The goal of my research is to develop socio-technical ecosystems that enable increasingly effective and scalable learning environments, given limited mentoring resources. Broadly speaking, I am interested in how these collectives of technical systems, effective processes, and social structures integrate in ways that optimally utilize the limited resources available in a community. Towards this goal, I design, implement, and empirically evaluate learning ecosystems that scale effective research training. I take a design-based research approach, integrating the fields of Human-Computer Interaction (HCI), Learning Sciences (LS), and Computer-Supported Cooperative Work (CSCW). Long term, I aspire to implement learning ecosystems that enhance and extend the natural ways in which we practice, learn, grow and support one another in our communities.

To tackle today's most challenging problems, we must explore effective and scalable ways to train the next generation in how to lead the design and research of high-impact solutions. In addition to core design-research skills (i.e. prototyping techniques and research methodologies), people must also develop the **metacognitive skills** necessary for self-directing this work. For instance, one must learn to strategically *plan* out their work, *seek help* from their network of resources, and regularly *reflect* on and improve their ways of working in order to make meaningful progress. Undergraduate research training provides an opportunity to study how we might better prepare the future workforce. Authentic undergraduate research experiences where students lead core research tasks (i.e. designing a research plan, collecting and analyzing data, and preparing manuscripts) provide numerous personal, professional, and societal benefits, including enhancing student learning, and broadening student participation and retention in diverse fields of study.

However, **scaling effective environments for such training is difficult when mentoring resources are limited**. Often, student researchers learn through 1:1 apprenticeship alongside an expert. While effective, this approach is hard to scale, limiting most faculty to training a small number of graduate students, and leaving undergraduates with rote tasks such as data cleaning or transcription. Some research groups scale by adopting a hierarchical model, where undergraduate training is delegated to graduate students. While scalable, this approach is less effective, as graduate students have yet to master research, let alone effective research advising. These practical shortcomings can lead students to undervalue research experiences and even lower their self-efficacy in leading complex work, resulting in fewer students receiving the promised benefits of undergraduate research programs.

My focus is to develop ***Agile Research Studios (ARS)***, **a socio-technical ecosystem that guides learners in how to execute their metacognitive practices across available community supports to effectively self-direct research**. To enable effective research training, ARS fosters a *self-directed learning environment*, where students focus on the metacognitive skills required to lead design-research work. To enable scalability despite limited mentoring resources, ARS takes a *dispersed control approach* to distribute learning across a community of practicing researchers. The ARS ecosystem is composed of *component supports* (i.e. virtual tools, agile processes, social structures, training resources, feedback and practice venues) that weave together as *subsystems* designed to scaffold students in planning, helpseeking, and reflection skills. To help students execute their metacognitive practice across the supports available in the ecosystem, ARS implements *process management frameworks* that integrate into existing supports, enabling students to monitor and improve their practice, as they practice.

By designing socio-technical ecosystems that support metacognitive practice in communities like ARS, we can achieve increasingly scalable and effective learning environments that train students in the skills they need to drive the high-impact solutions of tomorrow. Moving forward, I seek to explore how we can expand these learning ecosystems to support additional skills, and how these ecosystems can advance alternative learning environments for innovation and entrepreneurship. Below, I detail my dissertation work, and present my future research agenda.

1. A Socio-technical Ecosystem for Research Training

Undergraduate research experiences provide numerous personal, professional, and societal benefits, including enhancing student learning and broadening student participation and retention in diverse fields of study. Research experiences that incorporate factors like quality mentoring, sustained training, and practicing core modes of thinking in the discipline contribute to student intellectual growth and interest in science and research careers, especially among women and underrepresented minority students. Effective mentorship is central to training students as they practice the diverse set of skills needed to lead such work. However, scaling effective environments for this kind of research training is difficult when mentoring resources are limited. Typically, student researchers learn through the 1:1 apprenticeship model: a combination of observation, coaching, and practice alongside an expert mentor. While effective, 1-on-1 mentoring is time-intensive, and thus hard to scale. Consequently, most faculty are limited to training only small numbers of graduate students, often leaving undergraduates to rote activities such as data cleaning, transcription, or tagging. In an effort to scale, some research groups adopt a 1:1:1 hierarchical model, where faculty mentors delegate undergraduate mentoring to graduate students. While scalable, this approach provides less effective training to students, as graduate students themselves have yet to master research, let alone methods for effectively mentoring others.

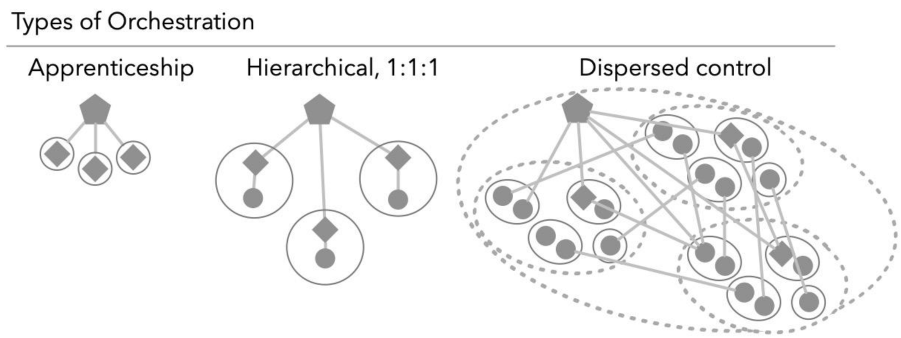

Figure 1. To scale effective research training given limited mentoring resources in the community, Agile Research Studios (ARS) fosters a *self-directed learning environment* that takes a *dispersed control approach* that distributes learning across an ecosystem of existing supports in the community.

To overcome the practical limitations of scaling such training environments, we introduce ***Agile Research Studios (ARS)*, a learning ecosystem of socio-technical supports designed to scaffold students to plan, seek help, and reflect as they learn to self-direct complex work within this community** [1]. To enable effective research training, ARS fosters a *self-directed learning environment* that focuses on developing the underlying metacognitive skills requisite for leading such research work. To enable scalability, ARS takes a *dispersed control approach* that distributes learning across the community (see Figure 1). In other words, the ARS model explicitly trains students to distribute their learning and practice across the ecosystem of available supports in the community. The ARS ecosystem is composed of *components* (i.e. virtual tools, agile processes, social structures, training resources, feedback and practice venues) that help students hone aspects of their metacognitive practice. For instance, students can use a component like their Sprint Log tool to lay out an actionable and agile iteration plan for the next two weeks. Further, ARS weaves together these components as *subsystems* -- collections of supports designed to advance a particular metacognitive skillset (e.g. planning, help seeking, and reflection), as seen in Figure 2. For instance, to practice planning, students can use the Sprint Log tool to construct their project plans, and bring that into the Special Interest Group (SIG) planning meeting venue to get feedback from an expert mentor on the risks in their approach and planned next steps. These components and subsystems work together as a learning ecosystem rich with socio-technical support, designed to equip students with the skills they need to advance their practice.

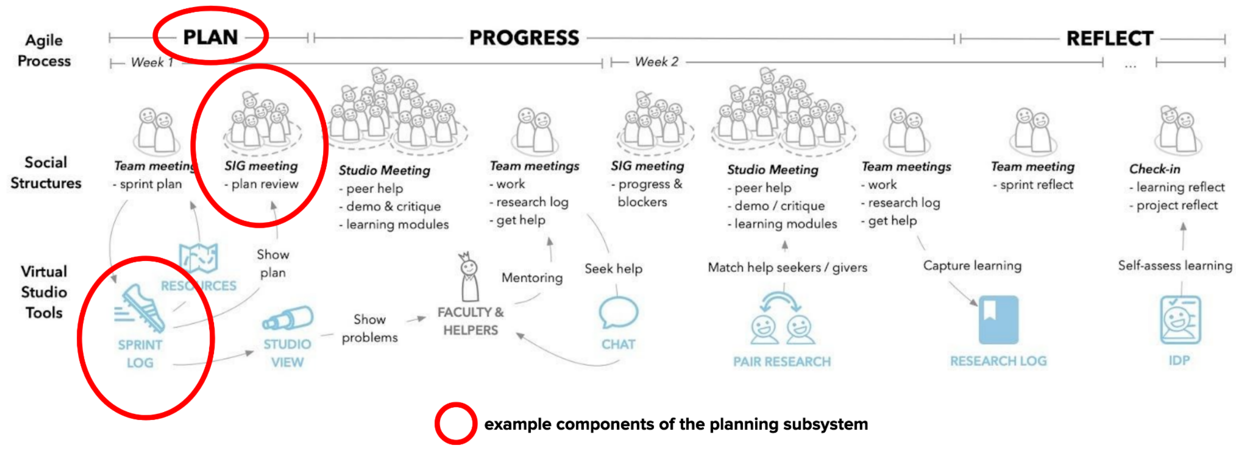

Figure 2. The Agile Research Studios (ARS) model introduces an *ecosystem of socio-technical supports* -- virtual tools, agile processes, social structures, training resources, feedback and practice venues. These components weave together as subsystems designed to scaffold students to plan, seek help, and reflect as they learn to self-direct complex work within the community. Here, we emphasize the components that make up the planning subsystem.

Our 2-year pilot study showed early results on how learning ecosystems like ARS can scale effective research training. First, we saw initial evidence that suggested the ARS model was scalable. The Design, Technology, Research (DTR) studio that piloted the model supported a community of 21 student researchers, including 18 undergraduates, 1 post-bac, and 2 Ph.D. students with less than 12 hours of faculty time each week. Further, our results demonstrated that the ARS model could be effective. Over two years, the DTR studio hosted 36 students who led 18 research projects, published 9 papers and extended abstracts at peer-reviewed ACM and AAAI conferences, and won 3 awards at ACM Student Research Competitions. Perhaps more remarkable than research outcomes, analysis of ARS activities showed significant engagement in metacognitive processes as they learned to self-direct complex work. Results showed that students engaged in planning activities, and reported developing planning skills. Further, students helped one another regularly across project teams, and reported shifts in their dispositions on help-seeking and help-giving in the community.

2. Augmenting An Ecosystem to Address Critical Subsystem Gaps

As I studied how students practiced in the ecosystem, I observed that **students still faced critical gaps in their planning, helpseeking, and reflection processes**. I closely studied the expert processes that mentors would coach their students to follow. Building on existing literature, I defined models of expert practice for each of the three skills. When we identified a critical gap in our scaffolding, we introduced new tools and processes to augment these planning, helpseeking, and reflection subsystems. For instance, upon studying the expert planning process, I recognized that expert design-researchers visualize the argumentation structure of their design problem, diagnose risks in that structure, and then focus their iteration plan on first tackling the most critical risks. Our previous scaffolding focused on using the Sprint Log tool to help students break down their plans into detailed tasks, and SIG planning meetings, where they could get mentor feedback on their planning strategies for the upcoming week. However, we lacked explicit scaffolding for two key components of the expert planning process -- visualizing the design problem and diagnosing risks (see Figure 3).

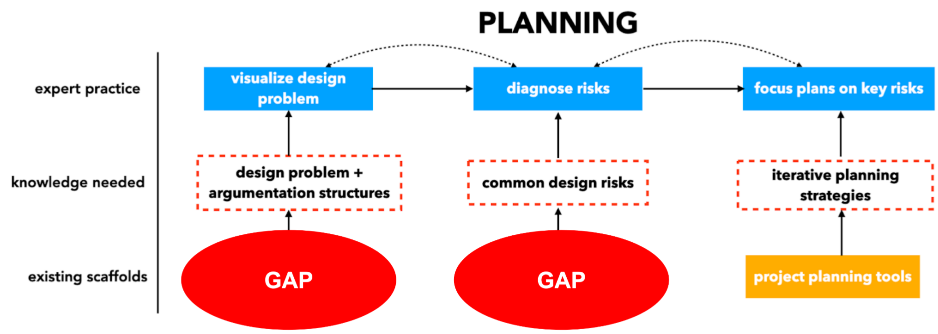

Figure 3. While the existing ARS subsystem scaffolded students to construct iteration plans via the Sprint Log tool and SIG planning meetings, there were still critical gaps -- namely, scaffolding students to visualize design problem structures and diagnose them for risks as experts do.

To address these gaps in our planning scaffolds, we augmented the planning subsystem with ***Polaris*, a representation and risk-assessment tool to scaffold students in constructing and evaluating the argumentation behind their designs** [2]. Polaris embeds expert structural knowledge and diagnostic practice into a *design argument template* and *reflection prompts* (see Figure 4) that focus a novice's attention on three types of issues: *gaps* (i.e. are there components of the argument that are missing?), *lack of depth* (i.e. what is the depth required for each component to form a convincing argument?), and *misalignment* (i.e. what are the links required between and across components to form a cohesive argument?). Using Polaris, students are able to pinpoint the critical risks in their project work, on which to focus their planned next steps.

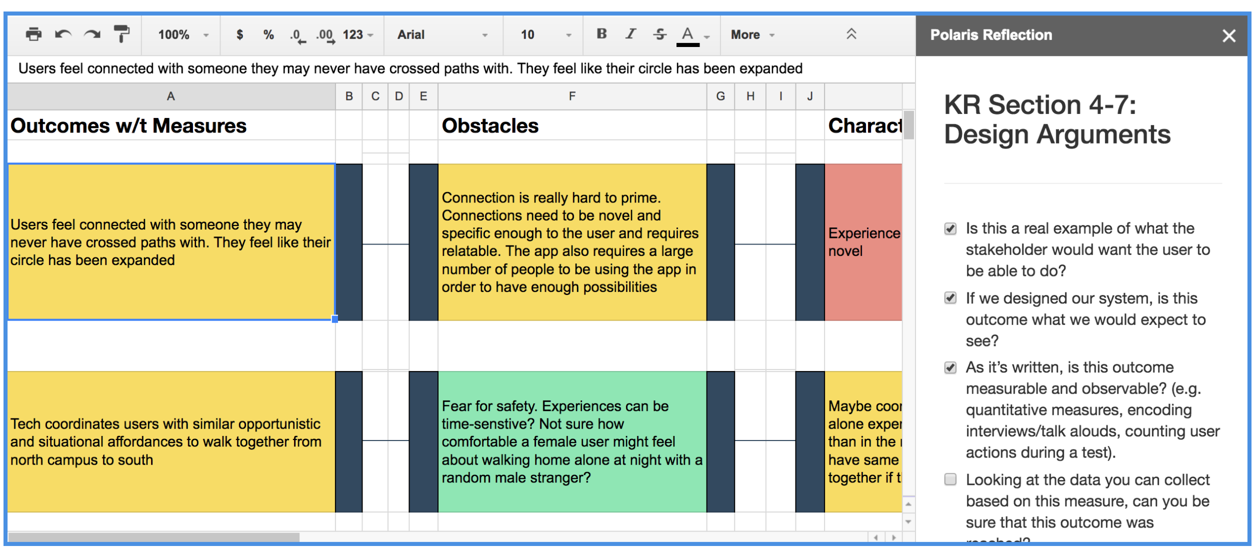

Figure 4. *Polaris* is a learner-centered diagnostic tool that embeds expert knowledge and practice to scaffold novices to construct and evaluate their design arguments. Novices use the *design argument template* (left) and the *reflection prompts* (right) to visually and procedurally evaluate their design arguments for structural issues.

We conducted a pilot study with 13 undergraduates leading 10 independent research projects. Of the 91 issues that students identified with Polaris, 95.6% of the issues focused on core design argument components, and 96.7% of issues focused on three core types of structural issues: gaps, a lack of depth, or misalignment in their design argumentation. To explore the quality of the issues from the perspective of a mentor, we also asked mentors to generate their own issues, and to evaluate the issues generated by 6 of the 10 teams (71 issues reviewed). Findings show that on average, mentors rated the issues that students identified as accurate (4.06/5) and severe (4.11/5). When comparing mentor and student issues, findings also show that students identified 55.17% of the critical issues identified by mentors. Moreover, mentors felt that student issues expressed a student's current understanding, and informed how mentors would coach students to overcome misunderstandings. These findings suggest that diagnostic tools such as Polaris can scaffold novices to identify structural risks in their design argumentation -- risks they can then use to plan iterations that focus on improving the critical aspects of their designs.

3. Process Scaffolds to Execute Effective Practice within an Ecosystem

However, this approach of augmenting the subsystems with new tools and processes in response to each emerging gap can have unintended consequences that disrupt the overall learning ecosystem. Namely, **the introduction of more tools and processes means that the subsystems and the overall ecosystem grow in complexity.** For instance, despite the introduction of Polaris to help students represent and assess risks in their design argumentation, we learned that students conducting design-research needed additional representations for other aspects of their project rationale (i.e. interface and systems arguments to argue for how a design should be instantiated nd how it will functionally work, or an approach tree to help students argue for the novelty of approach compared to existing approaches.) In response, we expanded Polaris as **linked canvas tools**, templates with additional risk-assessment prompts that helped students represent and assess different argumentation layers of their approach. To provide students with direct coaching and feedback on their argumentation, we introduced **Mysore**, a feedback and practice venue where students can workshop a risky slice of their argumentation alongside a research mentor. While well intended, **a complex learning ecosystem rich with supports can actually inhibit a novice trying to navigate that ecosystem as they learn**. Despite these augmentations, I observed that students still struggled to monitor and improve the ways in which they practice metacognitive strategies across the community supports available to them.

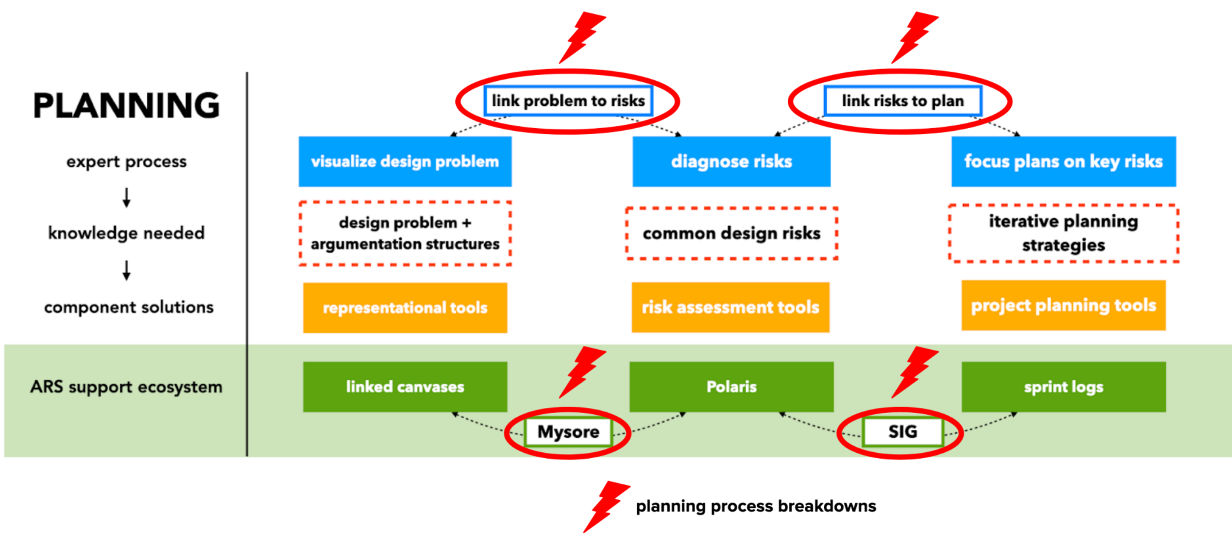

Figure 5. As we augment existing subsystems with new tools and processes, the overall learning ecosystem grows in complexity. We began to observe process breakdowns as students attempted to leverage the ecosystem towards their learning. Here, we see planning process breakdowns, where students still struggle to connect their understanding of the problem to critical risks they have, and then connect those risks to their iteration plan.

While the ARS model introduces this rich ecosystem of supports designed to scaffold students in these metacognitive strategies, the approach fails to explicitly train students to think about how to execute these strategies across the ecosystem of supports available to them, as experts coach them to do. In my work, I have observed **process management breakdowns** (see Figure 5). As an example, students who are planning out their work may set deliverables that address risks they identified at the beginning of their sprint. As they continue working, the Polaris risk assessment tool, a Mysore argumentation feedback session, or a SIG planning meeting may surface a new risk. In such cases, we've observed that students often continue with their previous plan until their mentor raises an issue, rather than adapting their plan to the new risk that was surfaced. This is an example of a **planning process breakdown, where students fail to link the planning feedback they've received via ARS supports to the ways in which they revise their planning process.** As a consequence, students miss out on opportunities to implement the new strategies that the ecosystem of ARS supports helped them surface. For the ecosystem, this can mean poor utilization of the existing supports, limiting it's potential scalability. For the students, this can mean hindering their metacognitive practice and overall development as a self-directed design-researcher.

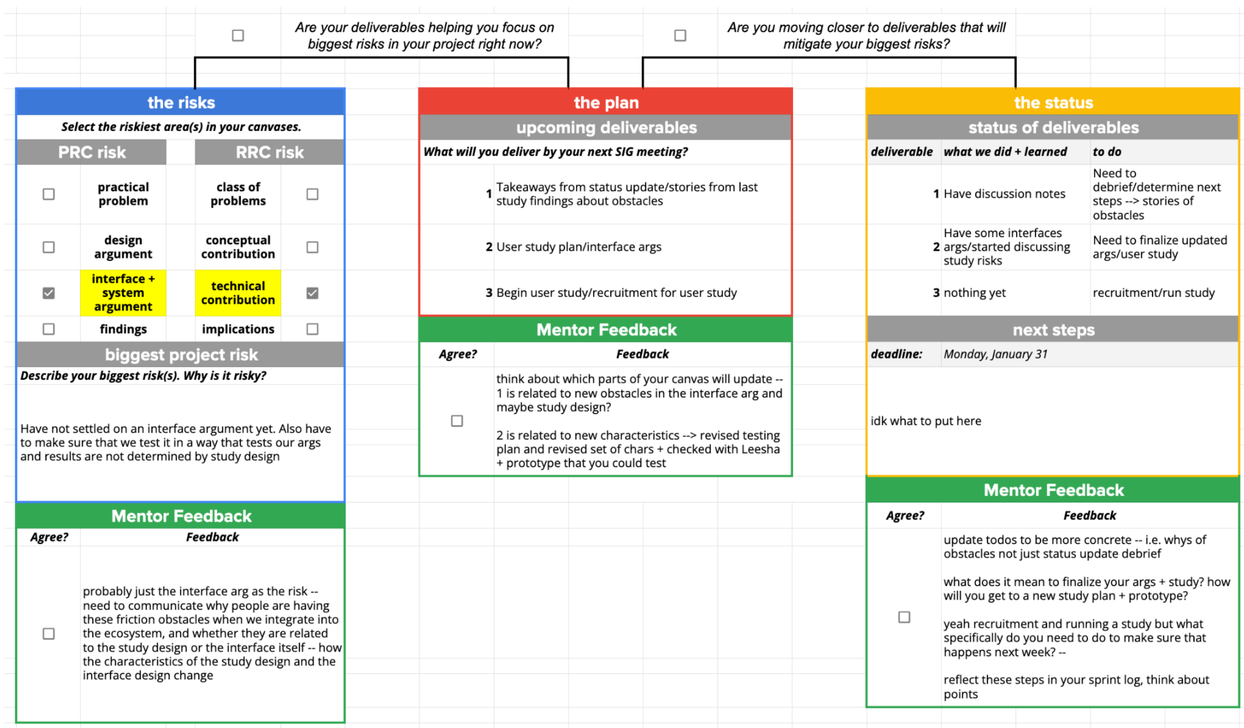

Figure 6. A planning process management framework implemented as (A) a weekly planning dashboard and (B) planning cues via Slack. The dashboard provides students with a view that helps them assess whether their weekly deliverables will address their project risks. The planning cues serve as in-action check-ins that remind students to execute their planning processes at opportune moments (e.g. having students sprint plan before SIG meeting, asking them mid-week if they are still on track for their deliverables, or checking in after a mysore or SIG session to see if they updated risks or plans based on mentor feedback.

To overcome barriers to fully leveraging the ecosystem of available supports, I introduce a ***process management framework* that guides students in how to monitor and revise their metacognitive practice as they move across available supports in the ecosystem**. The process management framework uses a combination of *on-action dashboards* and *in-action cues*. On-action dashboards help students zoom out to plan out, monitor, diagnose, and improve the strategies they practice across supports in the ecosystem (see Figure 6). For example, the planning dashboard helps students assess whether the risks they identified in the Polaris tool are aligned with the deliverables they detailed in their Sprint Log tool. In-action cues help students identify opportunities to enact desired practices as they work with the supports in the ecosystem (see Figure 7). For example, in-action cues can prompt a student to incorporate planning feedback they received in a SIG meeting (e.g. reprioritizing their planned next steps) into their Sprint Log tool, or remind students mid-week to work in alignment with their risks and deliverables. This process management framework *embeds expert process strategies* that model how mentors coach students to monitor and revise the ways in which they execute their practice within the ecosystem (e.g. checking that they are working towards a deliverable that mitigates the riskiest parts of their design and research work as they work). Further, thiis framework *integrates into the existing ecosystem supports* that students already use to practice (e.g. a dashboard view that pulls summative planning process data from the sprint log tool, or as Slack cues sent in their project channel shortly after their SIG meeting). By integrating these expert process strategies into the existing ecosystem supports, these process management scaffolds enable students to recognize and resolve gaps in their practice, as they are practicing in the community. **Integrating a process management framework into existing supports can help students leverage existing opportunities to implement the metacognitive strategies that the ARS ecosystem is designed to surface.** Such scaffolding better equips students to learn how to fully harness the power of socio-technical learning ecosystems like ARS.

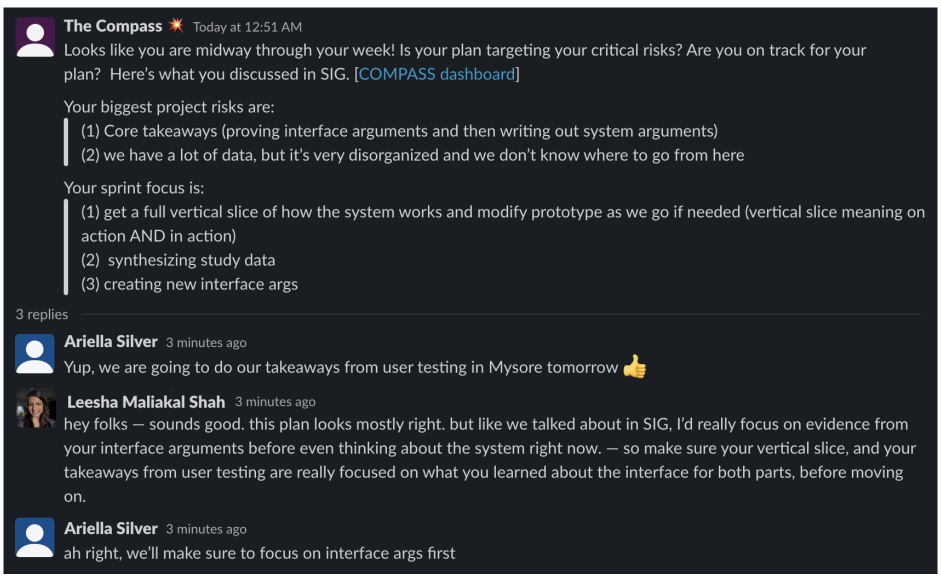

Figure 7. An example planning cue is sent to student's project channel via Slack reminders. It cues them to review their SIG risks and planned next steps, and check if they are on track for their deliverables or need to replan after their SIG meetings. Mentors can monitor how students use these cues, and even add in their own ad-hoc coaching as needed.

Future Research Agenda

I look forward to extending my research by (a) expanding learning ecosystems to guide different skills; (b) adapting ecosystems to varying academic settings; and (c) extending these ecosystem approaches to alternative innovation learning environments.

Expanding Learning Ecosystems with Process Frameworks to Guide Different Skills. With my students, I have begun to explore how to expand our process frameworks to scaffold helpseeking and reflection skills. For instance, mentors frequently coach students to enact particular helpseeking strategies throughout the week. such as routing a student to an expert in the community based on the expertise they need to overcome an obstacle in their work, or guiding students in framing help requests for upcoming feedback and practice venues. Similarly, mentors coach their students to enact particular reflection strategies as they work. For example, how a student's progress on a project risk (e.g. "Work on defining measurable outcomes for your user testing this week") might be inhibited by risks in their ways of working (e.g. "You planned an ambitious user test and likely don't have the hours to execute it. Rather than overcrank, consider focusing your user test on the core functionality you want to test") I look forward to further exploring how process frameworks can also support these different subsystems of practice within an ecosystem.

Adapting Learning Ecosystems for Various Academic Settings. In addition, I have begun exploring how I might adapt these ecosystem models for alternative academic settings. For instance, by adapting many of these ecosystem approaches, I have successfully re-designed the Introduction to HCI course at Northwestern to scalably train 120+ undergraduate students in skills of design argumentation, risk assessment, and iterative planning. Along another vein, how might the ecosystem design adapt to settings where Ph.D. students are not readily available as mentors? Computer Science departments that focus on undergraduate and Masters education provide a unique opportunity to play with models where Masters students or senior undergraduate students practice as research advisors for novice undergraduate students. I am curious to further play with how I might adapt my conceptual approaches to the varying educational needs in academia.

Extending Learning Ecosystems to Innovation Learning Environments. Longer term, I plan to explore how metacognitive training environments might serve settings beyond academia, for those who aspire to design innovative solutions to the problems they face, but may not have access to formal research opportunities. For instance, small business owners and start-up ventures aspire to produce innovative products and services. However, many aspiring innovators face real-world constraints on the resources and supports available to them. In such circumstances, the lack of metacogniitve skills in planning, helpseeking, and reflection can inhibit a person's ability to successfully tackle the real-world problems in their community. In future work, I plan to design learning ecosystems that focus on supporting communities of aspiring entrepreneurs and innovators to develop the metacognitive skills required to lead innovative work.

References

*mentored students

1. Haoqi Zhang, Matthew W. Easterday, Elizabeth M. Gerber, Daniel Rees Lewis, and **Leesha V. Maliakal.** "Agile research studios: Orchestrating communities of practice to advance research training." In Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing, pp. 220-232.

2. **Leesha Maliakal Shah**, Daniel Rees Lewis, *Bomani McClendon, *Sameer Srivastava, Matthew Easterday, Darren Gergle, and Haoqi Zhang. "Polaris: Scaffolding the Creation and Evaluation of Design Arguments for Novice Designers." Computer Supported Cooperative Work (CSCW) 2023. *In preparation.*

3. *Aimee van den Berg, *Ariella Silver, Haoqi Zhang, and **Leesha Maliakal Shah**. "The STASH: Scaffolding the Helpseeking Process within Learning Ecosystems." CHI Late-Breaking Work 2022. *In preparation.*

4. *Molly Pribble, *Neha Sharma, Haoqi Zhang, and **Leesha Maliakal Shah**. "MindYoga: Scaffolding the Reflection Process within Learning Ecosystems." CHI Late-Breaking Work 2022. *Accepted for publication.*