How Technology and Collaboration Promote Formative Feedback: A Role for CSCL Research in Active Learning Interventions

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Abstract: Recent evidence for the effectiveness of active learning interventions has led educators to advocate for widespread adoption of active learning in undergraduate science, technology, engineering, and mathematics courses. Active learning interventions implement technology and collaboration to engage students actively with the content. Yet, it is unclear how these features contribute to their effectiveness. Research suggests that these features may enhance learning by providing formative feedback. To understand how technology and collaboration support learning by providing formative feedback, we conducted an observational study in a traditional and an active learning version of an undergraduate chemistry course. Results suggest that technology-provided feedback in the active learning intervention enhanced collaboration. We identify specific challenges and opportunities in technology design and active learning interventions for computer-supported collaborative learning research to address.

Introduction

Recent research in undergraduate science, technology, engineering, and mathematics (STEM) education shows that *active learning* is more effective than traditional lectures (Freeman et al., 2014). This research describes active learning as a broad range of interventions in which students learn through activities and/or discussion in class, whereas in traditional instruction, students learn through passively listening to a lecture (Freeman et al., 2014). In accordance with the disciplinary-based STEM education research, recent interventions often involve the use of technology and collaboration to foster student learning from peers (Eddy, Converse, & Wenderoth, 2015; Lom, 2012). However, this active learning research has produced little theory about why and how technologies and collaboration can support student learning when compared to traditional undergraduate STEM courses.

One potential reason why active learning interventions are effective is that technologies and collaboration provide *formative feedback*. In traditional STEM courses, instructors typically provide summative correctness feedback based on the content, but they provide little formative feedback on how to learn the content. According to Sadler (1989), formative feedback helps students (1) understand what expert performance looks like and (2) assess their current performance, so that they can take measures to (3) bridge the gap between current and expert performance. Indeed, formative feedback has been shown to enhance student learning by providing correctness and corrective guidance about progress towards expert performance (Hattie & Timperley, 2007). Active learning interventions produce more formative feedback because of their use of technology and collaboration (Eddy et al., 2015), yet it is an open question whether students benefit from the additional feedback. Investigating how students use feedback provided in active learning interventions may provide insight into why active learning is effective and inform the design of technology-enhanced collaborative learning in such interventions.

Gaps in prior research gives rise to the question we examine in this paper: how does technology use and collaboration in active learning interventions support students' learning by providing formative feedback, as compared to common practice in traditional instruction? To address this question, we conducted an observational study of a traditional and an active learning version of discussion sections in an undergraduate chemistry course.

Active learning in STEM instruction

Recent evidence for the effectiveness of active learning interventions has instigated widespread interest in implementing *active learning* in STEM courses, instead of passive lectures (Eddy et al., 2015). The editor of Journal of Chemical Education stated, "to put it bluntly, everyone should be taken off the control (i.e., traditional lecture) and switched to the treatment (i.e., carefully considered active learning methodologies)" (Pienta, 2015, p. 1). Indeed, chemistry education research has shown that active learning interventions lead to significantly higher learning outcomes than traditional lectures (Mahalingam, Schaefer, & Morlino, 2008; Paulson, 1999).

Active learning interventions emphasize learning by doing (Chi, 2009). Typical active learning interventions involve *technologies* such as clickers, online practice problems, or simulations, and *collaboration* such as discussions, problem-based workshops, and roundtables (Eddy et al., 2015). Prior research on active learning has focused on the effects of implementing these features in lectures held in auditorium-style classrooms (Lom, 2012).

To supplement lectures, STEM courses often include *discussion sections* (also known as recitations or review sessions). Discussion sections provide opportunity for an instructor to engage with a smaller group of students and answer students' questions about the course content. Discussion sections are assumed to naturally foster discussion, but research shows that they often foster passive learning found in traditional lectures because students can copy solutions as the instructor solves them (Mahalingam et al., 2008; Paulson, 1999). Therefore, it is important that we understand how to design discussion sections so that they actively engage students with course content. Most research on active learning interventions has focused on lecture settings, not on discussion settings (Eddy et al., 2015; Lom, 2012). Therefore, we know little about how active learning interventions change learning processes in *discussion sections*. To address this gap, our study compares traditional and active learning interventions implemented in discussion sections, particularly on the formative feedback provided.

Components of formative feedback

Formative feedback can guide student interactions by indicating *correctness* on students' performance and providing *corrective* redirection for students' progress. In general, "[f]eedback is commonly defined in terms of information given to the student about the quality of performance" (Sadler, 1989, p. 142). This definition is in line with other definitions of feedback that convey passing of information to the learner by instructors or instructional technologies (Shute, 2008; Van der Kleij, Feskens, & Eggen, 2015). Effective forms of formative feedback take into account students' needs for redirection (Hattie & Timperley, 2007). Sadler (1989) proposed that formative feedback to improve student performance should support students in: (1) understanding expert performance, (2) assessing their current performance, and (3) bridging the gap between current and expert performance.

Unless these three components are supported, students cannot act upon the feedback to improve learning. Specifically, without (1) an understanding of expert performance, students may proceed in unproductive directions. Without (2) an assessment of their current performance, students may not identify the gaps in their understanding. Without (3) the ability to bridge the gap, students cannot improve their current performance towards expert performance. The latter component may explain why "even when teachers provide students with valid and reliable judgments about the quality of their work, improvement does not necessarily follow" (Sadler, 1989, p. 119). Instructors must provide correctness and corrective feedback that help students improve their performance (Mahalingam et al., 2008; Michael, 2006), and students must act upon the feedback (Hattie & Timperley, 2007).

Technologies offer an effective way to provide formative feedback. For instance, technologies can provide practice problems with immediate feedback and detailed explanations that help students assess and bridge their performance in relation to expert performance. Immediate feedback from technologies has shown to be effective at enhancing student learning (Van der Kleij et al., 2015). Further, *collaboration* offers opportunities for formative feedback. When students work with peers, they have numerous opportunities to give and receive correctness and corrective feedback (Hattie & Timperley, 2007). Our present study seeks to understand the role of technologies and collaboration for providing formative feedback in traditional and active learning interventions.

Active learning interventions and computer-supported collaborative learning

Research on active learning has been mostly situated in discipline-based education literature. These literatures focus on practice-oriented recommendations as to how best to implement active learning interventions. They recommend incorporating technology into STEM courses because it can increase accountability to specific tasks, reduce apprehension by anonymizing responses, and address multiple student responses all at once (Eddy et al., 2015; Lom, 2012). Further, they recommend incorporating collaboration into STEM courses because working in groups can foster deeper understanding of the content (Eddy et al., 2015; Mahalingam et al., 2008). However, discipline-based education research has failed to provide a theoretical explanation of why and how technology and collaboration interact in enhancing students' ability to actively engage with learning materials.

Therefore, our research examines how technologies and collaboration interact by providing formative feedback that can help students learn. This research is of relevance to the field of computer-supported collaborative learning (CSCL) for several reasons. First, our research seeks to uncover how the use of technologies in active learning interventions helps students collaborate. This may reveal insight into technology development for CSCL that meets the demands of active learning interventions. Second, our research seeks to uncover how collaboration helps students benefit from technology feedback. This may reveal additional opportunities for structuring collaborative activities in a way that helps students bridge the gap between their own and expert performance. To address these questions, we conducted an observational study to examine how technologies and collaboration support students' learning through formative feedback in traditional and active learning discussion sections.

Method

We situated our observational study in an introductory accelerated chemistry course taught at a large Midwestern university in Fall 2015. The course involved three weekly lectures, a weekly laboratory, and a weekly discussion section. We observed two discussion sections taught by teaching assistants (TAs): a traditional discussion section that involved problem-solving activities without technology support and an active learning discussion section that involved problem-solving activities and incorporated technology support and collaboration.

Setting

Traditional discussion sections were held in classrooms in the Chemistry building with a table for the TA at the front, individual desks in rows oriented towards the front, and chalkboards and periodic tables on the walls. Twelve of the 16 discussion sections of the chemistry course were held in this traditional setting. The traditional sections emphasized problem solving through activities that asked students to engage with course content (e.g., worksheets). The TA circulated the room to monitor students' progress, provide feedback, and answer questions. Students could collaborate on the problems, but received no particular support for collaboration. At the end of the discussion section, the TA reviewed answers to the worksheets or emailed the answer key to the students.

The professor of the course designated four sections as *active learning discussion sections*. These sections were held in a nearby building that provided active learning spaces. These spaces provided large circular tables with outlets, rolling seats, and whiteboards to facilitate collaboration and use of technology (see Figure 1). The four active learning sections emphasized collaborative problem solving. In these sections, students completed paper worksheets that guided student activity. Worksheets included six to nine questions related to concepts discussed in a previous lecture. Each question directed students to complete a set of online problems followed by a worksheet question. Online problems provided correctness feedback and detailed explanations. The follow-up worksheet question asked about more complex concepts and encouraged students to collaboratively discuss concepts with their partners, table groups, or the TA.

Figure 1. Example classroom space designed for active learning. Image from https://teachingacademy.wisc.edu/teach-in-sterling-clc-this-spring/.

Data collection and analysis

The first author observed a traditional section taught by Ted and an active learning section taught by Addie (all names are pseudonyms) from week two to week eight of the semester. In the traditional section, she sat at a desk in a back corner of the class and observed groups of students who worked together near her desk. In the active learning section, she sat at a table in the back corner of the classroom and observed a group of six students who sat at the table each week. While observing, she did not participate in student discussions but conducted fly-on-the-wall observations using a pen and notebook. She typed up observations following the discussion sections.

In week nine of the semester, the first author conducted interviews with the professor, the TAs (Addie and Ted), and five students (three from Ted's and two from Addie's section). Two student interviewees were members of observed groups, and the other three sat in other areas of the discussion sections that the first author did not observe, to provide a comparison of student experiences. Interviews were audio recorded and transcribed.

We conducted a bottom-up and top-down analysis of the field notes and interviews (Miles & Huberman, 1994). Our bottom-up analysis yielded 33 codes describing student interactions with technology and peers in three co-occurring categories: who was involved in the interactions (people), how they interacted (social interactions), and what they used (materials). Then, we applied the framework proposed by Sadler (1989) for formative feedback to co-occurring codes (e.g., TA + give-explanation + chalkboard/whiteboard).

Results

We organize our results from interviews and observations in relation to components of formative feedback (Sadler, 1989): (1) understanding expert performance, (2) assessing current performance, and (3) bridging the gap.

Feedback component 1: Understanding expert performance

According to Sadler (1989), students first need to understand expert performance. Our observations revealed that information about expert performance was often provided in the form of *correctness explanations* by the TA or by instructional materials (e.g., textbook, answer keys, and online problems). In the active learning section, we observed students reading explanations in online problems. In both the traditional and active learning sections, we observed TAs giving explanations to the whole class using the board or worksheets. For example, the TA of the traditional section, Ted, spent 15 minutes during one session at the chalkboard explaining crystalline solids, a topic that he said was not discussed in lecture. He said that "exposure will come from [the discussion section] and lab" and advised students to "read more about it." In each discussion section, Ted provided answers and explanations to the whole class, individual students, and groups. Ted said he used his discussion section to "connect [worksheets] with what we [instructors] [are] trying to talk about—probably for the exam, for what [students] are going to use in the future." He believed the goal of "the discussion session is more like trying to deliver what the class is talking about." He wanted to provide feedback that helps students understand expert performance because students will be tested on it on exams and potentially in future courses.

Similarly, we observed Addie, the TA of the active learning discussion section, circulating the room to monitor collaboration, troubleshoot issues, check understanding of concepts, and explain concepts that students did not understand. Each time she gave feedback on students' explanations, she also provided her own explanation. For example, in an interview, a student explained, "sometimes the worksheet does have you like tell [Addie] what your answer was and why, which is good because she is usually very critical about that and if you're sort of vaguely explaining something, she wants you to do a better job and she'll go through [the explanation] too." Thus, both Ted and Addie viewed providing expert feedback as a key aspect of their role as TA.

However, Addie believed that her role differed slightly from TAs in traditional sections. As she explained in her interview: "The setup of the discussion section does impact my role somewhat, so I guess if it wasn't structured in the way that it currently was, I would probably spend more time like answering questions […] to see like [students] had any general questions on material in lecture, or on... like their pre-discussion worksheets and such." In Addie's section, feedback from online problems helped to answer student questions. The feedback provided expert performance that Addie otherwise would have provided if she was in a traditional section.

Students' understanding of expert performance seemed to be a key aspect of the course. The professor stated in his interview that he and the other instructors try to "make [the course] better preparation for students who are going to engineering or bio-medical areas." He then listed the concepts and skills important to the course. His focus on course content highlights how expert performance is emphasized in the design of the course.

Our results suggest that understanding expert performance is prevalent in course design and instructor interactions. The key difference between traditional and active learning sections was that online problems provided extra support for expert feedback by indicating correctness of responses. Thus, students in the active learning sections received more feedback for understanding expert performance than students in the traditional section.

Feedback component 2: Assessing current performance

Next, students need to assess their current performance (Sadler, 1989). Our observations revealed that students and TAs assessed students' performance by *checking answers for correctness* on worksheets or online problems.

Both TAs circulated the room to check students' answers. As Addie explained in her interview: "If I notice that […] they got the question wrong, then I might ask them if they understand what's going on, and […] if they don't have any questions, then I would move onto the next […] table to see if they have any questions." Addie explained that she stopped to check students' answers, but that she had to move on to other students to make sure she addresses all student questions. This suggests that she had limited time for each student and may therefore not be able to help all students assess their current performance.

Our observations suggested that peers can augment TA feedback by helping each other assess their current performance. For example, in Ted's section, we observed a student, Tammy, helping another student, Tom:

> Tammy: "What about phosphorus?" (*looking over at Tom's worksheet*)
>
> Tom: "It's …." (*trying to explain his answer*) "Oh no, no it's not… ah phosphorus, why you do that to me?" *(he erases work on his paper)*

This excerpt illustrates that Tom did not realize his error until Tammy asked about his answer and he attempted to explain it. Our observations showed that feedback from peers often triggered students' assessment of their current performance. This example also suggests that collaboration can help students self-assess their current performance through explaining. In an interview, a student in the active learning discussion section, Colleen, stated that explaining is "one way [she] like[s] to self-assess, it's being able to explain it." The following example illustrates a common observation from the active learning discussion section where students explained concepts to each other and used feedback from online problems to assess their performance on a specific problem:

> Carl: "2-2NO"
>
> Colleen: "Wait"
>
> Carl: "I don't think we need this other box"
>
> Colleen: "But we aren't allowed to put intermediates in the rate law"
>
> Carl: "No..."
>
> *Colleen and Carl stare at the computer.*
>
> Colleen: "I'll try one..." (*clicks on the computer)*
>
> Carl: "So then the reaction is dependent on that, right? I think…" (*starts to explain his reasoning while drawing on his paper, and then suggests an answer*)
>
> Colleen: "Oh, I'll try it" (*clicks on the computer)*
>
> Colleen: "Yes" (*announcing that they were correct*)

In this excerpt, Carl and Colleen were unsure how to approach a problem. Carl found a solution but needed feedback from the online problem to assess whether his understanding and explanation was correct.

Further, correctness feedback from online problems can help students address gaps in their understanding. For example, a student explained that online problems helped her because "if you got [a problem] wrong, that's where you learn a lot because I can go back and […] if I just know the numerical answer, like if it's 8.3, and my answer is way off, then I could just go back and just try different ways to do it and then the one way that works, then I'll know, ok, this is the technique that I need to use to do this problem. Or I can see where I went wrong, I guess, and that really helps me 'cause the next time I do it, I make sure I don't make that same mistake." This quote illustrates that correctness feedback from online problems may help students identify *what* they do not understand. Further, the feedback may also help students identify *how* to resolve such gaps.

In sum, our observations showed that feedback assessing students' current performance can be provided by TAs, peers, and online problems. Because TAs must manage many students and can hence not always be readily available, students had to rely on additional feedback sources to assess their current performance. In the traditional discussion section, peers served as feedback sources when they checked each other's answers for correctness. In the active learning discussion section, peers and online problems served as feedback sources. Particularly, online problems provided correctness feedback that augments students' assessment of current performance.

Feedback Component 3: Bridging the Gap Between Current and Expert Performance

Third, students need to bridge the gap between current and expert performance (Sadler, 1989). Our observations revealed that TAs and students bridged the gap by providing *corrective explanations*. For instance, students may explain concepts not covered in the course to support *what* students do not understand and *how* to address it:

> Colleen: "Ok, I'm completely unfamiliar" (*referring to the problem regarding the heat formula and how to calculate it*) "It was not in the textbook or the lecture"
>
> Carl: "You probably remember q = MCaT" (*the heat formula*)
>
> Colleen: "I didn't take AP Chem"
>
> Carl: "I can explain it if you want"
>
> Aaron: "Explain it please" (*looks over from his computer*)
>
> Carl: "You too?" (*turns to Aaron*)
>
> Aaron: "I like how he explains it" (*looks at both Colleen and Carl*)
>
> *Carl explains the use of the heat formula by drawing a diagram on his paper.*
>
> *Addie comes over and hears the end of the explanation. She suggests paying attention to the units because they are different (joules vs. kilojoules).*
>
> *Addie then looks at the paper and realizes students do not understand the heat formula. She suggests that Aaron and Colleen do question 3 on the worksheet to get the background.*

In this example, Colleen and Aaron asked Carl to explain a concept that was not covered in existing instruction. Colleen mentioned in her interview that Carl often explained concepts as they worked together (see also the excerpt of Carl and Colleen in the above section). She finds that Carl is "really helpful. He took AP Chemistry so I think he just knows some of the basics better." Hence, Aaron and Colleen seem to value his explanations. Further, Carl's explanation helped the TA, Addie, realize what students did not understand and provide corrective feedback needed to bridge the gap. Hence, collaboration not only helped students, but also the TA, identify and bridge gaps.

This observation also suggests that TAs may not be able to resolve the gap easily because their thinking differs from students. Interviews provided further evidence for this observation. For instance, Ted said that he "can see the answers most of the time, but [students] don't, so [...] if we [TAs] work it out too fast, [students] are [...] confused... I'm not sure if they do understand or don't understand it." A student in Addie's active learning section also identified this difference: "there's peers who [...] try to explain it in a way that you understand, rather than teachers explaining it in the way that they think people understand maybe, which is sometimes right." She appreciated peer explanations because TA explanations were not always useful to her own understanding.

Addie's student also added that, "it's also helpful to listen to other people's questions because a lot of times like you haven't quite gotten to that yet, or like they have a different insight [...] and then um it's also helpful like to try to explain to other people too, so like if you think you have a good aspect on that, it would help them out." This student found collaboration useful because it allowed her to ask questions, explain to peers, and to listen to exchanges among other students.

Our observations suggest that collaboration and student explanations occurred less frequently in traditional sections. A student in Ted's traditional section articulates this observation: "[Ted] says, you can work together but a lot of people don't work together that much, and I'm probably one of them too, because I don't know, I wish there was a different way to have us work together than just ok, here's a worksheet [...] no one has seen the materials before, so then, I don't know it's hard to just be able to work together on it because you have to really understand it personally. A lot of times working together, it's usually like ok, here's the answer." This quote illustrates that many students in the traditional section did not work together. Those who worked together checked answers for correctness to assess their current performance, but did not work with each other to bridge gaps.

The student further explained she was hesitant to collaborate because there is risk in working with peers: "I would rather get help from a student, but I probably go to the TA to get help because it's more convenient [...] students could tell me the wrong way to do problems. You have to be careful of that, make sure it's the right way and the right answer." This student worried that corrective feedback from peer explanations included incorrect information. Hence, she relied on the TA for feedback. This suggests that, without *correctness* feedback from an expert on "the right way and the right answer," students may be hesitant to collaborate and help each other bridge the gap between current and expert performance because they perceived peers' corrective explanations as risky.

In sum, our findings suggest that feedback from TAs may not sufficiently bridge the gaps that students identify. Peer feedback seemed to be most effective in helping students bridge the gap between current and expert performance because students have a better understanding of their peer's gaps. Such peer collaboration was prevalent in the active learning discussion section, but not in the traditional discussion section because students did not trust corrective feedback from peers without correctness feedback.

Discussion

This paper presents an observational study of active learning and traditional discussion sections in an undergraduate chemistry course. Interview and observational data showed that students received formative feedback from: (1) TAs and online problems to help students understand expert performance, (2) TAs, online problems, and peers to help students assess their current performance, and (3) TAs and peers to bridge the gap between expert and current performance. In regards to bridging the gap, results suggest that students wanted collaboration and more feedback from peers, because peers "explain it in a way that [they] understand." Such peer explanations were more prevalent in the active learning sections than in the traditional sections.

One key difference between the active learning and traditional discussion sections was the availability of online problems. In the active learning discussion section, students received correctness feedback from online problems. The correctness feedback may have helped students address confusions and identify gaps between their current and expert performance. Then, students could ask their TAs and peers to help them bridge specific gaps with *corrective* feedback. In the traditional discussion section, students were not provided feedback from online problems to assess whether their answers were correct. These students checked answers with peers to assess their current performance, but they did not trust the correctness feedback or corrective explanations from peers because they might provide incorrect information. Hence, they did not engage in peer explanations to help them bridge the gap. Therefore, one possible explanation of how technology supported collaboration in active learning interventions is that correctness feedback from the online problems helps students trust corrective feedback from peers, particularly in bridging gaps between expert and current performance. Figure 2 shows a theoretical model of this process for active learning and traditional discussion sections.

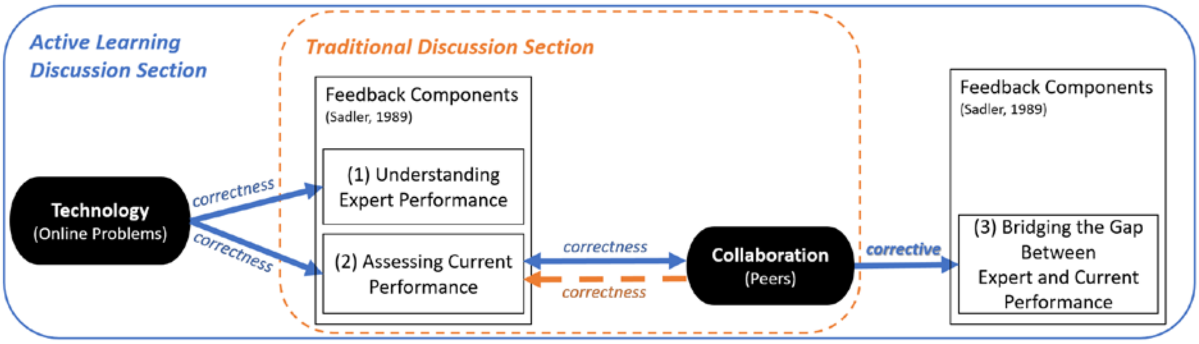

Figure 2. Theoretical model of the interactions between technology, collaboration, and feedback in active learning discussion section (blue, solid lines) and traditional discussion section (orange, dashed lines).

From a CSCL perspective, it is striking that the online problems did not directly support collaboration. Rather, they *indirectly* supported collaborative learning by providing feedback that students elaborated on in peer collaboration. Specifically, the online problems in our study focused on content, not on collaboration. This finding extends CSCL research, which has typically investigated technologies designed to directly affect student collaboration and learning (Strijbos, Kirschner, & Martens, 2004). On the one hand, this indicates that CSCL research should investigate how content-focused technologies enhance collaboration without explicitly being intended to do so. Because active learning interventions describe a broad range of interventions that use various types of educational technologies and collaborative interventions, these interventions provide a rich context to investigate how technologies enhance learning through collaboration. In this context, CSCL provides a useful perspective that can help explain which mechanisms account for the effectiveness of active learning interventions (Strijbos et al., 2004). On the other hand, CSCL research may further improve active learning interventions. If indirect supports for collaboration are effective, can *direct* computer-based supports with elaborated feedback further enhance collaborative learning and yield even more effective active learning interventions?

The fact that content-focused correctness feedback supported collaboration by fostering trust in peers' corrective feedback highlights the need to consider *trust* when designing technology to support collaborative learning in STEM courses. While students preferred peer feedback, students did not trust it unless it was informed by correctness feedback. Students' apprehension may result from the emphasis of exams in STEM courses on *one* correct answer as an indicator of expert performance. Thus, students require content-focused correctness feedback that assure progress towards expert performance. This has important implications for technology design and implementation. For instance, technology could enhance collaboration by providing access to peer explanations, but students may not trust that feedback without confirmation from an expert that the explanations are correct. Once students received correctness feedback that they trust, they may engage with peer explanations that enable them to bridge the gap. Future investigations should confirm our findings that correctness feedback makes active learning interventions effective for collaboration in order to inform the implementation of active learning in STEM courses. For instance, a follow-up study could investigate whether providing online problems that only provide correctness feedback to students in the traditional discussion section can also promote collaboration.

Our study also raises questions regarding the role of instructors and peers with collaboration and technology. Feedback supports students in understanding expert performance, assessing current performance, and bridging the gap between them. Instructors typically provide all three types of feedback. However, our findings suggest that they may not be able to effectively do so for all the students. Hence, instructors and students may both benefit from technology support that adapts feedback to instructor and student needs. Investigating how instructors and students use technology feedback can provide insights into how educational technologies might provide more specific, tailored guidance that supports student learning (Van der Kleij et al., 2015).

Limitations

Our study should be interpreted in light of the following limitations. In general, qualitative studies serve to reveal causal mechanisms in the specific study context. They do not attempt to prove generalizable causal relationships. As with all qualitative studies, our study provides an account of a specific sample, context, and setting. A variety of factors may contribute to the feedback and collaboration between peers and TAs, such as motivation and ability of students to provide quality feedback to each other (Nicol & Macfarlane-Dick, 2006). Future research will investigate how these factors influenced interactions among students, instructors, and computer-supported instructional materials and whether they contribute to the effectiveness of active learning interventions. Further, this study focused on formative feedback. Many other aspects affect student learning such as the group dynamics in which interactions are situated. Future analyses of this data will investigate the sociocultural factors in the discussion sections that may explain the effectiveness of active learning interventions and provide further insight into the mechanisms underlying how technology and collaboration support student learning.

Conclusion

In sum, an observational study showed an indirect role for technology on collaboration between students in an active learning discussion section. The technology provided formative feedback that helped students understand expert performance and assess their current performance. By supporting these two key components of feedback, the technology indirectly enhanced students' ability to collaboratively bridge gaps between current and expert performance. The technology also enhanced the instructors' ability to provide appropriate feedback. Our results provide a first attempt at building a theoretical model describing the mechanisms that account for the effectiveness of active learning interventions in STEM courses. Further, our findings provide directions for further CSCL research that should test whether enhanced technology-supported feedback or direct support for collaboration may further enhance the effectiveness of active learning interventions.

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