MindYoga: Scaffolding the Reflection Process Within Learning Ecosystems

MOLLY PRIBBLE, Northwestern University
NEHA SHARMA, Northwestern University
HAOQI ZHANG, Northwestern University
LEESHA MALIAKAL SHAH, Northwestern University

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To learn how to self-direct research, students must learn to reflect and improve upon a diverse set of metacognitive skills. Models like Agile Research Studios (ARS) provide ecosystems of tools and processes designed to help students hone their reflection skills as they practice research. However, students still struggle to execute their reflection processes across the supports available to them, as experts coach them to do. MindYoga integrates process scaffolds that help students monitor and execute their metacognitive reflection process across an ARS ecosystem. Findings show students using MindYoga were (1) able to monitor which metacognitive risks may affect their upcoming project work, (2) able to develop action plans based on mentor feedback to address these risks, and (3) actively reminded of their action items during relevant practice sessions. Moving forward, process scaffolds like MindYoga can help learners develop and improve their work processes as they practice within learning ecosystems.

CCS Concepts: • **Human-centered computing → Collaborative and social computing systems and tools**.

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1 INTRODUCTION

For novice student-researchers, learning to reflect on their ways of working is fundamental to improving how they learn, practice, and approach new problems [1–3, 13]. Researchers agree that reflection is an essential skill that drives metacognitive development in expert learners [10–12]. Literature suggests that expert learners execute a metacognitive reflection process, where they monitor, evaluate, and focus their ways of working as they practice. For example, an expert learner may identify that they often forget upcoming deadlines, which means they are frequently rushing to complete their deliverables. They may address this by introducing the use of a planner, sprint log, or to-do list to their work processes. Agile Research Studio (ARS) introduces a learning ecosystem for student-researchers that is designed to develop these metacognitive reflection skills as they learn to self-direct research work [18]. ARS scaffolds the reflection process through a series of tools, venues, social structures, and processes (i.e. a metacognitive goal setting process at the start of term, a weekly meeting for planning feedback, a mid-term and end-of-term self-assessment tool, an end-of-term metacognitive reflection feedback session). Together, these components weave together to scaffold students in metacognitive reflection as they practice research.

While learning ecosystems like ARS may provide a rich set of supports to help students practice metacognitive reflection, we have observed that students still struggle to monitor and execute their metacognitive process across all of the supports available to them. This occurs because students often lack awareness of the risks in their metacognitive practice and how to practically address these risks as they work. Prior work has produced systems that are designed to improve students' metacognitive skills, such as template-based systems and cognitive tutors. While template-based systems can provide structure that guides a student in a metacognitive process, they lack awareness of the state of a specific user's metacognitive skills and provide the same type of scaffolding to all users, irrespective of their unique practice needs at the time. Cognitive tutors can give real-time, tailored feedback to a student, but are often limited to discreet, detectable metacognitive behaviors.

To help students better monitor and execute their metacognitive reflection process across the available supports, we introduce MindYoga: a three-part system that guides students to monitor their metacognitive processes, evaluate strategies they can use to improve these processes, and implement these improvements in practice. MindYoga uses an on-action dashboard to help students and mentors review their metacognitive strategies across weeks, the 4-box model to develop a plan to address risks based on mentor feedback, and in-action cues to point students towards practice opportunities. Based on a 2-week pilot study with four student teams and three mentors, we found that MindYoga was able to guide students through the metacognitive reflection process. Students were able to (1) monitor which metacognitive risks may affect their upcoming project work, (2) develop action plans based on mentor feedback to address these risks, and (3) be actively reminded of their action items during relevant practice sessions. By helping students monitor for challenges and act on opportunities to practice metacognitive practice, such process scaffolds can train students to fully leverage the learning environments in which they practice.

2 BACKGROUND

Cognitive psychology defines metacognition as the ways in which a person reflects on and improves their problem solving strategies [4, 5, 11, 12]. Researchers who have studied metacognitive practice across disciplines assert that reflection is the essential skill that drives metacognitive improvements in expert learners [10]. Further, literature on metacognition and deliberate practice suggests that expert learners reflect and set specific practice goals as they work, where they focus their efforts on the most critical gaps in their skills and practices [3, 7–10, 16, 17]. When expert learners practice reflection as they work, they iterate between (1) monitoring for key risks in their ways of working and (2) evaluating specific strategies they can practice in response, and (3) selecting specific strategies to apply to their practice that overcome their most critical risks [3, 7–10, 17]. Often, such expert practices are learned through a combination of observation, coaching, and practice alongside an expert mentor [6]. While effective, this 1:1 training is not scalable when mentoring resources are limited.

Research has explored how technical systems might support students in monitoring and improving metacognitive practices. Some existing systems take a template-based approach which provides a structured process that learners can use to practice and improve upon a metacognitive skill. For instance, Digital Ideakeeper provides a template that outlines a generalizable synthesis process (i.e. skim, read, summarize) for students learning to conduct online research [14]. However, template-based systems typically provide the same scaffolding for each student, irrespective of the unique metacognitive risks each student faces. For instance, a student writing a research paper may need to focus on improving their helpseeking abilities by asking for peer feedback more often. Another student running a study may need to improve their planning skills when allocating time for follow-up interviews. While template-based systems can provide helpful structure to scaffold a student's metacognitive practice, they are limited in the tailored support they can provide to students.

Other systems like cognitive tutors can adapt to the individual metacognitive behaviors of students by monitoring and sending real-time feedback on their metacognitive processes. For instance, HelpTutor is an adaptive cognitive tutor system which improves helpseeking behavior as students work through geometry problem sets [15]. HelpTutor monitors for when students click the "hint" button as they work through a problem, and provides students real-time feedback on their helpseeking strategy (e.g. if students do not attempt the problem first, they are prompted to do so before asking for a hint). While these systems can monitor and respond to a student's metacognitive practice, they tend to only support specific behaviors (i.e. requesting help before attempting a problem) in specific areas of metacognition (i.e. helpseeking). Further, these systems are not designed to detect metacognitive behaviors that are difficult to identify automatically. For example, within helpseeking, it is much more complex to define and quantify why a student asks for help or how they formulate their help requests, which are important to improving their overall helpseeking process. For novice student-researchers seeking to improve their practice, it's important that scaffolds can flexibly adapt to the variety of complex metacognitive strategies that are requisite for leading research work.

3 NEEDFINDING

Within an Agile Research Studio (ARS), students have access to a number of supports designed to scaffold the metacognitive reflection process (i.e. a weekly planning meeting, a process of setting term-long metacognitive goals for the term, a mid-term and an end-of-term self-assessment tool, and a final reflection feedback meeting). At the beginning of the term, all students set a metacognitive goal that they want to focus on throughout the term and a project goal they want to reach by the end of the term. Mentors coach students on metacognitive practice during weekly planning meetings, During the mid-term check-in, students independently reflect on their progress towards each of these goals using the self-assessment tool, and meet with mentors to get feedback on their plan for the remainder of the term to reach these goals. Finally, the students use the self-assessment tool at the end of term to reflect on if they were successful in reaching these goals, and get feedback from mentors in their final reflection meeting. Together, these supports try to scaffold students to monitor and improve their ways of working. Despite these existing scaffolds in an ARS ecosystem, we observed process breakdowns that still occur for novices as they attempt to engage in the metacognitive reflection process.

3.1 Lack of Awareness of Metacognitive Risks

We observed that novices often have trouble monitoring their ways of working because they lack awareness of how their metacognitive processes impact their project work week to week. During weekly planning meetings, students often do not consider risks in their metacognitive practices and only cite practical risks that relate directly to their project work. Project teams focused on risks such as: "lack of prototype", "designing a user study to test our prototype", and "our findings section [of our end-of-term paper] is still weak", and often didn't recognize how their ways of working may also be risky. Even when mentors raised a metacognitive risk to the student as feedback, we observed multiple instances of students still focusing on the practical feedback that directly references their project work instead. For example, in an interview a mentor paraphrased the feedback they gave as: *"I gave them feedback on 'believing in themselves as an expert designer.' I told them 'you don't have to take baby steps' and that you already have a lot of the knowledge and expertise you need."* However, the student interpreted their feedback as: *"They gave us feedback on 'ways to collect data on conversations surrounding various situations [using] prior research.' For example, 'using what we already know from our*

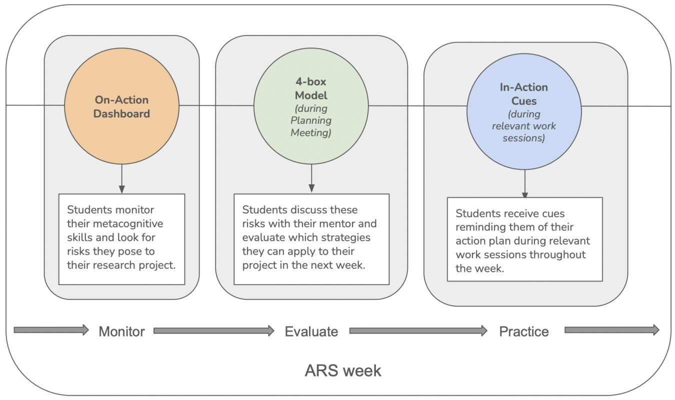

Fig. 1. An overview of how the three components of MindYoga (on-action dashboard, 4-box model, and in-action cues) work together to help students monitor, evaluate, and practice better metacognitive reflection each week.

experience with user studies so far, talking with friends etc."' Here, we see that mentor's feedback is much more focused on the novice's *process*: that they do not have to "take baby steps" in their research process and that they should believe in the knowledge they already have instead of designing a new study.

3.2 Failure to Identify Metacognitive Practice Opportunities While Working

We also observed that students in an ARS have trouble evaluating metacognitive strategies and applying these strategies to their ways of working after they have identified a metacognitive risk. Students were often unsure of how to turn a metacognitive risk into a practical task that can improve their ways of working while also making progress on their project. They often came up with ways to address these risks that were too broad and not easily actionable (e.g. I should "helpseek better"). This makes it difficult for students to implement better metacognitive strategies because it is unclear how they can and should implement these changes in their practice (i.e. what does practicing "better" helpseeking look like in the context of this student's project?). Even if students are able to identify their most critical metacognitive challenge and select an appropriate and specific strategy to overcome it, they commonly reported forgetting to implement this strategy in practice. Students may intend to use the strategy in an upcoming work session, but by the time it arrives, they often forgot what the strategy was, which prevented them from ever implementing the strategy.

4 THE MINDYOGA SYSTEM

MindYoga consists of three components to scaffold each stage of the reflection: an on-action dashboard that scaffolds students in monitoring their metacognitive skills, the 4-box model that scaffolds students in evaluating their plans to improve their ways of working, and in-action cues that scaffold students in incorporating these plans into their practice (see Figure 1).

The *on-action dashboard* integrates into the planning view used to discuss project risks during the planning meeting, and gives users a place to monitor their metacognitive skills and identify their risks alongside their project details across weeks (see Figure 2). To overcome challenges of lacking awareness of their metacognitive risks the dashboard

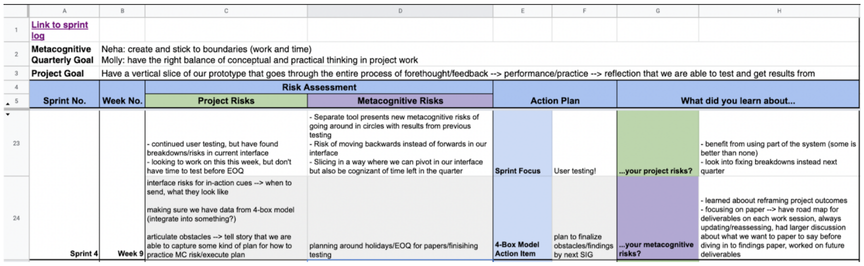

Fig. 2. An example of the MindYoga dashboard view. The dashboard highlights to students the alignment between their metacognitive and project risks for the week, their action item that will help them mitigate both, and their takeaway learnings for their project and their process.

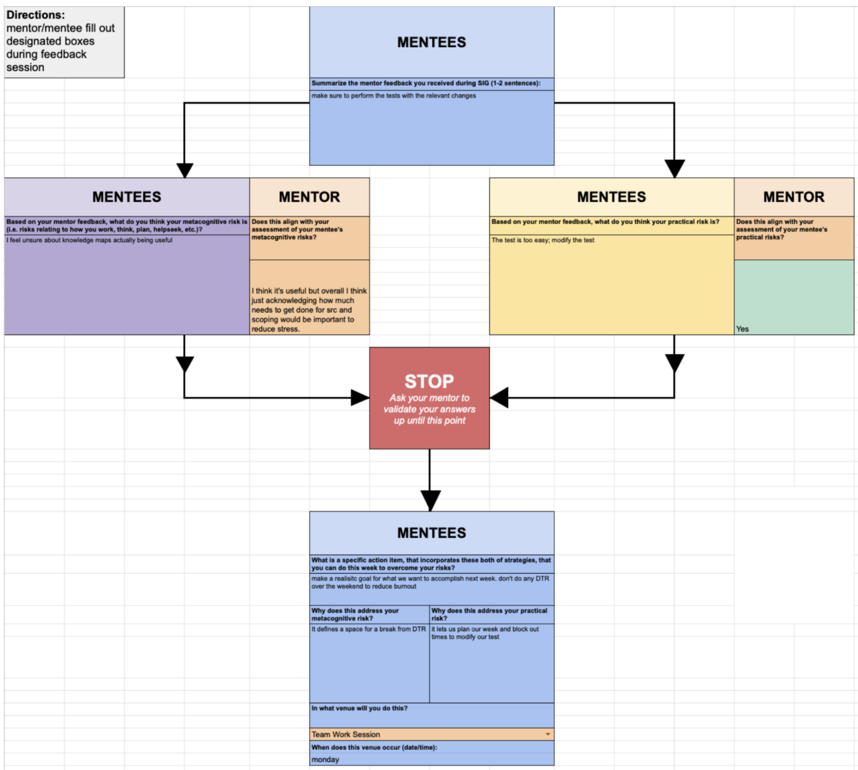

Fig. 3. The 4-box model interface is used in an ARS during weekly planning meetings to guide students and mentors in an explicit conversation about project and metacognitive feedback.

helps students keep track of their metacognitive risks alongside their project risks week-to-week. The dashboard not only shows a history of the student’s project and metacognitive risks, but also shows the student’s planned strategies to practice, and an area where they can reflect on how they’ve overcome both risks that week.

The *4-box model* integrates into the weekly planning meeting to help students evaluate their metacognitive process as they discuss their project plan with their mentors during the last 10 minutes (see Figure 3).Students first capture

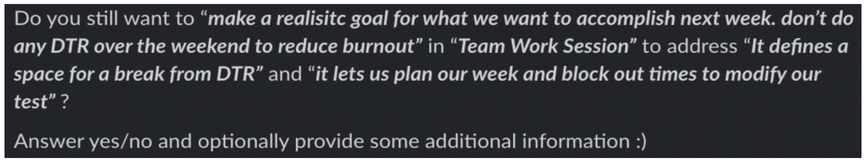

Fig. 4. An example in-action MindYoga cue sent to students over Slack. The cue reminds them at the beginning of their work session of the action item they identified in their 4-box model, designed to tackle the project and metacognitive risks they discussed with their mentor in their planning meeting.

their interpretation of the mentor's overall feedback (see top), and are then guided to parse out the project feedback from the metacognitive feedback (see left and right sides). Mentors can then validate, correct, or expand upon their feedback, ensuring accurate interpretation. Students are then guided to develop a specific action plan that addresses their metacognitive risks in their project work (see bottom). The action plan section requires students to describe a task that addresses both risks, how this task addresses both risks, and a specific upcoming opportunity where they can practice this task. This structure guides students and mentors to explicitly discuss the metacognitive risks and strategies most relevant to their upcoming project work. Notably, this approach captures the tailored mentor feedback on metacognitive practice that generalizable templates may miss, and automated systems may struggle to detect (e.g. a mentor can observe that while a student is great at requesting help at appropriate times, they are struggling to formulate their help requests and, therefore, are unable to receive the help they need).

The *in-action cues* consist of a Slack notification integrated into team channels to remind them of their action plan during the practice opportunity they indicate in their action plan (see Figure 4). The cues aim to scaffold students to practice improved metacognitive reflection processes at the opportune practice moments they self-identify (i.e. during their next work session). By sending a cue to the student during the opportunity they identified in their 4-box model, they are actively reminded of their action plan when they plan to enact it. Unlike cognitive tutors that are limited to detectable metacognitive practices, this approach carries forward the student-specific practices, validated by mentors, that would be useful for that student to attempt in the moment. The in-action cues take the following structure, with each message using the following input from the 4-box model to remind students of their personal action plan: *"Do you still want to [task] in [practice opportunity] to address [metacognitive risks] and [practical risks]?"*

5 METHODS

To understand how MindYoga might support a student's metacognitive reflection process across supports in an ARS ecosystem, we recruited three mentors and seven students across four project teams from an existing ARS to participate in a 2-week study. We asked participants to incorporate our prototype into their existing ARS work processes. At the end of the study, we asked all students to fill out a feedback survey about their experience. This included binary questions about the perceived benefit of the different scaffolds within the MindYoga system and places for the students to elaborate on why and how they found the system to be helpful or not. Additionally, we conducted follow-up interviews with three students and with two mentors. Based on user input into the system and user responses to the feedback survey, we evaluated if users were able to reflect on the changes to their metacognitive processes (risks, strategies and actions) and reassess their risks (RQ1), were able to determine their metacognitive risks and an action plan for addressing them in the 4-box model with alignment from their mentors (RQ2), were they reminded of this action plan during relevant work sessions (RQ3).

	P1: On-action dashboard (RQ1)		*P2: 4-box model (RQ2)*		*P3: Slack in-action cues (RQ3)*	
Project Team #	*# Times Used*	*# Times Reflection of Metacognitive Process Changes Complete*	*# Times Used*	*# Times Metacognitive Risks and Action Plan Identified*	*# Times Used*	*# Times Reminded of Action Plan During Work Session*
1	2	2	2	2	1	1
2	1	1	1	1	1	1
3	0	0	2	2	0	0
4	0	0	1	1	1	1

Fig. 5. Scaffold used vs. outcomes reached for each project team in user study

6 FINDINGS

Our results show that our users were able to reach all three outcomes when they engaged with our prototype at the appropriate stages (see Figure 5). We had two project teams that engaged with the entire reflection process at least once with our prototype. Project teams 1 and 2 reflected on their risks in the on-action dashboard, used the 4-box model, and interacted with our in-action cues during relevant work sessions, thereby completing all three stages of metacognitive reflection at least once. Project team 3 only used the 4-box model scaffold, while project team 4 used the 4-box model and the in-action cues. Even in project teams that did not engage with the prototype in all three stages, we still saw improvements in the stages where they did utilize the prototype.

The on-action dashboard is where we were able to observe improvements in the metacognitive processes of the project teams. Project team 2's reflected on their metacognitive practice across weeks: *"I didn't really understand what [my mentor] meant when [they] kept telling me to be agile but I think i really internalized it this week– I spend a lot of time worrying about all the risks when it's best for me to just try to test something"*. With this scaffold, project teams 1 and 2 were able to monitor their metacognitive processes and identify metacognitive risks for that week (RQ1). Both teams also reported that this prototype helped "internalize" the metacognitive strategies they used and produced reflections in the on-action dashboard on how these strategies helped their work process. Additionally, these teams were able to explicitly identify metacognitive risks that were impacting their project work for the upcoming week, as evidenced by user input in the on-action dashboard.

The 4-box model support helped these project teams clarify their understanding of the mentor's metacognitive feedback. One member of project team 1 reported: *"...getting [mentor] feedback on what we thought was *[their]* feedback made the actual feedback extra clear. Often we were just wrong about the metacognitive feedback and so doing this made [our mentor] actually say our metacognitive feedback directly, which we wouldn't have gotten otherwise."* We also received feedback that the 4-box model's structured conversation promoted reflection around metacognition in the planning meetings that was beneficial. Project team 2 reported: *"just being given the space to reflect was helpful" and "the 4 box model does force us to talk ab[ou]t [metacognitive risks], whereas sometimes metacognitive risks get skipped."* From these results, we determined the 4-box model was useful for students in creating a space for reflecting on their metacognitive risks and structuring a conversation about how to address them. We can see that the tool promotes discussion and reflection within the mentor-student dynamic in an existing ARS support (i.e. the weekly planning meeting). This gives the students an opportunity to become self-aware and direct their metacognitive process while also giving the mentor visibility into the students' current metacognitive processes. These findings show that the students were able to use the mentor feedback to evaluate their metacognitive processes and develop an action plan to address any relevant risks (RQ2).

In project teams 3 and 4, we saw evidence of increased awareness of their metacognitive risks and the development of action plans after using the 4-box model through user behaviors and quotes. A user in project team 3 reported that: *"I sometimes am able to [identify metacognitive risks in the weekly planning meeting], but generally I identify those risks after the [weekly planning] meeting or only think about them when filling out the 4-box model."* This quote reinforces that students and mentors do not usually talk about the metacognitive risks in the weekly planning meeting and the introduction of the 4-box model improves that process. Similarly, a user from project team 4 reported the 4-box model helped them to create their action plan, saying: *"[The 4-box model] helped me reflect on the feedback and solidify an action item in my head."* The members on project team 4 had been struggling with burnout and staying on top of busy schedules. During our user study, we observed that this team did not discuss the issues of scheduling and burnout until they engaged with the 4-box model. After filling it out, this team identified their action plan to be: *"Make a realistic goal for what we want to accomplish next week. Don't do any [project work] over the weekend to reduce burnout."* This evidence shows that both project teams 3 and 4 demonstrated improved ability to determine their risky metacognitive processes from mentor feedback and develop an action plan to address these risks after using the 4-box model (RQ2).

Both project teams interacted with the in-action cues during the time of their work session indicated in the action plan. Project team 2 stated that *"I would have never done [my action plan] if not for Slack [reminders]"*. This shows that users are reminded of their action plan during relevant work sessions (RQ3). Additionally, we saw improvement in project team 4 in the practice phase. One user from project team 4 reported that the in-action cues were helpful and occurred at an optimal frequency: *"Seeing my action item visually a few days later was helpful but any more reminders would have been too much."* The team also demonstrated behavior change to address their risks around burnout. We observed project team 4 ask to have an upcoming project presentation postponed to make their workload more manageable. This improvement in time management of project deliverables seems to stem from the conversation surfaced by the 4-box model, and (coupled with the user feedback) demonstrates that students were reminded of their action plans and were able to enact them (RQ3).

7 DISCUSSION

From our findings we determined that students using MindYoga were able to engage in the metacognitive reflection process. Students were able to monitor their metacognitive processes and identify metacognitive risks in the on-action dashboard (RQ1), use mentor feedback to evaluate their metacognitive risks and to address them in the context of their project with the 4-box model (RQ2), and more actively think about their plan to practice improved metacognitive strategies with our in-action cues (RQ3). Because our tool is able to further scaffold the metacognitive reflection process within an ARS ecosystem, students can more actively improve their metacognitive processes in the context of their research projects. MindYoga is also able to provide individualized support for a wider range of metacognitive process risks than existing systems by helping capture the metacognitive feedback that mentors surface that is specific to each student's metacognitive practice, relevant to project goals, and difficult to detect automatically. By utilizing mentor and student input to customize the in-action cues students receive, MindYoga is able to provide contextualized support to each user depending on their personal and project needs, overcoming a major limitation of template-based and cognitive tutor systems. By scaffolding the metacognitive reflection process itself as opposed to one specific strategy, this approach can scaffold many more metacognitive processes. MindYoga's approach of scaffolding the expert metacognitive reflection process also has potential implications for other learning communities outside of ARS. For instance, such scaffolding could also support a student learning to be an effective teaching assistant in a classroom ecosystem. Future work can explore how this approach might be used in scenarios where the learners seek to improve their metacognitive processes as they practice in a community.

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