Muse: Scaffolding Metacognitive Reflection in Design-Based Research

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ABSTRACT

While learning science research has explored approaches improving students' problem solving skills by introducing tools that support students in metacognitive reflection, this work has focused on problems with clear solutions, rather than addressing the question of how metacognitive reflection can help students develop their self-regulation skills, which help students understand and control their learning environment through planning, practice, and self-evaluation [9]. This paper presents Muse, an in-action chatbot interface that prompts students to reflect metacognitively on their self-direction process in the midst of working on their independent research projects. Students participate in the *Design, Technology, and Research* (DTR) program, which provides several undergrads the opportunity to self-direct an independent research project by using the socio-technological model *Agile Research Studios* (ARS) [8]. Results from a case study suggest that Muse helps students identify time consuming habits and set aside less important tasks by giving participants the opportunity to act on their reflections and adjust aspects of their process that they deem less effective.

INTRODUCTION

Although existing reflection practices have demonstrated that digital learning environments provide an effective space to enhance learning performance through metacognitive reflection [4], these existing solutions do not effectively address the problems that students face in DTR be-

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VOCABULARY

Metacognitive Reflection: Reflection that helps students understand and regulate their cognitive processes, or actions they take to gain and develop knowledge

Self-Regulation: Learning guided by *metacognition*, or thinking about one's thinking, which involves planning, practice, and self-evaluation in order to take control of one's process

Learning Strategy: A metacognitive strategy a student uses to study a task domain and complete the task at hand

In-Action Reflection: Reflection in the midst of conducting an action as a means of tackling problems when there is no secure body of knowledge; generally thought of as a strategy for improvisation

Metacognitive Behavior Change: The process of identifying a more effective learning strategy and changing one's initial behaviour to apply that learning strategy

Agile Research Studios (ARS): A socio-technical system that expands research training opportunities by supporting research communities of practice without increasing faculty mentoring resources

Design, Technology, and Research (DTR): A program at Northwestern University that employs the ARS model and gives students the opportunity to participate in independent, self-directed research

cause prior work has focused on problems with clearly defined solutions, such as math problems. Reflection has also been studied primarily as a retrospective activity, in which students look back at an activity that has already been completed, and the opportunity to apply a more effective learning strategy has passed, and students may forget the takeaways of their reflections [6].

In this paper, we address these challenges with a system called Muse, which employs both metacognitive and in-action reflection techniques to encourage students to evaluate their current process and iteratively improve the learning strategies they are applying. Through Muse, we suggest that in-action reflection techniques could possibly help students improve their self-regulation skills and experience metacognitive behavior change. We define metacognitive behavior change as the process of identifying a more effective learning strategy and changing their initial behavior to apply that learning strategy [1]. During user testing, Muse helped students clarify the obstacles they were facing and exhibit signs of metacognitive behavior change when they were struggling.

The conceptual contribution of this paper is applying in-action reflection to the practice of self-regulation in design-based research through computer based scaffolds, rather than looking at reflection purely through a retrospective lens, as it has been in prior work. Through a chatbot interface, Muse intentionally intertwines the reflection stage of the self-regulated learning cycle with that of the practice stage in order to give students the opportunity to iterate on their practice and adapt a more efficient process as they work independently.

RELATED WORK

Prior work has demonstrated that higher quality and more frequent use of self-regulatory processes in students yields high correlations with improved academic achievement and higher results on standardized test scores [9]. Within the model of self-regulated learning, metacognitive reflection plays a pivotal role because it allows students to make informed decisions when choosing a learning strategy to reach attainable goals [3].

A learning strategy is a metacognitive strategy a student uses to study a task domain and complete the task at hand [6]. Prior research has demonstrated that a digital metacognitive tutor and reduced error rate. However, literature has also shown that being aware of learning strategies is not the same as being able to apply them regularly, and "after students have mastered a learning strategy, they may still choose not to use it" [6]. In Muse, we attempt to scaffold students to apply learning strategies that they have previously learned. We also sought to understand why it may be difficult for students to continuously apply previously learned strategies that they have identified as beneficial.

Factors that affect metacognition include awareness of the problem at hand, cognitive strategy, which puts learning strategies into practice, planning, and self-checking or self-evaluation [2]. An effective metacognitive reflection accounts for these factors in order to help students improve their

Code	*Definition*	*Example*
Gaining awareness of problem, acknowledging resources, analyzing what they learned	1. They talked about identifying a problem 2. They tried to pinpoint where they might have gone wrong 3. They talked about something they learned	1. "We realized that I had a very difficult time explaining my interface contributions, which I took to be the result of my not fully understanding them myself.
Evaluating Strengths & Weaknesses	1. They talked about accepting flaws in their process/what they could be doing better 2. They talked about acknowledging past mistakes 3. They talked about what they did well	3. "I was much more efficient in terms of work in general. I attribute that to 3 things: having people around me to pressure me into working, having a mentor nearby to get feedback from, and having a whiteboard to draw diagrams on."
Applying Strategies	1. They talked about strategies they applied 2. They evaluated how effective those strategies were	2. "I thought removing all distractions was very helpful for me, as it forced me to concentrate."
Planning	1. They talked about prioritizing/setting aside tasks that are not feasible 2. They talked about making progress and actions/goals needed to move forward 3. They talked about risks in their plans	2. "I do want to adjust my direction so I can have some sort of demo ready by the end of the quarter. Again I want to splice my tech more."
Recapitulating	1. Attempts to understand why things occur 2. Evaluates satisfaction 3. Makes changes to strategies or applies what they learned	3. "Changes I made included removing my phone from my vicinity and trying new methods to help debug... They helped increase my speed of work."

Table 1: Codes and definitions to identify instances of metacognition, along with examples from a student.

self-regulation skills. In Muse, we ask students in-action reflection questions that scaffold for these metacognitive factors. The idea of in-action reflection was first introduced by Schön as a means of tackling problems when there is no secure body of knowledge [5]. Rather than a metacognitive strategy, Schön's theory on reflection in-action focused on working professionals who may need to improvise. For example, in teaching, reflection in-action may occur when teachers supervise their students' understanding and improvise with new questions to further the individual student's comprehension. Muse applies this strategy in a digital context to help further students' self-regulation skills by prompting them to metacognitively reflect on a problem they are currently working on and improvise after evaluating the efficacy of their current learning strategies.

In order to test Muse with problems that do not have clearly defined solutions, we identified DTR as a good setting to test and inform the design of our system. Since projects in HCI research may not always have straightforward answers, metacognitive reflection and self-regulation are deeply ingrained in the design of ARS. ARS's main reflection tools are Special Interest Group (SIG) meetings, in which students meet with their mentors to discuss how they can overcome their current blockers (obstacles), and end of term self-assessments that require students to answer a series of retrospective, metacognitive questions [8]. Despite these good reflection practices, students have stated in needfinding that they still struggle with continuously adapting beneficial learning strategies. As a result, Muse was developed to identify the ways in which students may struggle to reflect and turn their reflections into actionable results.

PRELIMINARY STUDY

We conducted an initial needfinding study with 15 undergraduate and five graduate students in DTR, followed by two iterations of prototype testing with three DTR undergrads. Students recorded three to five minute audio reflections about a blocker, they faced in their research project within the last week. Afterwards, similar to a peer review, students traded their recordings with a partner and gave advice to each other based on their partner's reflection. At the end of the activity, participants provided feedback in a Google Doc, describing what they felt was helpful and unhelpful. Participants were also required to listen to their reflections from the prior week.

Our initial study demonstrated the need for further scaffolding, as some students struggled to identify a blocker and did not know what to talk about. "If I didn't know what my blocker was, I would just describe my project," one participant said. We also saw that the exercise demonstrated that students do not actively self-monitor their cognitive processes and learning strategies. "I did not actually ever think about blockers until I made the recording, which is an indicator that I did not take the initiative to reflect on my mistakes," another participant said.

Later prototypes included scaffolding, and although. Many of the reflections demonstrated instances of metacognition based on our coding schema (Table 1), we found that students did not feel like they had opportunities to apply the alternative learning strategies they reflected on, de-

Figure 1: The Muse interface, a Slackbot that sends reflection questions to students during specified work times.

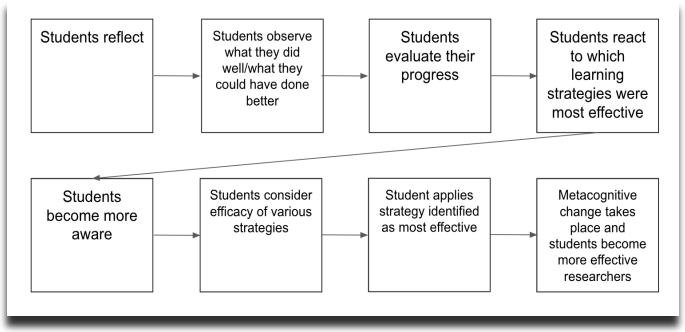

Figure 2: Causal model depicting the process leading to metacognitive behavior change.

spite reporting increased awareness. Students said that the benefits of listening to their original reflection varied because blockers may change on a weekly basis, and they may have forgotten what they reflected on: "I think I tend to forget the ideas that come about when reflecting, and if the issue isn't chronic it's hard to stay aware of the necessary changes to do better in the moment."

SYSTEM DESCRIPTION

Muse is a chatbot interface in which students are prompted to answer metacognitive reflection questions over Slack, a messaging platform already integrated in DTR. Muse is a Slackbot designed specifically for DTR and prompts undergraduate researchers to be more aware of their self-regulatory processes while actively working on their research projects. The system initially asks students for a time interval when students will be working on their projects independently and can answer reflection questions. These prompts and our model for understanding metacognitive behavior change were informed by literature.

Once students have input their times, students are prompted to conduct two rounds of mini reflection. Students are first prompted to reflect towards the beginning of their work session and later complete a second, retrospective mini reflection upon finishing their work. The system asks questions that prompt students to 1) monitor their actions 2) evaluate the amount of progress they made toward their goals 3) judge how satisfied they their progress.

Mini Reflection Questions

These mini reflection questions (Table 2) were designed to take no longer than 5 minutes per round in order to account for the limited amount of time students may have to answer them. The first round of reflection questions focuses on the blockers students are facing during their current work session, and acts as an in-action reflection by prompting students to reflect on their current actions. Muse prompts students to recall the learning strategies discussed with their mentors and reminds students to apply and consider available alternatives if they are stuck. The purpose of the second round of retrospective questions is to prompt students to 1) evaluate the progress students made with their current learning strategies 2) review if they made changes to their process.

Learning Strategies Checklist

During the second round of reflection, the system also sends a checklist of learning strategies specific to DTR, and asks students to mark the strategies they applied during their work session. By filling out the checklist, students will be required to actively think about the strategies they applied and can see other beneficial strategies in DTR that could have been used. The learning strategies in this checklist were based on the final self-assessment students fill out towards the end of term in DTR. After filling out the checklist, students are asked to reflect on a specific strategy they applied and evaluate the impact this learning strategy had on their progress.

Model for Understanding Metacognitive Behavior Change

The system is designed to help students experience the stages of the model depicted in Figure 2. By scaffolding for these metacognitive and cognitive processes, Muse helps students achieve meta-

Round	*Question*	*Code(s)*
1	What did go over during SIG? Are you currently applying what you went over to your project? What strategies did you talk about?	Awareness, Applying Strategies, Planning
1	What are you currently doing well, and what could you do better?	Strengths & Weaknesses
1	Are you satisfied with your current progress, or do you feel the need to adjust your direction? Explain why, and if you need to make changes, detail what those changes would be.	Strengths & Weaknesses, Recapitulating
2	How do you feel about your progress during this work session? Did you feel the need to make any changes to your process? Why or why not?	Strengths & Weaknesses, Recapitulating
2	Describe what you thought was effective or ineffective about your process. Highlight which of the following metacognitive strategies you applied in the learning strategies checklist.	Awareness, Strengths & Weaknesses
2	Describe how applying one of the strategies from the learning strategies checklist helped you.	Applying Strategies, Recapitulating

Table 2: Mini reflection questions asked, along with corresponding codes from Table 1.

Student	*A*	*S&W*	*S*	*P*	*R*	*T*	*MBC*
1	1	1	1	1	2	6	Yes
2	2	1	1	0	0	4	No
3	2	1	2	1	3	9	Yes
4	1	2	1	0	2	6	Yes
5	2	1	1	0	2	6	Yes

Table: Results from the case study, according to codes from Table 1. A=Awareness, S&W=Strengths & Weaknesses, P=Planning, R=Recapitulating, T=Total, MBC=Metacognitive Behavior Change.

cognitive change and become more effective researchers.

EXPERIMENT AND DISCUSSION

We designed an experiment with five DTR students to determine if researchers using Muse could achieve the following outcomes: 1) catch blockers as they arise 2) demonstrate awareness of their learning strategies and how they impact their progress 3) exhibit metacognitive behavior change. The main hypothesis of our study was that students are likely to show metacognitive behavior change as defined by our coding schema with in-action reflections.

Participants were required to use Muse while working independently on their research projects. Afterwards, students were interviewed to understand their thought process while using Muse. Users were also required to do a separate reflection independent of the tool to see if they could continue to produce metacognitive reflections without Muse's scaffolding.

Reflections were evaluated for metacognition based on the same rubric from our preliminary study (Table 1) that coded for the following categories: 1) awareness of blocker, resources, and knowledge 2) evaluating strengths and weaknesses 3) applying learning strategies 4) planning 5) recapitulating or understanding the impact of their actions. The schemas for identifying these behaviors were adapted from Jonassen's framework for metacognitive problem solving [2]. We also kept track of whether metacognitive behavior change occurred by looking for changes in process mentioned in students' reflections or interviews.

Based on our measures, four out of five students exhibited some sign of metacognitive behavior change (Table 2). We noticed that reflections that more metacognitive were more likely to indicate some sign of metacognitive behavior change, supporting our original hypothesis.

The student who did not exhibit metacognitive behavior change failed to provide an alternative learning strategy. Compared to the other students, they scored lower in recapitulating and did not spend as much time analyzing the impact of their learning strategies. Despite identifying procrastination and distraction as obstacles, the student did not try to address these blockers. In their reflection, they stated, "I did not make any changes to my process because I prefer to stick with my process until I start working on a new task."

We also noticed that there was not a strong indication that students could continue to produce strong metacognitive reflections after removing Muse's scaffolding. This observation implied that students still needed the scaffolds to practice applying good learning strategies. Out of the four students that completed the separate reflection, two students produced reflections that were significantly less metacognitive than their reflections with Muse. In a follow-up interview, one student said, "I don't think [Muse] impacted my learning or reflection in any way. I did actually reflect, but I don't think that impacted any of my future actions."

Data collected from follow-up interviews indicated that the experience of using Muse helped students complete tasks more efficiently by either reducing the amount of time spent on a task or adjusting the number of tasks students aimed to complete. "[Muse] kind of reminded me that if I do work the way I usually do, I'll probably end up being really inefficient. I end up completing tasks I don't really have to do," one student said.

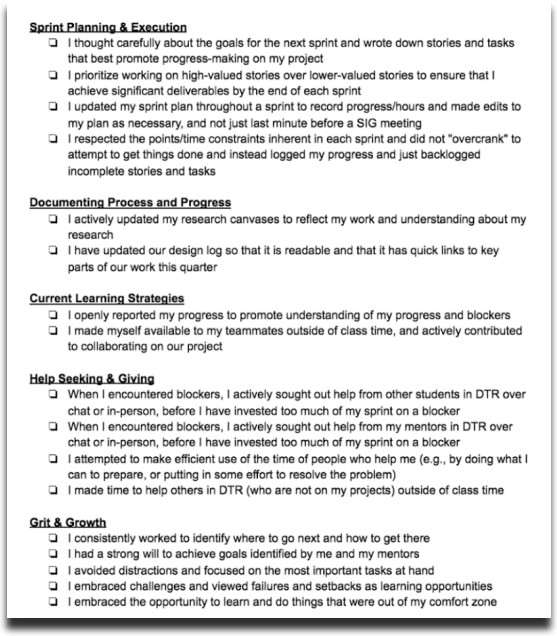

Figure 3: Learning strategy checklist with strategies specific to DTR.

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CONCLUSION AND FUTURE WORK

Muse demonstrates that in-action reflection can help students apply beneficial learning strategies, pointing to signs of metacognitive behavior change. Muse leverages the interactivity of messaging systems to scaffold students to monitor their behavior while working, giving them the opportunity to disrupt bad habits as they occur.

One core limitation of this work is the small sample size, as only five students used Muse in our case study. These students all participate in DTR, which already scaffolds for reflection. It is uncertain if students who are less familiar with self-regulation practices will benefit similarly from using the system. Another core limitation was that the system does not effectively introduce alternative learning strategies if students do not know strategies to apply to their situation. Although the learning strategies checklist provided some support, we concluded that further scaffolding was needed.

Our future work aims to investigate how metacognitive reflection habits can be formed so that students continue to apply previously learned strategies. We also intend to investigate the benefit of suggesting alternative learning strategies by integrating direct feedback from mentors, who can make suggestions specific to the challenges their students are facing.

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