Designing Tools for Autodidactic Learning of Skills

Dishita Turakhia
MIT CSAIL
Cambridge, USA
dishita@mit.edu

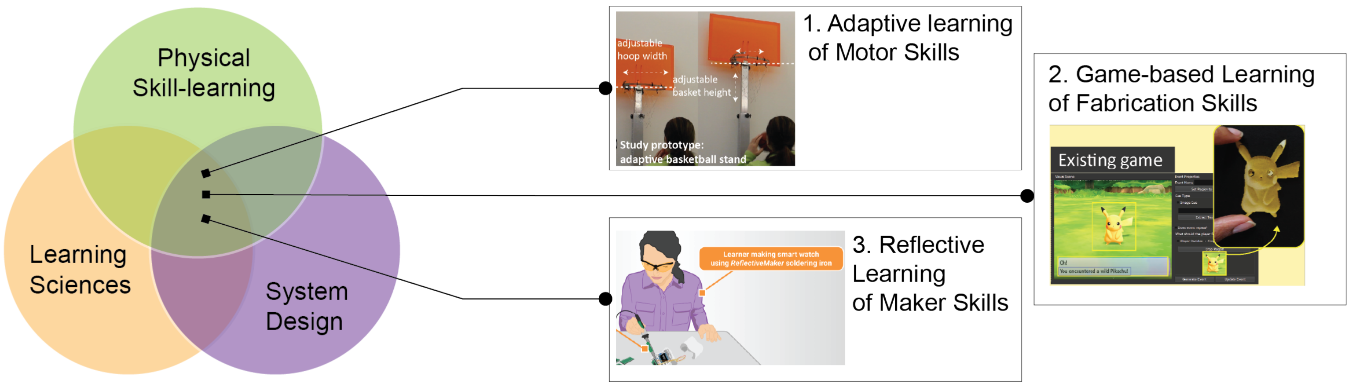

Figure 1: My research lies at the intersection of system design, learning sciences, and technologies that support learning of physical skills. In particular, I have worked on three sets of projects - (1) adaptive learning of motor skills, (2) game-based learning for fabrication skills, and (3) reflection-based learning of maker skills.

ABSTRACT

In the last decade, HCI researchers have designed and engineered several systems to lower the entry barrier for beginners and support novices in learning hands-on creative skills, such as motor skills, fabrication, circuit prototyping, and design.

In my research, I contribute to this body of work by designing tools that enable learning by oneself, also known as *autodidactism*. My research lies at the intersection of system design, learning sciences, and technologies that support physical skill-learning. Through my research projects, I propose to re-imagine the design of systems for skill-learning through the lens of learner-centric theories and frameworks.

I present three sets of research projects - (1) adaptive learning of motor skills, (2) game-based learning for fabrication skills, and (3) reflection-based learning of maker skills. Through these projects, I demonstrate how we can leverage existing theories, frameworks, and approaches from the learning sciences to design autodidactic systems for skill- learning.

CCS CONCEPTS

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

KEYWORDS

Adaptive Learning, Motor Skills, Fabrication Games, Reflective Learning, Maker-skills Learning

ACM Reference Format:
Dishita Turakhia. 2022. Designing Tools for Autodidactic Learning of Skills. In *The Adjunct Publication of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22 Adjunct), October 29-November 2, 2022, Bend, OR, USA.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3526114.3558526

ACM ISBN 978-1-4503-9321-8/22/10.
https://doi.org/10.1145/3526114.3558526

1 INTRODUCTION

In the last decade, HCI researchers have designed and engineered several systems to lower the entry barrier for beginners and support novices in learning hands-on creative skills, such as motor skills, fabrication, circuit prototyping, and design. These examples demonstrate how we can leverage advances in enabling technologies, such as better sensing hardware, data-driven AI algorithms, and AR/XR devices to engineer learning systems that tightly integrate physical and digital mediums through multimodal intelligent feedback and guidance in the context of physical hands-on skills. With advances in these enabling technologies, new possibilities and opportunities have emerged to support novice learners with creative maker skills and there is growing excitement in the systems engineering community in HCI to reimagine the design of learning systems.

Despite the growing research and excitement around the design and engineering of systems for learning creative and maker skills, these systems can be improved to support learning by (re)centering the design of these systems around the learner, the instructor, and the learning processes instead of centering them around their enabling technologies [1]. HCI researchers in the learning sciences

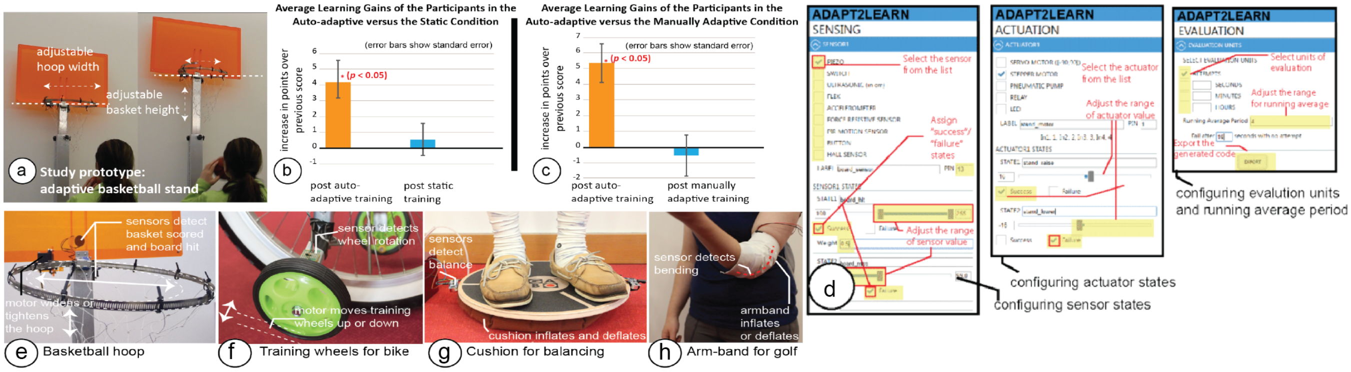

Figure 2: Adaptive Learning of Motor Skills: I used the framework of adaptive learning to build (a) physical tools that support training for motor skills. (b/c) Our studies showed significant learning gains after training in the adaptive condition. I also built (d) *Adapt2Learn* - a toolkit to support the design of various adaptive training tools, such as (e) an adaptive basketball stand (f) a bike with adaptive training wheels (g) a wobble-board with adaptive support and (h) an adaptive inflatable arm-band for golf swinging

have noted that supporting learners of hands-on skills in leveraging their cross-disciplinary knowledge, skills, and efficacy within and beyond the learning environment, can provide opportunities to reimagine environments for learning maker skills in ways that expand the cultural practices and knowledge bases [9].

In my thesis, I propose that reorienting the system design around theories of learning can support learning in a human-centered way. My research, that lies at the intersection of system design, learning sciences, and technologies that support learning, (for example, AR/VR and Computer Vision) addresses the limitations of technology-centric systems and demonstrates how autodidactic skill learning systems can contribute toward learner-centric systems.

In particular, I present three sets of projects - (1) adaptive learning of motor skills, (2) game-based learning for fabrication skills, and (3) reflection-based learning of maker skills. Through these projects, I have shown how we can leverage existing theories, frameworks, and approaches from the learning sciences, such as, adaptive learning, game-based learning, and reflection-based learning to design systems for autodidactic learning of various skills, such as motor skills, fabrication skills, and maker skills. These autodidactic skill-learning systems use enabling technologies such as computer vision and AR/VR to reinvent a learner's experience during skill-acquisition and thus, contribute toward reimagining the future of learning.

Next, I briefly describe the three sets of published projects from my research and explain how these systems offer a new paradigm for autodidactic learning.

2 ADAPTIVE LEARNING OF MOTOR SKILLS

One way to support autodidactic skill learning is using the adaptive learning framework, i.e., by adapting the difficulty of the training task according to the learner's skill levels. By maintaining the difficulty at an optimal challenge point, where the task is neither too easy nor too difficult for the learner, the learner has the highest potential for skill learning. This way of personalizing training also enables the learner to learn at their own pace and in an optimal way. In contrast to the conventional "one-size-fits-all" approach, adaptive learning personalizes the learning experience.

In my research, I utilized this framework of adaptive learning to teach motor skills and built physical prototypes of tools to support the learning. For example, an adaptive basketball stand (Figure 2a) that adjusted the hoop height and width based on the learner's skill level, meaning as the learners got better at scoring baskets, the hoop height increased and the hoop width decreased, thus increasing the task difficulty. The tool used our learning algorithm that maintained the training task difficulty at the optimal challenge point at all times, i.e., where the task is neither too easy nor too difficult for the learner.

We then conducted two user studies to test the effectiveness of using our adaptive tool and measured the learning gains in the participants' skill levels. Results from two user studies showed that adaptive learning led to statistically significant higher learning gains when compared to the static and manually adaptive methods of learning motor skills ($p < 0.05$) [6] (Figure 2b, c). Insights from the studies highlighted that learners struggled to assess their skill levels, often under-challenging or over-challenging themselves. Our adaptive learning tools thus offered a groundbreaking way for autodidactic learning of motor skills.

To apply the adaptive learning approach to other motor skills, I built a design and visualization toolkit (Figure 2d) that auto-generates the algorithm to adjust the adaptive tool during training and visualizes the learners' performances [8]. Using the toolkit, we built prototypes, such as an adaptive bike (Figure 2f), an adaptive wobble-board (Figure 2g), and an adaptive armband (Figure 2h) for autodidactic learning of biking, balancing, and golf-swinging, respectively [7].

3 LEARNING FABRICATION SKILLS THROUGH EXISTING VIDEOGAMES

Another way to support autodidactic learning of skills in an engaging way is by using games especially to support learning for

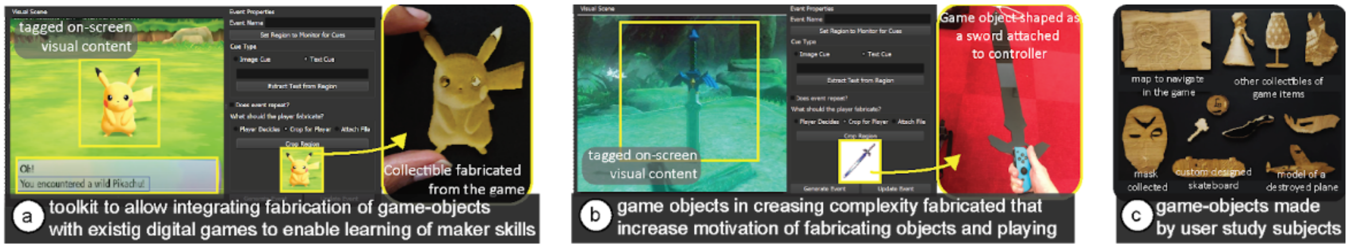

Figure 3: Game-based Learning of Fabrication Skills: In this project, I used the framework of game-based learning to support learning of fabrication skills, such as lasercutting. (a/b) I built *FabO*-a toolkit that allowed integrating fabrication events within existing games, (c) so that the learners could fabricate objects from their gameplay and learn fabrication along the way.

kids. While games are widely used to teach young learners (k-12) science and math, this approach was not explored in the context of teaching 2D fabrication skills, such as laser cutting and 3D printing. The early stages of teaching these skills can typically involve simple exercises like laser cutting or 3D printing basic shapes and objects - an activity that can be mundane in disengaging. To make the learning of these skills engaging and autodidactic, we used video games and integrated fabrication events within them [2]. Kids already play a myriad of video games that have countless digital objects and characters that the players engage with. While playing these games and interacting with the digital objects and characters (Figure 2), kids can fabricate them to interact with them in the physical world, and learn fabrication and maker skills along the way.

I designed a framework that used onscreen content to tag and detect the integrated fabrication events and to generate fabrication files for the game objects. I implemented this framework in a toolkit that utilized computer vision techniques such as object detection (to tag and detect fabrication events) and object extraction (to auto-generate 2D fabrication files for the game objects). This workflow allowed integrating fabrication with existing games without needing access to the game's source code and asset files. I evaluated the usability of the toolkit with two user studies and demonstrated the potential of using games to make the learning of fabrication skills engaging and fun. To support educators in designing fabrication events within existing games, I also developed a design framework that provided guidance on choosing the right game mechanics for integrating learning moments [5]. Through a co-design workshop with educators and fab-lab instructors, we are currently developing a game to integrate the curriculum for learning fabrication with a digital game for middle-school learners, so they can learn these skills on their own, at their own pace.

4 REFLECTIVE LEARNING OF MAKER SKILLS

Learning through self-reflection is another method of autodidactic learning, and the role of reflection is widely studied in HCI. Studies show that when learners reflect on their performances by analyzing successful and unsuccessful attempts at a task, they develop a deeper understanding of performing the skills that leads to better learning. However, currently, there are no tools to allow reflective learning of maker skills.

To bridge this gap, I am building a toolkit for experts and educators to design reflection exercises for novice learners in maker spaces [4]. Experts and educators can use the toolkit to design the

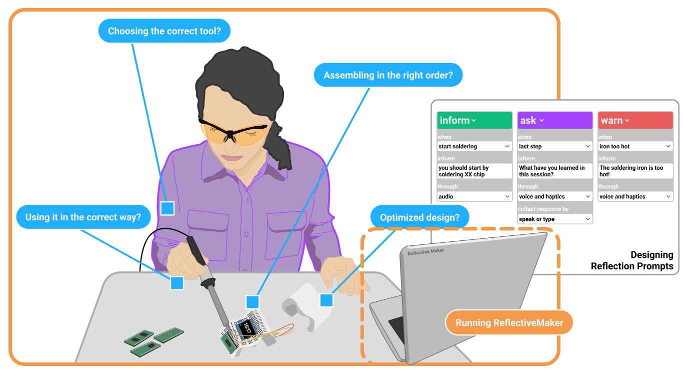

Figure 4: Reflective Learning of Maker Skills: In this project, I am using the framework of reflective learning to support skill-building in makerspaces. I am building a toolkit for experts and educators to design reflection exercises for novice learners in maker spaces. These exercises can prompt the learners to reflect on their projects during the prototyping stages.

reflection prompts during fabrication activities, to sense the user's activities and identify suitable events for prompting reflection, and to record the user's reflections and analyze data on their learning stages. I am currently in the process of implementing the system design, which has three components: (a) a designer interface to design the reflection prompts during fabrication activities, (b) a set of fabrication tools to sense the user's activities and (c) a reflection diary interface to record the user's reflections and analyze data on their learning stages.

5 MY RESEARCH CONTRIBUTIONS

My research, which lies at the unique intersection of learning science, and toolkit design, has contributed to the HCI research in several ways. First, the autodidactic learning approaches I examined in my work, namely, adaptive learning, games-based learning, and reflective learning demonstrate how the gaps between the learning sciences and systems design can be bridged by using the learning theories and frameworks to inform the system design. My work shifts the focus of system-design from being technology-centric to being learner-centric [3], and provide opportunities to re-imagine the future of autodidactic learning of skills.

ACKNOWLEDGMENTS

My research is supported the National Science Foundation under grant numbers 1828406 and 2008116, and the MIT Integrated Learning Initiative.

REFERENCES

[1] Michael Tan. 2019. When makerspaces meet school: Negotiating tensions between instruction and construction. *Journal of Science Education and Technology* 28, 2 (2019), 75–89. https://doi.org/10.1007/s10956-018-9749-x

[2] Dishita G Turakhia, Harrison Mitchell Allen, Kayla DesPortes, and Stefanie Mueller. 2021. FabO: Integrating Fabrication with a Player's Gameplay in Existing Digital Games. In *Creativity and Cognition*. 1–10. https://doi.org/10.1145/3450741.3465239

[3] Dishita G Turakhia, Paulo Blikstein, Nathan R Holbert, Marcelo Worsley, Jennifer Jacobs, Fraser Anderson, Jun Gong, Kayla DesPortes, and Stefanie Mueller. 2022. Reimagining Systems for Learning Hands-on Creative and Maker Skills. In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI EA '22)*. Association for Computing Machinery, New York, NY, USA, Article 94, 7 pages. https://doi.org/10.1145/3491101.3503732

[4] Dishita G Turakhia, Peiling Jiang, Brent Liu, Mackenzie Leake, and Stefanie Mueller. 2022. The Reflective Maker: Using Reflection to Support Skill-learning in Makerspaces. In *The Adjunct Publication of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22 Adjunct), October 29-November 2, 2022, Bend, OR, USA*. https://doi.org/10.1145/3526114.3558716

[5] Dishita G Turakhia, Stefanie Mueller, and Kayla DesPortes. 2022. Identifying Game Mechanics for Integrating Fabrication Activities within Existing Digital Games. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 87, 13 pages. https://doi.org/10.1145/3491102.3517721

[6] Dishita G Turakhia, Yini Qi, Lotta-Gili Blumberg, Andrew Wong, and Stefanie Mueller. 2021. Can Physical Tools that Adapt their Shape based on a Learner's Performance Help in Motor Skill Training?. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*. 1–12. https://doi.org/10.1145/3430524.3440636

[7] Dishita G Turakhia, Andrew Wong, Yini Qi, Lotta-Gili Blumberg, and Yoonji Kim. 2021. *Designing Adaptive Tools for Motor Skill Training*. Association for Computing Machinery, New York, NY, USA, 137–139. https://doi.org/10.1145/3474349.3480205

[8] Dishita G Turakhia, Andrew Wong, Yini Qi, Lotta-Gili Blumberg, Yoonji Kim, and Stefanie Mueller. 2021. Adapt2Learn: A Toolkit for Configuring the Learning Algorithm for Adaptive Physical Tools for Motor-Skill Learning. In *Designing Interactive Systems Conference 2021*. 1301–1312. https://doi.org/10.1145/3461778.3462128

[9] Shirin Vossoughi, Paula K Hooper, and Meg Escudé. 2016. Making through the lens of culture and power: Toward transformative visions for educational equity. *Harvard Educational Review* 86, 2 (2016), 206–232. https://doi.org/10.17763/0017-8055.86.2.206