Revising Biology Misconceptions Using an Online Activity With Retrieval Practice and Explanation Prompts.

Merrin C. Oliver, Mercer University, oliver_mc@mercer.edu
Maggie D. Renken, Georgia State University, mrenken@gsu.edu
Joseph J. Williams, National University of Singapore, williams@comp.nus.edu.cg

Abstract: Conceptual change instruction is crucial in domains like science, where students come into the classroom with intuitive misconceptions that need to be revised. While previous conceptual change instruction has focused on classroom-based environments, this study designed an online activity that identified misconceptions with a retrieval-practice task and compared the effects of subsequent self-explanation and instructional explanation prompts on knowledge revision. Results indicated that the retrieval practice activity induced cognitive conflict in learners who had misconceptions, and learners who received subsequent prompts to explain the correct answers had significantly higher post-test scores than students who read refuting explanations. We suggest that self-explaining is a particularly effective revision task for online Biology courses, where students may not actively engage with the refuting explanations that are used in classroom-based conceptual change instruction.

Keywords: conceptual change, self-explaining, misconception, refutation text, photosynthesis

Introduction

When learners enter classes with pre-existing misconceptions about the content, traditional instruction is not sufficient to correct those misconceptions, and learning is hindered (Chi, 2013). Specially-designed instruction is often necessary to correct misconceptions through conceptual change, and most of this instruction continues to assess and utilize revision activities in classroom-based learning environments (Tippet, 2010).

Bridging the gap between traditional conceptual change instruction and adaptive educational technologies could optimize distance learning in domains like science and potentially increase the fit of adaptive models (Liu, Patel, & Koedinger, 2016). To begin building this bridge, we should examine the effectiveness of revision tasks in online environments and design ways to identify misconceptions–and thus the need for adaptation to a revision task–during normal instruction. In this study, we designed an online retrieval practice activity that used misconception inventory items coupled with confidence ratings to identify misconceptions and compared the effects of two revision tasks, self-explanations and instructional explanations, on conceptual change.

Theoretical framework

Conceptual change

Students naturally interpret new information according to what they already know and bring with them knowledge from both informal and formal learning experiences (Chinn & Brewer, 1993). However, often learner's prior knowledge is misconceived and inaccurate. To optimize subsequent learning, misconceptions need to be revised through conceptual change; a complex type of learning that replaces the misconception with correct knowledge (Chi, 2013).

While encountering new information that conflicts with prior, intuitively-based knowledge is considered to be a fundamental aspect of learning science (Chinn & Brewer, 1993), it is notoriously difficult to get learners to revise their misconceptions and achieve conceptual change. Conceptual change is composed of a number of component processes that need to be facilitated through instruction for revision to occur. First, instruction should elicit cognitive conflict, where the learner noticeably experiences a conflict between the misconception and correct information, by simultaneously activating the misconception and correct information in working memory (Chi, 2013). After cognitive conflict is induced, instruction must encourage outdating of the incorrect knowledge and updating of the correct knowledge into the learner's knowledge structure (Kendeou & O'Brien, 2014).

The effectiveness of conceptual change instruction is often assessed qualitatively in interviews or quantitatively using pre-post changes in misconception inventory accuracy. However, the process of conceptual change is gradual (Kendeou & O'Brien, 2014). Learners will experience cognitive conflict for some amount of time before revision occurs, which would not be indicated in a posttest. The effects of a single task are better understood by examining relative changes in learner's confidence. Increased confidence in the inaccuracy of a misconception (i.e., knowledge outdating), increased confidence in the accuracy of the correct answer (i.e., knowledge updating), or decreased confidence in either (i.e., cognitive conflict) would indicate that conceptual change is underway to some degree.

Revision tasks

Most work on conceptual change instruction investigates the usefulness of modified instructional explanations, referred to as refutation texts, in facilitating change. Refutation texts typically include three primary components: the statement of the misconception, the refutation of that misconception–which the inaccuracy of the misconception is pointed out–and an explanation of the correct scientific understanding (Tippet, 2010). Refutation texts are designed to promote cognitive conflict in learners, and research consistently indicates that they are more effective than traditional instructional texts at facilitating conceptual change in science classrooms (Tippett, 2010).

Self-explaining may also be an effective revision task, because it actively engages students and encourages them to monitor their own learning (Chi, 2000). Like refutation texts, self-explaining prompts can encourage misconception revision by highlighting inconsistencies in knowledge to promote cognitive conflict. The positive effects of prompts to self-explain particular parts of content, a problem, or an answer are indicated in numerous studies looking at knowledge building–a finding known as the self-explanation effect (Chi, 2000)–and research has more recently evidenced effectiveness for knowledge revision online (Williams, Lombrozo, Hsu, Huber, & Kim, 2016).

We were interested in misconceptions found in Biology education, where students start and finish college level-biology courses with intuitive, but inaccurate, understandings of how plants get energy and mass for growth (Boomer & Latham, 2001). Like most work on conceptual change, refutation texts are the most commonly assessed method for revising misconceptions about photosynthesis and respiration (Tippet, 2010). While some studies designed and examined computer-assisted conceptual change instruction for photosynthesis misconceptions, like digitally presented content modules or computer-based concept mapping, the activities were incorporated into traditional face-to-face classes and facilitated by an instructor or peer group (Çepni, Taş, & Köse, 2006). Previous work provides little insight into the revision of these misconceptions in distance-learning environments and has not assessed whether providing revision activities to students who do not hold the targeted misconceptions is detrimental to learning.

Current Study

Multiple-choice questions with misconception lures are often used as pre-post assessments to measure the effects of revision activities like refutation texts, but their ability to be used *as* a revision activity for biology-based misconceptions has not been assessed. We designed an activity using multiple-choice questions with known misconception lures to activate existing misconceptions and employed confidence ratings to identify the component processes of conceptual change. Subsequently, some learners received prompts to self-explain or received prompts to read an instructional explanation of the correct answer. When paired with the correct answer feedback, the instructional explanations had all the components of a refutation text. We compared the effects of the activity with and without specific explanation prompts on conceptual change learning. We used changes in confidence ratings and posttest scores to answer the following research questions:

1. Which type of explanation prompt, self-explanations or instructional explanations, is more effective for learning about commonly misconceived biology content in an online activity?
2. How does retrieval practice, with and without explanation prompts, affect participant's confidence in correct answers and misconception lures?

Methods

Participants

Participants were 403 undergraduates in the second part of a two-sequence introductory Biology course at a large Southeastern university in the United States. 71% of participants were female, 28% male, and 1% preferred not to answer; 39% identified as African American, 28% Caucasian, 13% Asian/Pacific Islander, 8% Hispanic, 8% other/multiracial, and 4% preferred not to answer. Participants were randomly assigned to one of three conditions. After excluding participants who did not complete both sessions from analysis, group distributions were as follows: *self-explanation* condition (n = 118), *instructional explanation* condition (n = 140), or *no explanation* condition (n = 145). All participants passed a Biology I course that covered photosynthesis and respiration before participating in the study.

Procedure and materials

Participants completed two sessions of online activities housed on Qualtrics. The first session included a brief multiple-choice assessment of prior domain knowledge, followed by a 12-item revision activity to identify participants' misconceptions and to prompt them with an opportunity to revise them. One week later, the second session included a posttest to measure changes in knowledge from the revision activity. Participants' biology instructors assigned the sessions as homework by sharing links to the Qualtrics-based forms.

Session 1: Revision activity questions

We adapted previous measures of photosynthesis and respiration misconceptions (AAAS 2016; Amir & Tamir, 1994; Boomer & Latham, 2011) to create 12 revision activity questions. We worked with biology instructors to identify common photosynthesis and respiration misconceptions and to confirm the appropriateness of our revision activity questions. Each question was multiple choice and had 4 answer choices: 1 correct, 1 target misconception, and 2 incorrect answer choices. We included 4 target misconceptions in the items: ***Misconception 1 -*** plants get their food from the soil (AAAS, 2016), ***Misconception 2 -*** plants do not respire (Amir & Tamir, 1994), ***Misconception 3 -*** plants only respire when they are not photosynthesizing (Boomer & Latham, 2011), and ***Misconception 4 -*** respiration in plants is synonymous with breathing in animals (Amir & Tamir, 1994). We designed the revision activity to include both knowledge and application questions. Knowledge questions prompted participants to correctly identify facts or basic concepts (e.g., "Which of the following about respiration is true?"). Application questions prompted participants to apply their knowledge to a scenario (e.g., "In the experiment depicted above, what happened to the mass lost in the 'water, no light' treatment?").

Session 1: Confidence ratings

After reading a question, but before selecting an answer choice, the activity prompted participants to report how confident they were in the accuracy of *each* answer option using a 5-point Likert scale. Instructions prompted participants to, "*Please indicate how confident you are in the accuracy of each answer choice*," with *1* indicating *absolutely confident it's wrong* and *5* indicating *absolutely confident it's right*.

Session 1: Explanation tasks

After rating their confidence in each answer choice, participants saw the question again and were prompted to select the best answer. On the following page, the question was presented with correct answer feedback (i.e., correct answer highlighted and labeled correct). Directly below the correct answer feedback, any relevant explanation prompts were presented, followed by a cognitive load measure. See *Figure 1* for a visual depiction of an activity procedure.

For the self-explanation condition, participants were prompted to "in 3-5 sentences, please explain why X is the correct answer to the question" and subsequently entered their explanation into a text box. Participants in the instructional explanation condition were prompted to carefully read an instructional explanation, which was provided below the correct answer feedback.

For the instructional explanation condition, biology instructors wrote twelve paragraph-long explanations (~4 sentences). They explained the correct answer to each question and either indirectly refuted or directly refuted relevant misconceptions contained in the question. For example, in a question including the misconception *respiration only takes place when photosynthesis is not* in an answer choice, the instructional explanation for that question indirectly refuted the misconception (i.e., "respiration is taking place in plants at all times…"). In a different question including the misconception *plants get food from the ground* in an answer choice, the instructional explanation directly refuted that misconception (i.e., "Plants do not 'get food' from anywhere. Plants make their own food…"). Both direct and indirect refutations can be effective (Chi, 2013) and were chosen based on their appropriateness for the question format. Participants in the no explanation condition were only provided with the correct answer feedback and did not receive any explanation prompts.

Session 1: Cognitive load measure

Following their assigned explanation prompts (or lack thereof), all participants completed a cognitive load measure using a 7-point Likert scale. The scale in this study asked participants to self-report *how hard* it was to complete the activity, with *1* indicating *not difficult at all* and *7* indicating *very, very difficult*. After completing the cognitive load measure, the activity routed learners to the next activity question. The procedure (see Figure 1) continued like this for all 12 activity questions. The order of questions was randomized.

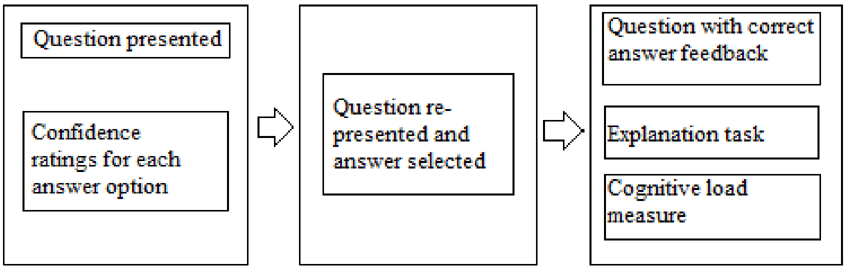

Figure 1. The procedure for each of the 12 activity questions.

Session 2: Posttest measure

One week later, participants completed the posttest. The posttest included 24 questions: the 12 original activity questions and 12 new transfer questions. Transfer questions addressed the same knowledge and maintained the same structure as activity questions; only the wording or specific examples differed. Similarly to the activity, participants were prompted to rate their confidence in the accuracy of each answer choice before selecting their answer to each question.

Findings

Photosynthesis misconceptions

Percentages of misconception lures selected with high confidence suggest that participants entered the activity with persistent misconceptions about photosynthesis and respiration. High confidence ratings distinguished between misconceptions and guessing; a low confidence rating of 1, 2, or 3 would indicated a guess, and ratings of 4 or 5 indicated the participants were confident the misconception lure was correct. The four primary misconceptions addressed in this study, the most commonly selected answer lure for each of those misconceptions, and percentages of participants that selected each overall and with high confidence are listed in Table 1. Percentages reported in Table 1 are likely underestimated; question order was randomized throughout the activity, and participant's likelihood of selecting a misconception may have decreased through the activity as they received correct answer feedback.

Table 1: Percentages of participants indicating the most common misconceptions

Misconception	Associated Answer Choice	Selected	High conf.
1) Plants get food from the ground.	Absorption of organic substances from the soil via the roots	43%	23%
2) Plants do not respire.		47%	37%
3) Respiration only takes place when photosynthesis is not.	It will weigh less because no photosynthesis is occurring.	20%	22%
4) Respiration is the same as breathing.	It is the exchange of carbon dioxide and oxygen gases…	35%	16%

Explanation prompts

To investigate how the effects of self-explaining and instructional explanations compared to no explanations, we used an ANCOVA to compare the effects of condition after controlling for prior knowledge. There was a significant effect of condition on overall posttest scores, F (2, 399) = 7.07, p = .015. Pairwise comparisons indicated that the self-explanation group (M = 40.71, SD = 19.44) had significantly higher posttest scores (p = .01 and p = .01, respectively) than instructional explanation group (M = 35.71, SD = 15.63) and no explanation group

($M = 35.98$, $SD = 15.74$), but posttest scores for the instructional explanation group were not significantly different than the no explanation group ($p = .99$). The same results were found when separately analyzing non-transfer posttest item scores, $F(2, 399) = 7.56$, $p = .001$, and transfer posttest item scores, $F(2, 399) = 3.51$, $p = .03$. It should be noted that for overall posttest scores and transfer posttest scores, means for the instructional explanation group were lower than means in the no explanation group, but not significantly. Mean comparisons of conditions can be seen in Figure 2.

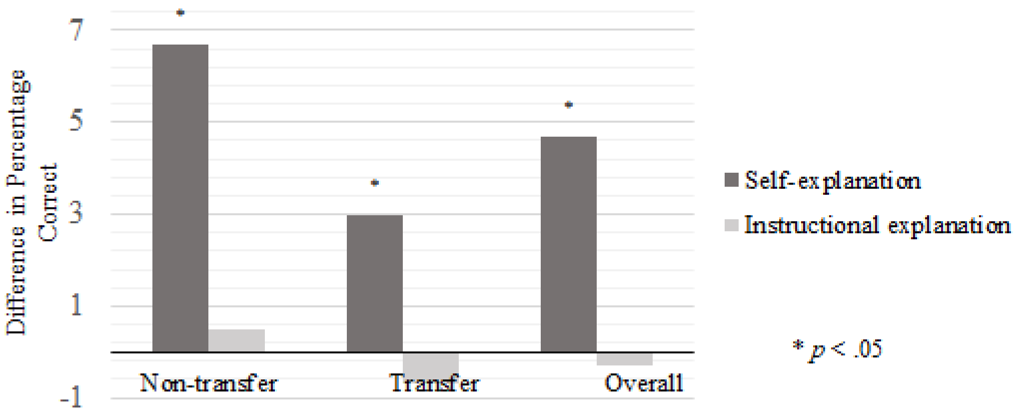

Figure 2. Differences in posttest accuracy compared to the no explanation condition. Scores are presented in relation to the no explanation condition as a baseline and are adjusted for prior knowledge scores.

Time, which may generally indicate engagement, in the activity provides context for some of the effects of condition. Participants in the self-explanation condition ($M = 29.92$) spent more minutes in the activity than participants in the instructional ($M = 24.24$) or no explanation condition ($M = 22.27$), $F(2, 400) = 19.44$, $p < .001$. After controlling for the effects of time and prior knowledge, the main effect of self-explaining was only marginally significant, $F(4, 397) = 2.46$, $p = .08$.

Changes in confidence

Item-level analyses on how confidence changed in relation to the neutral center of the scale–the selection of which indicates that the learner was neither confident in the accuracy nor the inaccuracy of the answer–provides insight into the specific processes associated with conceptual change. Movements towards the middle of the scale suggested cognitive conflict, because learners were becoming unsure of what they were previously confident in. Movements towards the upper end of the scale suggested updating, because learners were becoming more confident in the accuracy of that knowledge. Movements towards the lower end of the scale suggested outdating, because learners were becoming more confident that knowledge was wrong. See Figure 3 for an illustration of these processes.

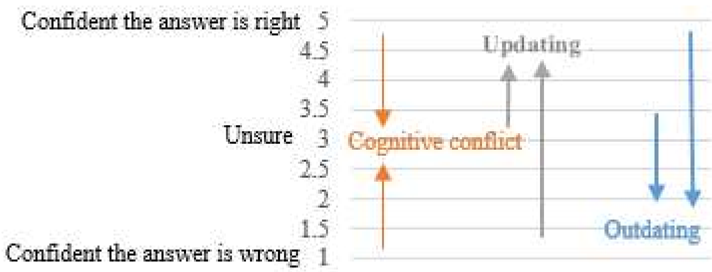

Figure 3. Graph illustrating changes in confidence and the conceptual change processes they suggest.

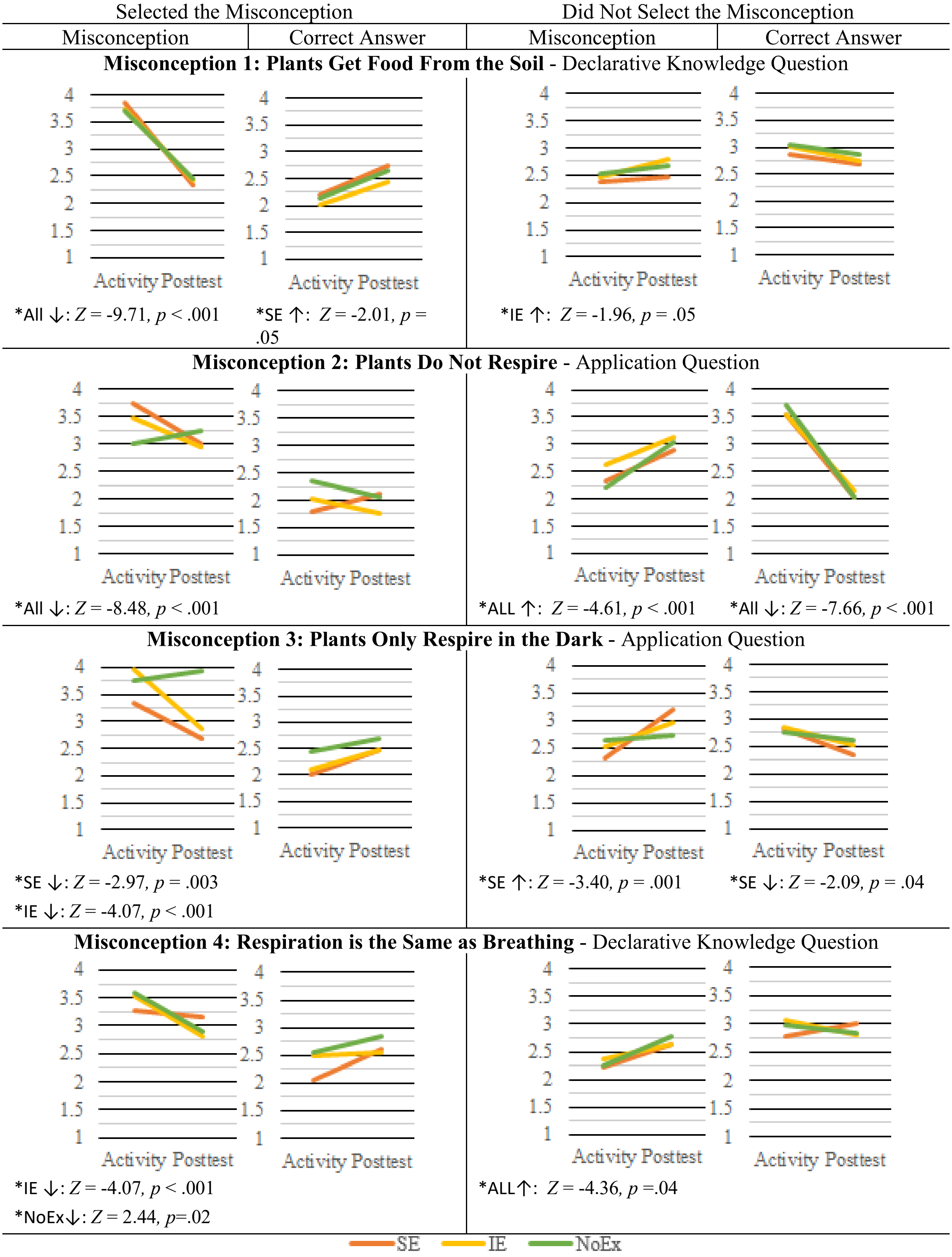

Figure 4. This array of graphs illustrates activity to posttest changes in the mean confidence for misconception lures and correct answers across conditions. The left side illustrates confidence for participants who selected the misconception lure. The right side illustrates confidence for participants who did not select the misconception lure. Statistics reported are based on Sign Test comparisons.

We examined changes in confidence ratings for the four most commonly selected misconception lures and separately analyzed learners who selected the misconception (i.e., indicated a need for conceptual change instruction) and learners who did not (i.e., did not indicate a need for conceptual change instruction). Confidence changes are illustrated in Figure 4. It should be noted that the activity was not a pretest; learning was occurring throughout, and question order was randomized. Any differences in activity confidence ratings across conditions may indicate the effects of the conditions up to that point.

Learners who selected the misconception

Confidence changes for learners who selected the misconception indicated that conceptual change was occurring. All conditions elicited outdating of misconception 1–*plants get food from the soil*–which was situated in a declarative knowledge question. All conditions elicited cognitive conflict for misconception 2–*plants do not respire*–which was situated in an application question that asked learners to identify which diagram correctly illustrated the carbon cycle. Cognitive conflict was also indicated across conditions for misconception 4–*respiration in plants is the same as breathing in animals*–which was situated in a declarative knowledge question. Interestingly, the self-explanation and instructional explanation conditions elicited cognitive conflict for misconception 3–*plants only respire in the dark*–which was situated in an application question that required a scenario-based prediction, but learners who did not receive an explanation prompt (i.e., no explanation condition) retained high confidence in the accuracy of that misconception. This interaction was also supported by a repeated measures analysis, $F(2, 137) = 3.15$, $p = .04$. Concerning the correct answers, there was no evidence to suggest that learners were updating their knowledge with the correct answers. However, confidence changes suggest that learners were moving towards cognitive conflict for the correct answers, indicating they were becoming less confident that the correct answers were wrong.

Learners who did not select the misconception

For participants who did not select the misconception lure, we expected their confidence in the misconception to remain the same or move towards cognitive conflict. This was largely the case; participants across conditions became more conflicted, or remained conflicted, about the accuracy of misconceptions 1, 2, and 4. However, for misconception 3–*plants only respire in the dark*–learners in the self-explaining condition moved towards updating their knowledge with the misconception; whereas learners in the other two conditions appeared to remain conflicted. This interaction was also supported by a repeated measures analysis, $F(2, 244) = 5.29$, $p < .01$. Further, self-explaining the correct answer associated with misconception 3 also decreased learners' confidence in the accuracy of the correct answer. Learners in all conditions appeared to outdate the correct answer associated with misconception 2–*plants do not respire*–and became more confident that the correct answer was wrong. Correct answer confidence did not change significantly for misconceptions 1 and 4.

Discussion and conclusions

Many of the undergraduate learners in this study indicated persistent misconceptions about photosynthesis and respiration. Even after covering photosynthesis and respiration in their previous biology course, almost 40% of our learners were confident that plants do not respire, and thus incorrectly believed that plants do not take in any oxygen. Other common misconceptions were indicated as well, and our activity aimed to simultaneously identify these misconceptions and provide an opportunity for revision.

The retrieval practice activity provided all students with correct answer feedback and prompted some students to self-explain or read explanations of the correct answer. Students who were prompted to self-explain the correct answers had the greatest improvements in posttest scores, and much of this effect may be because they spent more time in the activity. Reading instructional explanations, which included all the components of a refutation text when paired with correct answer feedback, did not have any effects above and beyond that of the retrieval practice portion of the activity alone. The learners in this study completed the activity as a homework assignment that was graded for completion, not accuracy. Thus, their motivation to actively engage the in activity may have been low. Self-explaining prompts appeared to require more engagement in the activity (i.e., time), which subsequently increased learning. More passive revision activities, like refutation texts, may not facilitate sufficient engagement in the conceptual change process when used in distance-learning environments.

Conceptual change is a gradual, multi-component processes that we did not expect to achieve through the single activity designed here. Rather, we aimed to see what effects the revision tasks had on the component processes of cognitive conflict, outdating, and updating. For learners who indicated a need for conceptual change instruction, retrieval practice alone (i.e., the no explanation condition) was sufficient to induce cognitive conflict for 2 of the 4 misconceptions examined and was sufficient to outdate the misconception in a declarative knowledge question. However, for an application question that required learners to use their knowledge to make predictions, explanation prompts were necessary to make learners doubt their misconception and experience conflict; although the type of explanation prompt did not seem to matter. Confidence changes did not provide any evidence that learners updated their knowledge with the correct answers. Although posttest scores indicated that self-explainers were better able to identify the correct answer–they may have just memorized the correct answers without changing the knowledge structure they use to solve problems. Thus, updating may be the challenge posed by persistent misconceptions that should receive special attention in conceptual change instructional design.

Two of our findings indicated that conceptual change instruction had unexpected effects on learners who did not hold the targeted misconceptions. In one case, learners lost confidence in the correct answer and began to think it was inaccurate. In another case, self-explaining an application question made learners more confident in the accuracy of a misconception. These observations may illustrate that conceptual change instruction is inappropriate in the absence of misconceptions, or these observations may just be the result of learners evaluating the accuracy of their knowledge more stringently in light of evaluating their own confidence in misconception lures, other incorrect answers, and correct answers. Further research is needed to provide additional context and distinguish between these two possibilities.

Although the activity in this study was not adaptive, it illustrates the potential for adaptive technologies to use retrieval practice activities to identify misconceptions and adapt instruction accordingly. It also indicates the utility of conceptual change retrieval practice activities (i.e., those with misconception lures and immediate correct answer feedback) in non-adaptive course management systems. We provide evidence that prompts to explain, but not refutation texts, are an effective way to engage learners with correct answer feedback and facilitate cognitive conflict in a distance-learning environment. Our future work will aim to identify the specific components of self-explanations (i.e., content, engagement, cognitive load, etc.) that predict conceptual change.

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