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Authors
Zhang, Tongyao
Gok, Sebahat
Gold, Gillian
et al.

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Effectiveness and Efficiency of Multimedia Worked Examples vs. Practice with Feedback on Learning Problem Solving

Tongyao Zhang (zhang.tongyao.2@gmail.com)[1†], Sebahat Gök[2†], Gillian Gold[3], Paulo F. Carvalho[3], Emily R. Fyfe[1]

[1]Department of Psychological and Brain Sciences, Indiana University
[2]Center for Connected Learning and Computer-Based Modeling, Northwestern University
[3]Human-Computer Interaction Institute, Carnegie Mellon University
[†]equal contribution

Abstract

Multimedia effects refer to the phenomenon that combining text with diagrams is generally more effective than text-only representations. The current study tests whether doing practice problems with multimedia feedback is more effective than multimedia worked examples. In the current preregistered study, 213 undergraduate students learned to solve conditional probability problems in one of three conditions: multimedia worked examples, practice with multimedia feedback, or combining both types of learning activities. Results showed that posttest performance did not differ significantly between the three conditions, but worked examples took less time than the practice-based conditions. Further, participants perceived the worked examples as more helpful and less difficult than practice with feedback activities, and receiving only worked examples led to overconfidence of how well they learned.

Keywords: worked examples; instruction; feedback; problem solving; active learning; metacognition

Introduction

Instructional choices in mathematics and science problem-solving can strongly influence how students engage with and learn from information. Two common approaches illustrate this contrast: instructors may present step-by-step demonstrations of the fully correct solution (i.e., worked examples) or they may ask students to attempt problems first, and then provide feedback with the correct solution (i.e., practice with feedback). Although both methods aim to support learning, they rely on distinct cognitive mechanisms. Worked examples reduce cognitive load by eliminating the need to search for a solution, which can ease the processing of information (Sweller, 2006). On the other hand, practice with feedback provides information tailored to the learner (i.e., whether a solution is correct or incorrect) that can help students recognize discrepancies between their current and desired performance (Hattie & Timpley, 2007).

One way to improve problem-solving demonstrations is to use multimedia representations that combine text with diagrams, rather than relying on text alone (Mayer & Anderson, 1992). A typical multimedia study incorporates these materials in worked examples (e.g., Eitel et al., 2013; Sung & Mayer, 2012). However, a recent study by Gök et al. (2025) found that it was more effective to incorporate multimedia representations into the feedback message rather than text-only feedback.

One interpretation of these findings is that practice with feedback is a more powerful learning approach where multimedia representations can have particularly positive impacts. This interpretation is consistent with recent findings highlighting the potential advantages of practice with feedback. Asher et al. (2025) compared video lectures, practice with feedback, and a combination of the two. They found that video lectures did not lead to any learning benefits over practice, while taking longer during instruction, making them relatively inefficient.

However, Gök et al. (2025) never directly compared instruction through worked examples, practice with feedback, and the combination. Their studies always included both. Thus, it remains unclear whether completing only one of the phases with multimedia representations is enough or if a combination is necessary.

Learning Problem Solving: Worked Examples vs. Practice with Feedback

Over the past decade, research has demonstrated the benefits of active learning, compared to traditional lecturing, for students' performance (Freeman et al., 2014; Chi & Wylie, 2014). Generating solutions, even when incorrect, followed by feedback supports learning through mechanisms such as retrieval, error detection, and conceptual refinement (e.g., Chi, 2009; Koedinger et al., 2015). Multimedia representations may be especially beneficial during practice with feedback because they can support error diagnosis and correct following an initial problem-solving attempt. Multimedia feedback may help localize misunderstanding, map errors onto visual representations, and update problem-solving procedures (Hu et al., 2021).

On the other hand, learning from worked examples, in which learners observe complete solution procedures, may support novice learners by allowing them to focus on acquiring problem-solving schemas rather than on managing the cognitive demands of generating solutions themselves (Sweller et al., 1988; Sweller, Ayres, & Kalyuga, 2011). During early stages of learning, particularly in mathematical domains, studying step-by-step examples has been shown to improve performance compared to problem-solving practice (Renkl, 2014; van Gog & Rummel, 2010).

However, it remains unclear how these forms of practice—either alone or in combination—compare in terms of both learning outcomes and learning efficiency. The current study directly compares learning from instructional examples, feedback-based practice, or the combination of both to clarify how different forms of guided practice influence performance and efficiency in complex problem-solving tasks using multimedia materials.

Effects of Instructional Fluency on Metacognitive Judgments

Beyond performance outcomes, worked examples and practice with feedback may differentially influence learners' metacognitive judgments. Learners often rely on subjective experiences of ease, clarity, or familiarity when judging how much they have learned (Koriat, 1997; Alter & Oppenheimer, 2009). Provided instruction, such as examples and explanations, is typically processed fluently, which can lead learners to perceive them as highly effective, even if that is not reflected in performance (Bjork, Dunlosky, & Kornell, 2013).

Reliance on fluency-based cues may result in systematic metacognitive errors. Learners frequently overestimate their learning following instruction that feels easy or well explained, which is seen in rereading, worked examples, and lectures (Carpenter et al., 2020). In contrast, answering practice questions often feels difficult and is therefore judged as less helpful, despite producing better long-term learning in some contexts (Bjork & Bjork, 2011).

On the other hand, feedback may support more accurate metacognitive calibration by providing learners with information about their understanding. Prior research suggests that engaging with feedback can reduce overconfidence and improve learners' ability to estimate their own performance, particularly when feedback highlights discrepancies between predicted and actual outcomes (Butler et al., 2013; Dunlosky & Rawson, 2012). However, learners may still underestimate the value of practice activities if their judgments are driven by perceived difficulty rather than by objective learning gains.

Taken together, these findings suggest a dissociation between subjective experience and learning effectiveness: instructional examples may be favored in learners' evaluations due to their fluency, whereas practice activities may be undervalued despite their effectiveness. Examining learners' judgments of difficulty, helpfulness, and confidence across these different learning activities will provide additional insight into how learning experiences affect both performance and metacognitive judgments.

The Current Study

Two open questions motivate the present work: (1) Are worked examples or practice with feedback more effective when learners receive multimedia solutions for mathematical problem solving? (2) Does an initial phase of worked examples provide benefits beyond practice with feedback alone?

We test these questions in the context of conditional probability problem-solving across three conditions: **worked examples, practice with feedback, and a combination**. Consistent with previous studies (Asher et al., 2025; Gök et al., 2025), we also examine learning efficiency across conditions and replicate and extend our metacognitive measures by asking participants to rate perceived problem difficulty and perceived solution helpfulness, and to predict their posttest performance.

Hypotheses

(1) Participants who have practice-based instruction will perform better on the final test, such that the practice-only and the combined conditions will perform similarly, and both be higher than the worked example condition.

(2) Participants in the practice with feedback condition will judge the activities as more difficult and/or less helpful than students in the worked example condition, indicating a perception–performance mismatch (Gök et al., 2025).

(3) Within the combined condition, participants will rate the worked example phase as less difficult and more helpful than the practice with feedback phase (Gök et al., 2025).

(4) Participants in the conditions with practice will have more accurate predictions of their performance. Specifically, participants in the practice-only condition will be less overconfident about their posttest performance than those in the worked example condition (Asher et al., 2025).

Methods

This study was preregistered at Open Science Framework. A link to the registration will be provided after the blinded review.

Participants

213 undergraduate students in a public university in the Midwest United States participated in the study. Participants' age ranged from 17 to 22 years, M = 18.62 years, SD = 0.86 years. 61.97% of the participants were female, 37.09% were male, and 0.94% chose not to report their gender. 74.18% of the participants were White, 11.74% were Asian or Asian American, 7.51% were Hispanic or Latino, 4.23% were Black or African American, 0.94% were Native American or Pacific Islander, 0.94% identified as other races, and 0.47% chose not to report their race. An additional 16 participants were not included in the final sample either because they did not complete the session (N = 10), or due to computer program errors (N = 6).

We conducted a preregistered *a priori* G*Power analysis of a fixed effect ANCOVA with 1 predictor (condition, 3 levels) and 1 covariate (pretest score). We conducted 3 post hoc pairwise comparisons which required Bonferroni corrections that divide alpha by 3. Therefore, we entered alpha error probability 0.017 instead of 0.05 in our power analysis to be on the conservative side. A sample size of 148 is required to achieve 80% power to detect an effect size of η_p^2 = .08 (taken from our previous study). Our final sample size of 213 therefore proved to be adequately powered.

Design

Participants were randomly assigned to one of the three instructional conditions: worked examples (n = 55), practice with feedback (n = 81), or the combination of both (n = 77). Regarding dependent variables, we compared participants' posttest performance and learning efficiency across conditions. We also compared participants' ratings of the difficulty and helpfulness of different learning activities, and participants' metacognitive accuracy.

Procedure

The study was completed in a single, in-person 60-minute computer-based session at a research lab. The participants received course credits for their participation. The procedure followed a pretest–training–posttest structure. Participants first completed a pretest consisting of five conditional probability problems across three scenarios. They then completed condition-specific training (described below) and finished with a posttest isomorphic to the pretest with different numerical values.

Only the training differed by condition. In the worked example condition, participants studied six worked examples. In the practice with feedback condition, participants solved six problems and then received explanatory feedback after each one, which included a right/wrong judgment, the correct answer, and the worked-out solution. In the combined condition, participants started by reading a problem at a time followed by its worked-out solution (worked example phase) and then completed the practice with feedback phase with parallel items using different numbers (see Figure 1 for an example question and solution item). In other words, the training in the combined condition is the sum of those of the worked example and practice feedback conditions.

After each phase (pretest, instruction, and posttest), participants rated the difficulty and helpfulness of the preceding section. Prior to the posttest, participants also estimated their upcoming posttest performance.

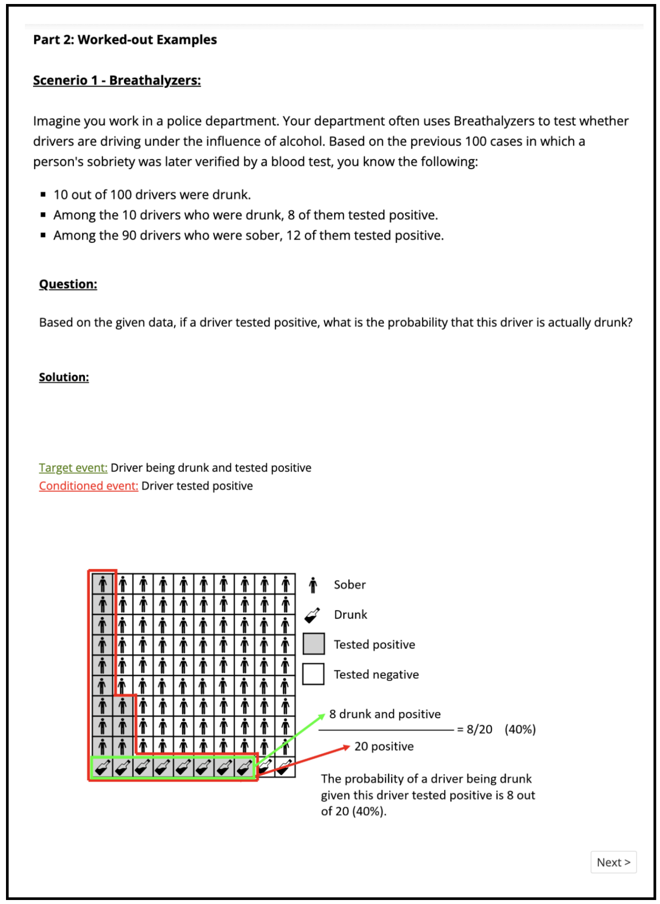

Figure 1. Screenshot of an example question and solution item.

Results

A link to anonymized data and analysis code for this study will be provided after the blinded review.

Posttest Performance

We conducted an ANCOVA with participants' posttest performance (percentage) as the outcome variable, condition as the main factor (worked example vs. practice with feedback vs. combined), and pretest accuracy as a covariate to account for individual differences in prior knowledge. There was no significant difference in posttest performance across the three conditions, $F(2, 209) = .16$, $p = .85$, $\eta_p^2 = .00$, see Figure 2.

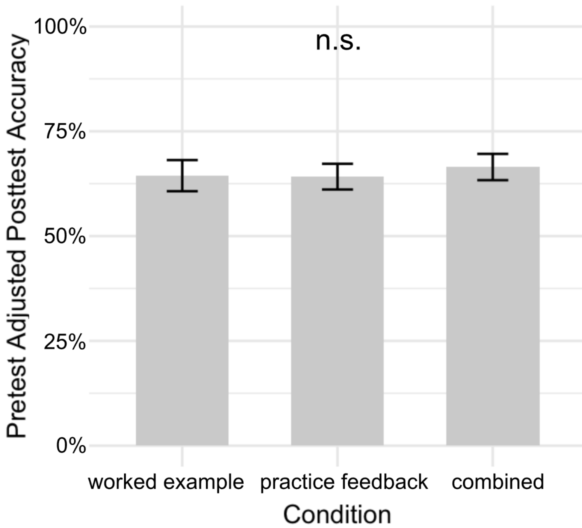

Figure 2: Pretest adjusted posttest performance (percentage) by conditions.

Learning Efficiency

We calculated participants' learning efficiency by dividing their improvement (percentage) from pretest to posttest by the total time (minutes) they spent on the training stages, efficiency = (posttest accuracy - pretest accuracy) / total time spent. We conducted an ANOVA with participants' efficiency index as the outcome variable and condition as the main factor (worked example vs. practice with feedback vs. combined). There was a significant condition effect, $F(2, 210) = 13.22$, $p < .001$, $\eta_p^2 = .11$, see Figure 3. The worked example condition appeared to be the most efficient, with its efficiency index significantly higher than the other two conditions, pairwise comparison *p*s < .001, while the combined condition and the practice feedback condition were not significantly different from each other, $p = 1$. All pairwise comparisons were Bonferroni corrected.

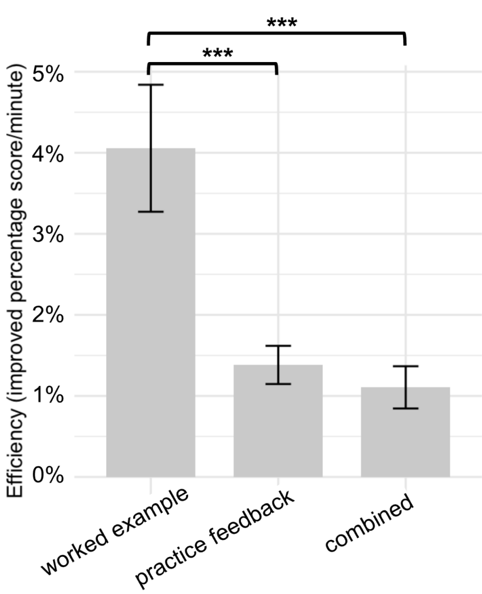

Figure 3: Learning efficiency across conditions.

Time Spent on Training

Participants in the worked example condition spent significantly shorter time on the whole training compared to the practice with feedback condition, $t(134) = 9.28$, $p < .001$, *Cohen's d* = 1.62. However, further analysis suggested that participants spent less time on the solutions provided in feedback than the solutions provided in worked examples, despite their informational and representational equivalence, $t(134) = 4.98$, $p < .001$, *Cohen's d* = .87.

Ratings of Training Difficulty and Helpfulness

At the end of each stage, participants rated, on a 5-point scale, the difficulty and helpfulness of the preceding stage. We then compared their ratings on worked examples and practice with feedback training stages between and within-subject (that is, worked example stage vs. practice with feedback stage within the combined condition) using independent and paired sample t-tests.

Perceived Difficulty. We compared participants' rating of training difficulty between-subjects and within-subjects as outlined above. See Figure 4 for descriptive trends of all four groups of ratings. As predicted, for the between-subject comparison, participants in the worked example condition rated instruction to be significantly less difficult than participants' ratings of the practice with feedback condition, $t(133) = 3.02$, $p = .002$, *Cohen's d* = .53.

Similarly, for the within-subject comparison, participants in the combined condition rated the worked example stage as less difficult than the practice with feedback stage, $t(76) = 2.24$, $p = .028$, *Cohen's d* = .28. See Figure 4 for a comprehensive visualization of the perceived difficulty across conditions and stages.

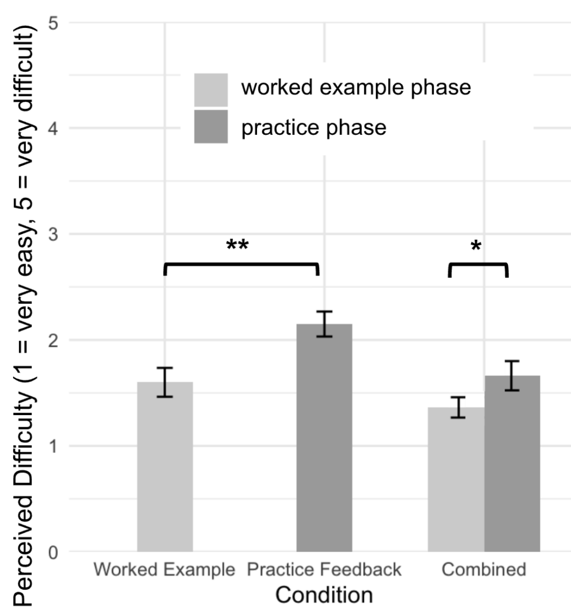

Figure 4: Perceived difficulty rated across phases of all conditions.

Perceived Helpfulness. Similarly, we compared participants' ratings of helpfulness of learning materials both between-subject and within-subject. See Figure 5 for descriptive trends of all four groups of ratings. As predicted, for the between-subject comparison, participants in the worked example condition rated instruction to be significantly more helpful than participants' rating of practice with feedback training of the practice feedback condition, $t(133) = 2.85$, $p = .005$, *Cohen's d* = .50.

Similarly, for the within-subject comparison, participants in the combined condition rated the worked example stage as more helpful than the practice with feedback stage, $t(76) = 3.08$, $p = .003$, *Cohen's d* = .40.

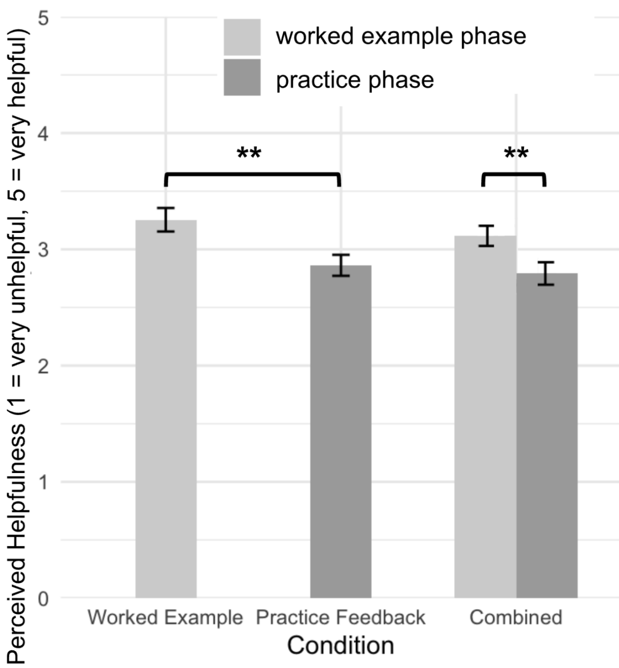

Figure 5: Perceived helpfulness rated across phases of all conditions.

Overconfidence

We calculated how much participants tend to overestimate their posttest performance, Overconfidence = estimated posttest performance - actual posttest performance (%). We conducted an ANOVA with overconfidence index as the outcome variable and condition as the main factor. There was a marginal main effect of condition, $F(2, 209) = 2.36$, $p = .097$, $\eta_p^2 = .02$, pairwise comparisons were not significant, ps > .12. However, the descriptive trend was as predicted: worked example > combined > practice-only. Participants in the practice with feedback condition were the only group to slightly underestimate their learning, see Figure 6.

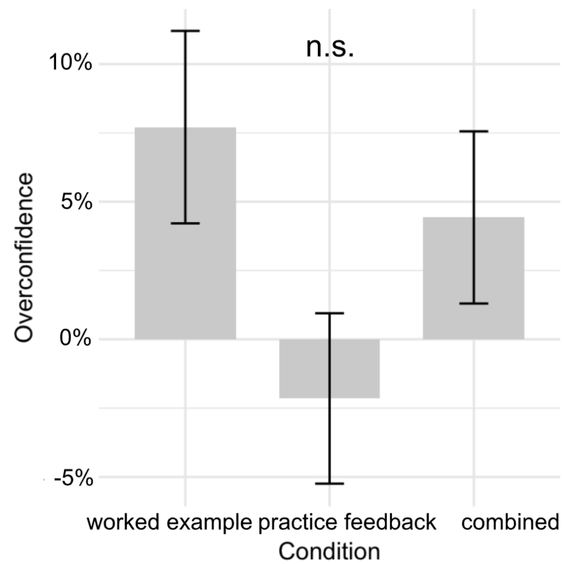

Figure 6: Overconfidence across conditions. Above 0% = overestimation of posttest performance, below 0% = underestimation.

Discussion

In this study, we experimentally investigated how multimedia learning from worked examples alone compared to practice with feedback alone and a combined version commonly used in prior literature. Contrary to our hypotheses, but similar to recent findings by Asher et al. (2025), we found no significant differences in performance outcomes across instructional conditions. These results further support that combining an initial informational event (a video lecture in their case, and worked examples in ours) with problem solving (i.e., practice with feedback) appears redundant.

However, contrary to Asher et al. (2025), we find that the most efficient instruction was not practice with multimedia feedback, but instead worked examples with multimedia. We found that the practice with the feedback stage was more time-consuming than the worked example stage, contrary to prior findings (Asher et al., 2025). When learning outcomes are equivalent, such differences in time on task are especially informative. Under these conditions, practice with feedback was less efficient, yielding comparable learning at a higher temporal cost.

Although participants spent more time overall in the practice with feedback condition, they spent considerably less time viewing the solutions when those solutions appeared as feedback than when they appeared as worked examples, replicating findings by Gök et al. (2025). This dissociation suggests that identical multimedia representations are processed qualitatively differently across instructional stages. One possibility is that an initial problem-solving attempt makes participants more efficient at attending to the most relevant aspects of the feedback , to narrow the gap between their current and the correct solution. In contrast, without such awareness of the knowledge gap, participants may be in a relatively less goal-oriented, more diffused attentional mode during worked examples.

Future studies could employ more direct measures to examine the accounts of the time difference between processing worked examples and feedback processing. Eye-tracking can reveal spatial and temporal differences between conditions across the two instructional stages, allowing researchers to test the hypothesis that feedback is processed with different goals and focus than the worked examples.

When contrasting with Asher et al.'s effects showing that practice is more efficient than video instruction, one possibility is that, contrary to videos, worked examples with multimedia representations are a more robust way to teach. Future work should directly compare video instruction, with worked examples and practice-based instruction.

Another important feature of the current study is the inclusion of a pretest. Many previous studies showing the advantage of practice and feedback compared to other forms of instruction did not include a pretest (e.g. Carvalho et al., 2022; Asher et al., 2025). However, in the present study, all participants completed a pretest consisting of problems closely aligned with the posttest before receiving any instructional content. The pretest itself may have functioned as a form of generative practice across all conditions, effectively equalizing learners' engagement with the target material. A growing body of research on the pretesting effect demonstrates that attempting to answer questions, even when learners are largely unsuccessful, can substantially enhance subsequent learning (e.g., Kornell, Hays, & Bjork, 2009; Little & Bjork, 2016; Pan & Carpenter, 2023; Pan & Sana, 2021; Richland et al., 2009). Following initial problem-solving attempts, learners in the worked example condition may have used the examples more strategically, attending selectively to the solution steps that addressed errors or knowledge gaps revealed during the pretest. This process would allow worked examples to support learning functionally similar to the feedback stage of the practice-based instruction. This might have rendered worked examples with multimedia the best of both worlds. Learners get to know what they need to learn in the pretest and then receive targeted, fast instruction in the form of a worked example with multimedia instruction. Therefore, future studies should compare the benefits of worked examples and practice with feedback without the inclusion of a pretest.

Processing Fluency and Miscalibration

Despite equivalent learning outcomes, students systematically rated the practice with feedback as more difficult and less helpful. This pattern is consistent with learners relying on processing fluency as a cue for learning effectiveness, conflating ease of processing with actual learning (Koriat, 1997; Alter & Oppenheimer, 2009). Instructional formations that feel more fluent, such as worked examples, are therefore perceived as more effective, even when this perception is not aligned with objective performance.

For example, learners are more confident after restudying materials than self-testing, despite higher learning outcomes associated with retrieval practice (Roediger & Karpicke, 2006). Self-testing can help students better gauge the difficulty of memory retrieval, making them less likely to overestimate how much they have learned. Consistent with this account and prior evidence (Asher & Carvalho, 2026), in the current study, students in the practice with feedback condition were less overconfident in their posttest performance compared to the worked example condition, suggesting that practice may have metacognitive advantages and improved calibration. Improved calibration and reduced overconfidence have been demonstrated to be better predictors of future learning and success (Hu et al., 2025), highlighting the importance of considering long-term outcomes and the potential for future learning inherent to practice but not worked examples.

Overall, these results highlight the importance of examining instructional methods beyond final performance outcomes, revealing dissociations between perceived learning effectiveness, efficiency, and metacognitive judgments. These distinctions may be critical for understanding when and why different instructional approaches are most beneficial in multimedia-supported problem solving.

Conclusions

The study described here demonstrated, in the context of multimedia instruction, that combined instruction is not efficient, and it is not necessary to combine practice and other forms of instruction. Importantly, contrary to prior evidence, multimedia worked examples resulted in the most efficient learning, suggesting that there might be situations where practice-only instruction might not be the best approach. Regardless, practice with feedback still had metacognitive advantages, reducing overconfidence, with potential positive learning consequences not measured here. These are important and impactful findings in understanding when and how to include practice in learning environments and for theoretical developments in our understanding of how learning takes place.

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