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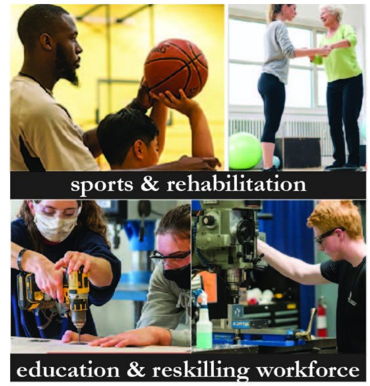
RESEARCH STATEMENT

Designing a human-centered future for skill-learning

Vision

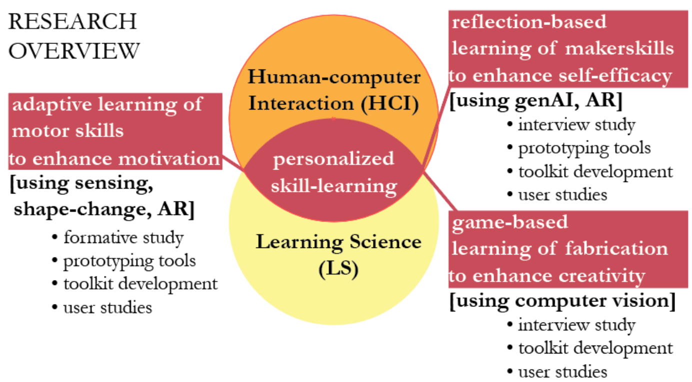


Learning physical skills is integral to our lives, whether for excelling in sports, mastering DIY tools, or gaining expertise in operating machinery. However, **the way we learn these physical skills is undergoing a profound transformation.** Leveraging ubiquitous wearables sensing data for behavior insights, integrated machine learning models for personalized learning, and advances in augmented and virtual reality (AR/VR) for immersive experiences is driving the EdTech industry to a staggering **$400B valuation by 2032.** With these enabling technologies being at an inflection point, a society in which every learner has a personalized educator outside the traditional classroom is not just a vision but a near-future possibility.

However, amidst this excitement of innovation, it is critical not to lose sight of the fundamental nature of human learning. **Every learner is unique** in their skill levels, learning speeds, and preferences. Likewise, **every learning experience is multifaceted,** exceeding beyond mere skill acquisition, and encompassing broader facets like cultivating self-motivation, self-efficacy, and creativity. Given this multifaceted nature of human learning, **my vision is to leverage technology to design learner-centric tools for comprehensive skill learning.**

Overview

I fulfill this vision through my research at the intersection of **Human-Computer Interaction (HCI)** and **Learning Science (LS)**. I combine HCI principles of tool design with LS frameworks to **personalize the learning of physical skills by enhancing motivation, creativity, and self-reflection.** I design, build, and study interventions grounded in learners' and educators' experiences thereby challenging prevailing techno-centric approaches that focus solely on skill enhancement.



Contributions

In my Ph.D., I have developed three frameworks for skill learning: i) **adaptive**, ii) **reflection-based**, and iii) **game-based** for learning three different sets of skills: **motor skills, maker skills, and fabrication skills.** These frameworks emerged from existing LS theories on multifaceted learning outcomes and my investigations into educators' teaching strategies. I have applied these frameworks to create tools that leverage technological advancements in sensing, shape-changing interfaces, computer vision, AR/VR, and generative AI. I then examined the deployment of these tools through extensive user studies. Altogether, my research has contributed to the field of human-computer interaction by **expanding the design space for learning tools** and **advancing our understanding of human learning**.

To incorporate the perspectives of various stakeholders in this multidisciplinary research, I have fostered **successful collaborations** with researchers from **diverse fields**, like mechanical eng and architecture; **universities**, like NYU, UCSD, UCSB, BU, Columbia, and Northwestern University; **industry labs** like the Meta Reality Labs and Autodesk Research; as well as **local nonprofit schools** and **global organizations** like the Fab Foundation. My projects have garnered over **$2 million in funding**, including NSF grants, resulted in **top-tier HCI conferences and LS journal publications,** and also received **media coverage** from MIT News, ACM News, and Digital Trends. This research involved **mentoring several students,** twelve of whom **co-authored publications** for the projects that I detail next.

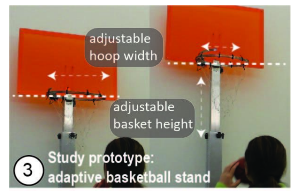
Research Projects

I have worked on **personalizing learning for two applications - motor skills** and **maker skills,** that I describe below:

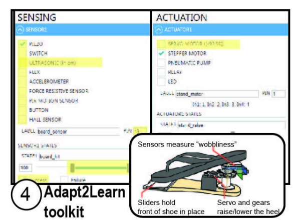
1. Personalized learning of motor skills to enhance learners' motivation

In my formative interviews with trainers, they emphasized tailoring training to an individual's abilities, particularly for mastering complex movements in sports and physiotherapy. Such personalized scaffolding, however, is often difficult to scale and make accessible to those lacking access to personal trainers. To address this challenge, I designed the approach of **Adaptive Learning** to personalize the learning **of Motor Skills** based on each learner's skill level [1, 2, 4, 13].

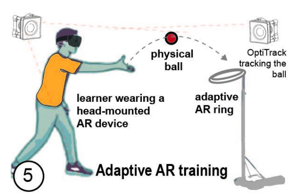
Adaptive learning of motor skills



A key innovation of this work was leveraging the shape-changing abilities of interactive tools to adapt the training task difficulty. For example, one design featured an adaptive basketball stand [fig3] that assessed the learner's performance using sensors, computed the optimal training difficulty for them, and accordingly adjusted the hoop's height and width using actuators. I validated the impact of this approach through two user studies which demonstrated that **adaptive learning not only outperformed non-adaptive training but also surpassed manually-adaptive training** [1]. The findings also shed light on **learners' inability to assess their skill levels**, often leading to suboptimal training as they either under-challenged or over-challenged themselves. Adaptive learning also **significantly increased motivation in learners,** as the tool's adjustments signaled their progress, further **underscoring the need to build such tools.**



To extend the design space for adaptivity, I developed the *Adapt2Learn* toolkit [fig4], which empowers designers to build adaptive tools for varied skills [2]. *Adapt2Learn* generated customized learning algorithms for their tools and provided a visualization feature for evaluating if the tool adapted correctly to the learner's performance. I evaluated the toolkit's usability through an MIT undergraduate course, where students prototyped tools for 16 different applications like swimming, music, and even walking in high heels. These **prototypes, showcased at UIST** [4], demonstrated how my approach of adaptive learning **expanded the design space for learning tools** including in **AR/VR environments.**



To further explore this expanded design space, I collaborated with **Meta Reality Labs** and designed adaptive training using AR tools [13], for example, an adaptive AR hoop for ball-throwing training [fig 5]. In this setup, we tracked the physical ball using OptiTrack, assessed the learner's performance, computed the optimal training difficulty, and adjusted the width of the AR hoop visible through the learner's HoloLens. Our studies on using this approach for training shed light on **which visual and environmental cues the learners rely on** during training. These findings unveiled new **design opportunities to adapt virtual cues for optimal personalized training in AR**, potentially making future AR tools indispensable for motor training.

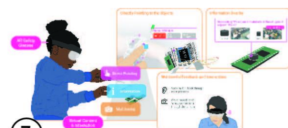
2. Personalized learning of makerskills to enhance learners' self-efficacy and creativity

Another area involving learning physical skills is STEAM education, particularly for building competencies like using workshop tools in makerspaces. To understand how the learning of these skills is scaffolded, I conducted in-depth interviews with educators in makerspaces across Greater Boston and global fab labs. This NSF-funded study revealed **how educators prioritize a myriad of learning goals beyond mere tool expertise**, **such as enhancing self-efficacy and creativity.** This study particularly provided **two key insights** on educators' scaffolding strategies that grounded my next two projects**:** first, **educators engage learners in a critical dialogue** to allow learning through reflection over providing them with direct answers; second, **educators designed playful activities to boost learners' creativity** in skill-building courses instead of giving them instructional exercises.

Reflection-based learning of makerskills


6 Reflective Maker toolkit

Building on the first insight, I developed a framework for reflection-based learning of makerskills and implemented it in *ReflectiveMaker -* a toolkit for educators to design reflection exercises for novice makers [8, fig6]. The toolkit has three components: i) a designer interface to craft reflection prompts for fabrication activities, ii) a set of maker tools embedded with sensors to monitor learners' activities, and iii) a reflection diary interface to record and analyze learners' reflections and progress. To further support the self-learning of makerskills among individuals who may not have access to makerspaces and instead rely on online tutorials like *Instructables*, I explored the use of **Large Language Models (LLMs)**, specifically OpenAI's GPT-4, for **generating personalized tutorials**. In this collaborative project with **UCSD Design Lab,** we built ***Reflectables,*** a toolkit to generate personalized *Instructables* designed to encourage self-reflection during the making process [14]. *Reflectables* leveraged the large corpora of existing *Instructable* tutorials and integrated tailored goal-oriented and contextual reflection prompts within them based on the learners' skills and learning styles. Preliminary evaluation of the work showed **increased self-efficacy** and **knowledge of tools** among learners as they gained a deeper understanding of how and when to use the tools - which is often missed when simply focusing on following instructions.


7 Reflective Make-AR toolkit

To further design an immersive environment centered on reflection-based learning, I developed *Reflective Make-AR:* an augmented reality system [fig7] for monitoring, prompting, and recording the learners' *"in-action reflections"* and studied the impact of immersive multimodal reflection on the learning experiences of makers [9]. Our findings from this research, which received **an honorable mention poster award at UIST**, indicated the need to adopt a **"less is more" approach when designing interventions** for reflection as learners engaged in more meaningful reflections with prompts that were less intrusive and less forceful.

Game-based learning of fabrication


8 FabO toolkit

Building on the second insight of using playfulness to boost creativity during skill-building, I developed a game-based framework for learning fabrication and implemented it in *FabO* - a toolkit to integrate fabrication activities within existing video games to teach digital fabrication [3,5]. *FabO* allowed learners to laser-cut and 3D print objects from their favorite games, such as collectibles or custom controllers crafted from game-related elements [fig8]. **A key novelty of this work was that *FabO* used computer vision to allow seamless integration of fabrication moments within existing games without needing access to the game's source files.** Through its *designer interface* and *player interface*, *FabO* allowed educators to design personalized learning, which our studies revealed **enhanced learners' motivation and engagement** by providing opportunities for **playfulness and creative self-expression**.

Research Impact

Together, these three projects on adaptive learning, reflection-based learning, and game-based learning demonstrate how **novel frameworks, tools, and interactions** for personalized learning of physical skills can be developed to **enhance self-motivation, self-efficacy, and creativity.** By utilizing a range of methodologies, my **intersectional work has pushed the edges of human-computer interaction and the learning sciences,** through the technical contribution of tool design and behavioral impact on human learning. By **expanding the design space** of tools for learning and providing **insights into how humans learn, my research has shed light on how to leverage enabling technologies for designing a learner-centric future of comprehensive skill development**.

Through my research, I have demonstrated building the skills, experience, and foundation necessary **to expand my vision of a learner-centric future.** My work opens avenues for research in **several impactful areas, like scalable learning, workforce training,** and **building an equitable future for skill-learning,** which I detail next.

Research Plans: Reimagining Learning

I am excited to **lead the design of a learner-centric future** by building tools for the following **three focus areas:**

1. Innovating for Learning at Scale *(potential funding sources: NSF DRK-12, NSF IUSE: CUE)*

I will focus on scaling personalized learning of physical skills and **making it accessible to learners** who may face **systemic barriers to educational resources** across the world through a two-pronged approach.

a) The first dimension of scalability involves taking **a specific physical skill** and developing methods to **personalize it on a mass scale**, potentially reaching millions. This approach, as demonstrated by *Adapt2Learn* and *FabO*, requires focusing on building dynamic systems that adapt to diverse skill levels and learning preferences. I plan to design, build, and study **data-driven machine-learning models** for effectively teaching specific skills at scale.

b) The second dimension of scalability centers on **leveraging the vast repository of educational content** available online, as demonstrated by my approach to developing *Reflectables*. By making existing tutorials like **YouTube videos multimodal and immersive** using AR/VR, and tailoring the interaction of instructional content to individual learners, I aim to reimagine **new ways of learning physical skills remotely** that also facilitate **social interaction and collaborative learning** among learners across the globe. By seeking NSF funding, I plan to equip my lab with the necessary AR/VR infrastructure for building tools and running controlled experiments.

2. Training the Future Workforce *(potential funding sources: NSF ECR:Core, NSF STEM)*

Besides educational applications, I aim to deploy computer-supported training tools to drastically reduce the time and cost of building a robust workforce of professionals, as well as for reskilling the existing workforce.

a) Training professionals like teachers, coaches, physiotherapists, and even surgeons continues to be a challenge for meeting the demands of a skilled workforce. I plan to extend the application of adaptive motor skill-learning tools for training professionals. **Building on my existing collaborations with physiotherapists at the Charles River Center** in Greater Boston, where I co-designed support tools for people with developmental disabilities, I will investigate how to also assist practitioners in their own training and in providing patient care.

b) My approaches hold the promise of providing effective training to **reskill the existing labor force** transitioning into new roles and industries, particularly manufacturing. I am currently **collaborating with the Mechanical Engineering department at MIT** to develop a VR system to train manufacturing proficiencies like machining, drilling, and lathing [12]. I plan to leverage this collaboration to further study how to assist **skill transfer from one domain to another**, thereby **promoting lifelong learning**.

3. Ensuring Equitable Access *(potential funding sources: NSF AISL, Meta Research Grants)*

A critical aspect of my work in HCI is to be cognizant of the **dual nature of technology,** which, while broadening access for the masses, can also potentially cause greater disparity. With a majority of the global population still lacking direct access to technological advances, it is imperative to design **low-tech and cost-effective learning solutions.** To spearhead the thinktank for innovating equitably, **I led a day-long workshop** on 'Reimagining Learning of Creative Skills' at the CHI'22 [6]. This workshop, attended by 16 professors and 25+ students from varying areas of HCI and LS, provided a platform to discuss and collaborate on designing and building equitable learning tools and inclusive learning environments. I plan to **leverage these connections** to design tools that bridge the digital divide, cater to a diverse range of learners, regardless of their socio-economic backgrounds, and thus **democratize learning**.

With these goals in mind, **I am enthusiastic to pursue the next bold steps required to lead the design of a future that innovates with a human-centered sensibility.**

References and Publications:

[1] **D. Turakhia,** Y. Qi, L. Blumberg, A. Wong, and S. Mueller. 2021. *"Can Physical Tools that Adapt their Shape based on a Learner's Performance Help in Motor Skill Training?"* In Conference on Tangible, Embedded, and Embodied Interaction **(ACM TEI '21)**.
https://doi.org/10.1145/3430524.3440636

[2] **D. Turakhia,** Y. Kim, Y. Qi, L. Blumberg, A. Wong, and S. Mueller. 2021. *"Adapt2Learn: A Toolkit for Configuring the Learning Algorithm for Adaptive Physical Tools for Motor-Skill Learning"* In Conference on Designing Interactive Systems Conference 2021 **(ACM DIS'21)**.
https://doi.org/10.1145/3461778.3462128

[3] **D. Turakhia,** H. Allen, K. DesPortes, and S. Mueller. 2021. *"FabO: Integrating Fabrication with a Player's Gameplay in Existing Digital Games"* In Conference on Creativity and Cognition 2021 **(ACM C&C '21)**.
https://doi.org/10.1145/3450741.3465239

[4] **D. Turakhia,** Y. Kim, Y. Qi, L. Blumberg, A. Wong, and S. Mueller. 2021. *"Designing Adaptive Tools for Motor-Skill Learning"* In The Adjunct Publication of User Interface Software and Technology **(ACM UIST '21 Adjunct)**.
https://doi.org/10.1145/3474349.3480205

[5] **D. Turakhia,** S. Mueller, and K. DesPortes. 2022. *"Identifying Game Mechanics for Integrating with Fabrication Activities in Existing Games"* In Human Factors for Computing **(ACM CHI '22)**
https://doi.org/10.1145/3491102.3517721

[6] **D. Turakhia,** P. Blikstein, N. Holbert, M. Worsley, J. Jacobs, F. Anderson, J. Gong, K. DesPortes, S. Mueller. 2022. *Reimagining Systems for Learning Hands-on Creative and Maker Skills.* In Extended Abstracts of Conference on Human Factors in Computing Systems
(ACM CHI EA '22)
https://doi.org/10.1145/3491102.3517721

[7] Y. Kim, J. Zhu, M. Trivedi, M.l Wessley, **D. Turakhia,** N. Wu, D. Ko, and S. Mueller. 2022. *SensorViz: Visualizing Sensor Data in the Context of 3D Models to Facilitate Prototyping.* **(ACM DIS '22)**
https://doi.org/10.1145/3532106.3533481

[8] **D. Turakhia,** P. Zhiang, B. Liu, M. Leake, S. Mueller. 2022. *The reflective maker: Using reflection to support skill-learning in makerspaces.* In The Adjunct Publication of User Interface Software and Technology **(ACM UIST '22 Adjunt)**
https://doi.org/10.1145/3526114.3558716

[9] **D. Turakhia,** Y. Kim, I. Wang, and S. Mueller. *The Reflective Make-AR In-Action: Using Augmented Reality for Reflection-based Learning of Makerskills.* 2023. In Extended Abstracts of Conference on Human Factors in Computing Systems **(ACM CHI EA '23)**
https://doi.org/10.1145/3544549.3585850

[10] **D. Turakhia,** D. Ludgin, S. Mueller, K. Desportes. *What Can We Learn From Educators About Teaching in Makerspaces?* 2023. In Extended Abstracts of Conference on Human Factors in Computing Systems **(ACM CHI EA '23)**
https://doi.org/10.1145/3544549.3585687

[11] **D. Turakhia,** S. Mueller, and K. DesPortes. *Understanding Educators Practices in Makerspaces.* 2023. In Journal for Educational Technology Research and Development **(ETRD '23)**.
https://doi.org/10.1007/s11423-023-10305-1

[12] H. Lie, K. Studer, Z. Zhao, B. Thomson, **D. Turakhia,** and J. Liu. 2023. *Training for Open-ended Drilling through a Virtual Reality Simulation.* In IEEE International Symposium for Mixed and Augmented Reality **(IEEE ISMAR '23)**
[accepted]

[13] **D. Turakhia,** M. Parent, M. Glueck, T. Grossman, and B. Lafreniere. *Motor-Skill Learning in Augmented Reality: Challenges and Opportunities for the Design of Adaptive Training Tools.*
[under review]

[14] **D. Turakhia,** Z. Mroue, P. Jiang, H. Xia, and S. Mueller. *Reflectables: Using Generative AI to Integrate Reflection Prompts for Makerskills within Instructable Tutorials.*
[under review]