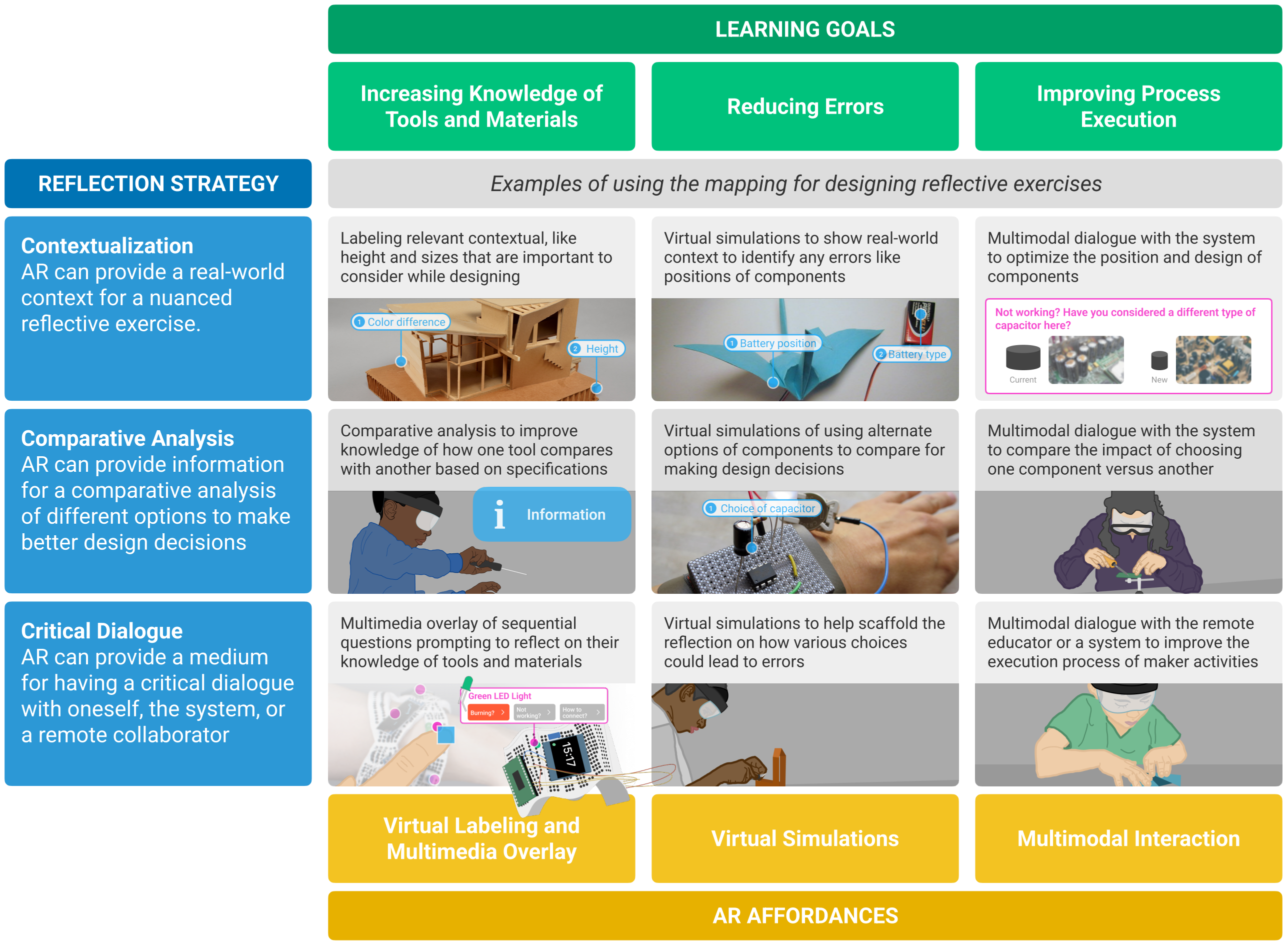

Figure 2: We propose our framework which enables us to scope the design space of AR-based reflection-in-action exercises. In this framework, we list the aspects of designing reflective exercises across three dimensions: the learning goals, the reflection strategies, and the AR affordances.

(2) *Comparative analysis:* Reflecting through a comparative analysis of different design options can help make informed design choices, by assessing the strengths and weaknesses of different design options, thinking about design from different perspectives, analyzing them, and making optimal decisions.
(3) *Critical Dialogue:* Reflective exercises involve engaging in a critical dialogue or an open discussion about the work, assessing design decisions, and learning from their actions, which helps learners gain new perspectives on their work.

AR affordances: The third axis for our design framework is AR affordances. AR can be used to augment the reflection strategies listed above by providing visual and interactive representations of the information being analyzed. For example, an AR could be used to show how a project fits into the larger context or to do the comparative analysis in a more engaging and interactive way. AR can also be used to facilitate critical dialogue by allowing learners to share and discuss their reflections in a more immersive and interactive environment and through multimodal mediums. In particular, we focus on the following AR affordances that we consider most aligned with supporting reflection.

(1) *Virtual labeling and Multimodal Overlay:* With AR, virtual labels can be added to physical objects or spaces in the real world. These labels can be multimodal containing text, images, videos, or animations that provide additional information about the object or space.
(2) *Virtual Simulations:* AR allows virtual simulations to be placed within the context of the real world, making them more realistic and relatable. These virtual simulations can help scaffold the learning of concepts and compare maker processes before performing the physical tasks.
(3) *Multimodal interaction:* Head-mounted display headsets allow multimodal interaction through audio, videos, and images displayed on the headset screen. This is beneficial for reflection exercises because the learner can continue focusing on the task but get the reflection prompts through audio or through on-screen cues.

3.2 Designing Reflective In-Action Exercises

To design the reflection exercises, we first choose the learning goal and then choose the reflection strategy and AR affordances for prompting reflection accordingly. The reflection strategies and the AR affordances together form the design space of our framework.

Consider the example of a product-design or interaction-design exercise of designing a smart watch (see Figure 1). Let us assume that the learning goal in this exercise is to increase the knowledge of tools and materials for building a smartwatch, one way to prompt reflection to improve the learner's understanding of tools and materials required to design and build the smartwatch is through an overlay of sequential points on the watch. As the learner clicks on those sequential points, the learner is asked to think about the function of those components. Based on the learner's responses, they are asked to reflect on how those components might be useful in their designs. In this manner, the learner can engage in a reflective exercise through the strategy of critical dialogue. This example illustrates how the mapping of the framework can be used to design reflective exercises in the context of learning makerskills.

3.3 Implementation

To implement these reflective exercises in AR, we use modified fabrication tools embedded with sensors. For example, a soldering iron and power drill, with embedded sensors like a heat sensor, an accelerometer, and a pressure sensor. These sensors provide real-time information about the learners' activities through the Arduino microcontroller's serial monitor. Using the serial communication API for HoloLens, and the information from the sensors through the Arduino microcontroller, we can identify when to trigger the reflection prompt. We also place unique IR tags on the physical objects in use in the environment. We use these IR tags to overlay the relevant information through labels, and multimodal overlay, such as images, animations, audio, and videos, through the HoleLens headset. We record the reflections of the learner by simply recording the HoloLens video stream.

3.4 Case Study Applications

We envision that our approach can support reflective activities spanning domains of art and design, engineering, and remote learning scenarios, as shown in Figure 3.

- **Art and Design:** Our approach can support architecture and design students during the design development phases by asking them contextualized open-ended reflection questions in AR, e.g., questioning critical design choices for them to summarize, evaluate, and iterate on the thinking process (Figure 3a). For example, students engaging in reflective exercises when making physical models can learn design through the process of making.
- **Engineering Projects:** Our approach can guide engineering and design students' design iterations and prototyping processes. Through AR, reflective exercises on component choices and placements, and reflecting on errors and mistakes during tool usage, we can scaffold skill learning in makerspaces (Figure 3b).
- **Remote Learning:** Our approach can make the remote learning of maker skills interactive and engaging. Learners can interact with the system by engaging in critical dialogues and reflecting on their design decisions and errors, or comparing their design choices with peers, with real-time guidance from instructors (Figure 3c).

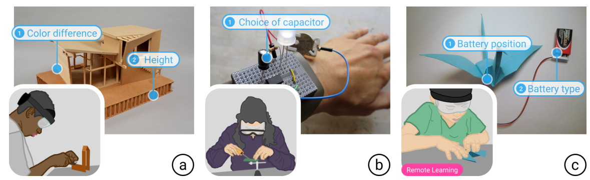

Figure 3: Case study applications: Using our approach of AR-based reflective learning, we can support students working on: (a) architecture and design projects, (b) engineering projects, and (c) remote learning.

4 CONCLUSION AND FUTURE WORK

We built on the prior research on reflective learning of makerskills and used augmented reality to monitor, prompt, and record reflections in real-time during the maker activities. We proposed a framework to design multi-modal reflective prompts for self-learning exercises. This work provides a basis for further research into this area. We briefly listed how our approach can be used to design applications for several skill-learning reflective activities in makerspaces.

For future work, we will build these case study prototypes to study, demonstrate, and assess how our approach applies to the case study applications we proposed. We will also run user studies to compare the learning gains achieved through AR and non-AR modes of reflection. Another aspect of future work is co-designing reflection prompts with existing educators of makerspaces. In the context of remote learning, we will study how synchronous and asynchronous interaction using our approach can scaffold skill learning. This work thus opens several avenues for future research in learning makerskills through reflection.

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