Process- and Product-Oriented Worked Examples and Self-Explanations to Improve Learning Performance

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Abstract

Worked examples and self-explanations studies have been conducted predominantly with college students in controlled laboratory settings. While there is evidence showing the independent effects of these learning strategies with college students, little is known about the combined effects with K-12 students in ecologically-valid environments. Additionally, most studies have only examined a single self-explanation format. In the current study, we seek to fill these gaps by examining middle school students learning performance with either worked examples (product vs. process) or self-explanation (menu-based vs focused). Participants (*N* =122) were randomly assigned to one of the four groups to study materials on geometric area and then assessed on their performance (practice problems, multiple-choice test and self-explanation) as well as their cognitive load. Results indicate significant main effects of self-explanation format on self-explanation scores, however no further main effects or interaction effects were obtained. Theoretical and practical implications are discussed.

Keywords: Worked examples, Self-explanations, Classroom-based

Research on the benefits of learning from worked examples and self-explanation prompts have focused largely on high school or college students and are often conducted in controlled laboratory settings (for example, see Berthold, Eysink & Renkl, 2009; Gerjets, Scheiter & Catrambone, 2006; Renkl, 2002; Schworm & Renkl, 2006). In the present study, we examine the combined effects of worked examples and self-explanation prompts on middle school students' learning of mathematics in a classroom environment. Based on the support for the independent effects of worked examples and self-explanation prompts identified in extant research, the present study extends the literature by examining the synergistic effects of process- and product-oriented worked examples and self-explanation with middle school students in an ecologically-valid context.

Worked Examples

The effectiveness of learning with worked examples is undisputable (Atkinson, Derry, Renkl, & Wortham, 2000; Sweller, Merriënboer, & Paas, 1998). Worked examples typically consist of the following: a problem statement, solution steps, and a final solution. However, researchers argue that these "product-oriented" worked examples do not provide sufficient support for one's understanding of the process information relevant to each solution step, and thus do not support learners' schema construction of the novel information with prior knowledge (van Gog, Pass, & Merriënboer, 2004, 2006). One way to enhance learning from product-oriented worked examples is to include instructional explanations that underlie the solution steps needed to solve the problem (Renkl, 2002). Worked examples that incorporate instructional explanations are thus referred to as "process-oriented" worked examples and are beneficial for supporting conceptual and procedural understanding of the solution (Wittwer & Renkl, 2010; van Gog et al., 2004, 2006). Learning from worked examples is further enhanced when learners have the opportunity to solve similar problems after studying the worked examples.

Research on worked examples provide evidence that worked examples is a superior instructional strategy particularly for low prior knowledge learners (Schwaighofer, Bühner & Fischer, 2016, p. 983; Wittwer & Renkl, 2010; Kalyuga, 2007; Atkinson et al., 2000) who are likely to engage in extraneous processing without developing cognitive schemas to guide transfer of knowledge (Renkl, 2014). The guidance from process-oriented worked examples may relief low prior knowledge learners of problem-solving, allowing them to concentrate on deepening understanding beyond surface features, thus enhancing generative processing. Empirical evidence suggests that learning from well-designed worked examples greatly benefits the initial skill and knowledge acquisition of low prior knowledge learners (Schwaighofer et al., 2016; van Loon-Hillen, van Gog, Brand-Gruwel, 2012; Kalyuga, Chandler, Touvinen, & Sweller, 2001); increase understanding of procedures and problem-solving skills acquisition (Renkl, 2014; Atkinson, et al., 2000; Sweller & Cooper, 1985); raise test scores on subsequent test problems; and shorten time spent on learning new material (Chen, Kalyuga, & Sweller, 2015, van Loon-Hillen et al., 2012). Finally, as learning from worked examples reduces the strain on working memory capacity for low-prior knowledge learners, these learners are able to allocate working memory capacity for other generative tasks such as self-explanation (Renkl, 2014).

Self-Explanation

Self-explanation is the practice of generating inferences for one to make sense of information by connecting the incoming information with their prior knowledge (Chi, 2000). During the process, learners may recognize and address discrepancies and/or contradictions and gaps in their knowledge, resulting in deep and robust learning (Wylie & Chi, 2014). The self-explanation principle (Wylie & Chi, 2014) suggests that self-explanation prompts fall along a continuum (open-ended, focused, scaffolded, resource-based, and menu-based). The specificity of the explanation prompts increases as one moves from one extreme of the continuum (open-ended) to the other extreme (menu-based). Open-ended self-explanation allows the learner to make any form of connection between the given information and prior knowledge. On the other end of the continuum, menu-based self-explanation facilitate thinking about the material by asking the learner to select a suitable explanation from a short list (Wylie & Chi, 2014). Between the two extremes are self-explanation prompts that provide structured instructions for the content of the expected response, such as focused, scaffolded, resource-based and menu-based explanation prompts. Research suggests that providing more specific explanations via structured explanation prompts facilitates learning better than generic or open-ended prompts (Wylie & Chi, 2014). Furthermore, these explanation prompts may benefit low prior knowledge learners as they encourage deep thinking (Wylie & Chi, 2014). In most situations, self-explanations are more effective for robust and deep learning than no self-explanations (Schworm & Renkl, 2006).

Cognitive Load Theory

The effectiveness of using worked examples and self-explanation prompts is rooted in Cognitive Load Theory (CLT; Sweller, 1988; Sweller et al., 1998). Instructional designs that use a combination of well-designed worked examples and self-explanation ensure that schema construction is supported as working memory resources can be devoted to dealing with the complex nature of the task, which in turn increases generative processing and the integration of incoming knowledge with prior knowledge (Mayer & Moreno, 2003; Paas & van Gog, 2006). The goal of CLT is to identify optimal instructional designs that efficiently utilize individuals' cognitive processing capacities to acquire and apply knowledge. This is done by first identifying the three cognitive loads that influence learning: extraneous cognitive load, intrinsic cognitive load and germane cognitive load. Extraneous cognitive load may be reduced by providing worked examples that are relevant to the learning objectives and excluding extraneous features that are irrelevant to the learning objectives. Additionally, presenting information with instructional explanations and prompting learners to self-explain may help them better identify key information necessary to be represented in working memory, thus reducing intrinsic cognitive load. Finally, germane cognitive load is likely to be experienced as learners engage in constructing relevant schemas and integrating mental representations with prior knowledge.

Learning from Worked Examples and Self-Explanation Prompts

Positive learning outcomes from studying worked examples depend on factors such as learners' ability to self-explain (Atkinson et al., 2000; Schworm & Renkl, 2006), and the presence of instructional explanations (Wittwer & Renkl, 2010; van Gog et al., 2004). The latter is important for learners who may potentially produce flawed self-explanations (Berthold & Renkl, 2009). These learners may benefit from instructional explanations that clarify the solution steps for them and fill the gaps in their knowledge. Research examining the combined effect of worked-examples and self-explanation provides the foundation for the current study and is paramount for our understanding of how to best use worked-examples in the classroom.

Previous studies that examined the effect of worked examples with instructional explanations and self-explanations only focused on the use of a single self-explanation format. For example, in a computer-based learning environment, Schworm and Renkl (2006) studied the effects of learning from solved-example problems with focused self-explanations and instructional explanations in a 2x2 design study. Results from the study provided support for learning with solved-example problems with self-explanations or instructional explanations respectively, but not when both strategies were combined. When solved-examples had self-explanations and instructional explanations, learning outcomes were not as favorable. However, participants preferred receiving instructional explanations rather than being prompted to self-explain. It may be possible that the demand on cognitive resources for instructional activities that requested learners' active engagement prevented learners from valuing such activities (Schworm & Renkl, 2006). Since researchers did not measure cognitive load during the learning activities, further investigation into the effects of cognitive load from learning with self-explanations and instructional explanations is warranted.

Huang and Reiser (2012) compared the effects of four worked examples conditions on proper comma use with sevenths and eighth graders: (1): worked examples with menu-based self-explanation, (2) worked examples with instructional explanation, (3) worked examples with both menu-based self-explanation and instructional explanation, (4) worked examples alone. Results from Huang and Reiser's study indicate that learning was significantly better when worked examples were paired with instructional explanations, self-explanations, or both, compared to the standard worked examples condition. However, no other significant differences between conditions were obtained for learning and transfer outcomes. The lack of a significant difference between worked examples with instructional explanation and worked examples with self-explanation and instructional explanation suggests that both conditions were effective for learning outcomes. However, similar to Schworm & Renkl's (2002) study, this study only explored the use of a single format of self-explanation. Thus, there is a need for further examination of the effectiveness of different formats of self-explanations with worked examples and instructional explanations.

In their meta-analysis, Wittwer and Renkl (2010) found that instructional explanations in worked examples without self-explanation prompts had a positive effect on learning outcome. However, those effects disappeared when learners received instructional explanations in worked examples and were encouraged to self-explain. Overall 28 studies were examined, and results show that the averaged effect size for studies with instructional explanations in worked examples ($k = 8$) was not significantly different from the averaged effect size for studies with instructional explanations in worked examples and self-explanation prompts ($k = 20$; $Q = 1.32$). Therefore, while instructional explanations may be beneficial for learning with worked examples under certain conditions, the inconclusive results from the meta-analysis warrants further investigation of the use of instructional explanations and the formats of self-explanation in worked examples.

It is well established that learning with worked examples and self-explanation or worked examples and instructional explanation is superior to learning with worked examples alone (Huang & Reiser, 2012; Wittwer & Renkl, 2010; Berthold, Eysink & Renkl, 2009; Renkl, 2002). However, the lack of significant difference between process-oriented worked examples and product-oriented worked examples with self-explanation warrants further investigation of the effectiveness of learning with process-oriented worked examples and self-explanation (Wittwer & Renkl, 2010). Furthermore, a recent meta-analysis on self-explanation by Bisra et al. (2018) highlights the importance of comparing the effects of different forms of self-explanation formats. We extend research in process-oriented worked examples and self-explanation, in the following three ways. First, unlike the majority of worked examples and self-explanation research, we explored the effectiveness of different formats of self-explanation prompts on learning with process-oriented worked examples. Second, since the combination of learning from worked examples and self-explanation is rooted in cognitive load theory we included a measure of cognitive load. Third, we conducted this study in an ecologically valid context.

Present Study

The present study was conducted with sixth graders from a middle school located in the northwestern United States. We predicted that menu-based self-explanation conditions would have a positive effect on learning outcomes grounding on the premise that these self-explanation prompts are more structured and provide guidance to learners (Hypothesis 1). We also predicted that there would be no difference on learning outcomes between the process- and product-oriented conditions based on previous research findings (Hypothesis 2) and that the process-oriented conditions would help students to produce better menu-based or focused self-explanations than their respective product-oriented conditions (Hypothesis 3). Finally, we predicted that cognitive load scores would be lower for the process-oriented conditions than the product-oriented conditions (Hypothesis 4).

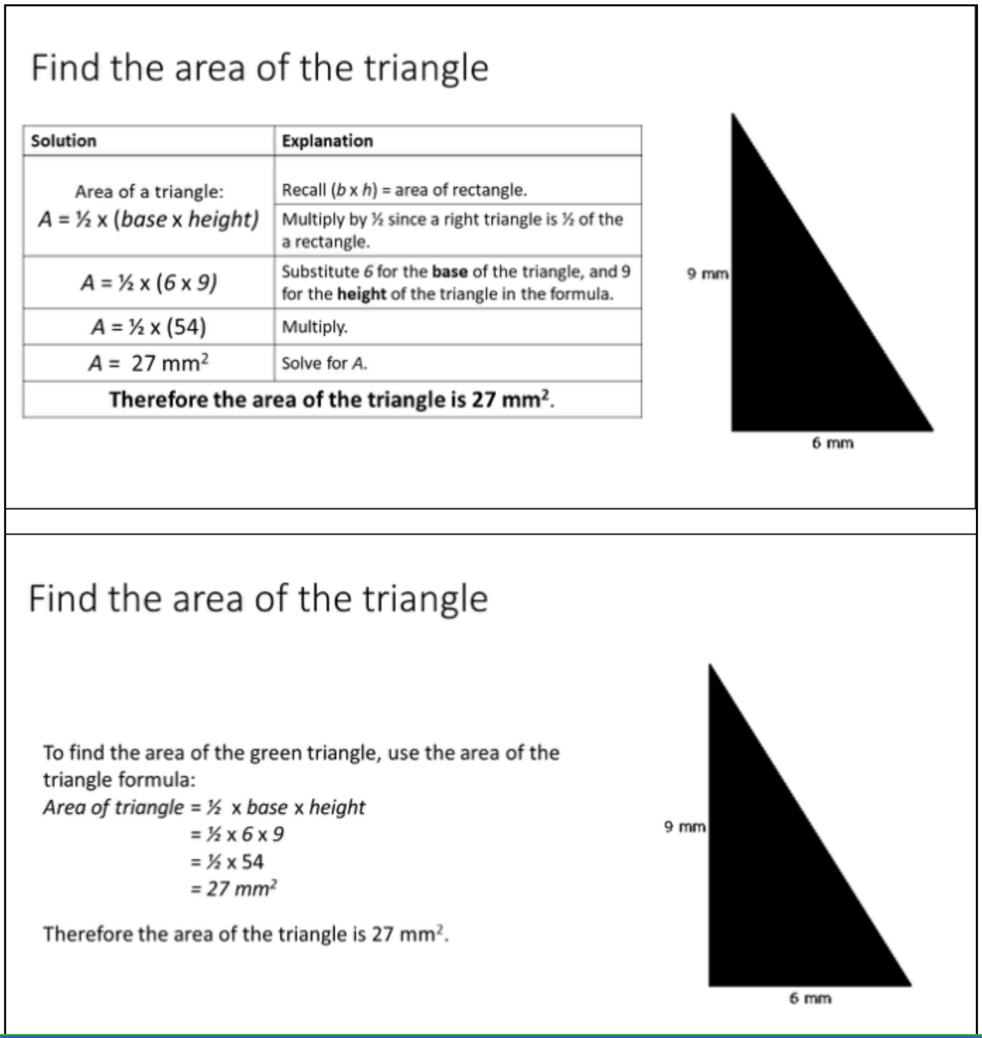
Methods

Participants

One hundred and twenty-two sixth graders (47 males, 75 females; mean age = 11.5 years, *SD* = .53) enrolled at a public school in the northwestern part of the United States participated in the study. The university's Institutional Review Board and the public-school district approved this study. Students were recruited through two middle school mathematics teachers and were from a high achieving mathematics class and a typically achieving mathematics class. Parental permission and students' assent were obtained. All students were randomly assigned to one of the four conditions in a 2x2 factorial design investigating the effects of worked examples (process vs. product) and self-explanations (menu-based vs. focused) on learning: process-oriented and menu-based self-explanation prompts (Process + MB; $n = 29$), process-oriented and focused self-explanation prompts (Process + F; $n = 33$), product-oriented and menu-based self-explanation prompts (Product + MB; $n = 26$), and product-oriented and focused self-explanation prompts (Product + F; $n = 34$). Students participated in this study during their normal mathematics class period in the school's computer lab.

Learning Material

The learning material was a lesson of the area of the right triangle and the area of composite figures and consisted of four worked examples that differed with respect to the worked examples conditions (process vs. product; see Figure 1). Students in the process-oriented conditions received worked examples with detailed instructional explanations, while students in the product-oriented conditions received solution examples without instructional explanations. The topic chosen for this study is included in the Common Core State Standards for Mathematics (Common Core State Standards Initiative for Mathematics, 2010, p. 44) for sixth graders. According to the mathematics teachers, students either had not yet been introduced to the topic or only received brief introduction by the time of the study. Two individuals with expertise in middle school mathematics deemed the learning materials suitable for a sixth-grade level.



Find the area of the triangle

Solution	Explanation
Area of a triangle: *A* = ½ x (*base* x *height*)	Recall (*b* x *h*) = area of rectangle.
	Multiply by ½ since a right triangle is ½ of the a rectangle.
A = ½ x (*6* x *9*)	Substitute *6* for the **base** of the triangle, and 9 for the **height** of the triangle in the formula.
A = ½ x (54)	Multiply.
A = 27 mm^2	Solve for *A*.
Therefore the area of the triangle is 27 mm^2.	

Find the area of the triangle

To find the area of the green triangle, use the area of the triangle formula:

Area of triangle = ½ x *base* x *height*
= ½ x 6 x 9
= ½ x 54
= *27* mm^2

Therefore the area of the triangle is 27 mm^2.

Figure 1. Examples of *Process-oriented Worked Examples* (top) and *Product-oriented Worked Examples* (bottom) used in study.

Measures and Scoring

Self-Explanation Prompts. Two formats of self-explanation prompts were included in this study.

Menu-based self-explanations. This form of self-explanation prompt includes a menu with several explanations to the solution. Students had to select an option by identifying the underlying procedural principles, for example:

Please explain how you got your answer.

a. *The formula for the area of a triangle =, since the area of a triangle is the same as a rectangle.*
b. *The formula for the area of a triangle = ½ ×* base × height, *since the area of a triangle is half the area of a rectangle.*

Focused self-explanations. Unlike the menu-based self-explanation prompts, focused self-explanation prompts are less structured. Students had to consider the relationship between the area of the triangle and the area of the rectangle in their answer, for example:

Thinking about the relationship between the area of the triangle and the area of the rectangle, please explain your answer.

Each accurate self-explanation provided by students was awarded one point, for a total of five points.

Practice Problems. Students received 5 practice problems to solve following the learning materials. The practice problems were isomorphic versions of the worked examples students studied. Each correct answer provided was awarded one point, resulting in a total of five points for practice problems.

Pretest and Posttest Questions. Pre- and post-tests were administered on Qualtrics, an online survey platform (https://www.qualtrics.com). Questions were adapted from an online database that provides comprehensive content that aligns with Common Core State Standards for Mathematics. There were 12 multiple-choice questions on the pre-test ($\alpha = .66$), and 10 questions on the post-test ($\alpha = .68$). The pre-test and post-test contained several of the following multiple-choice questions along with relevant geometric figures: (1) "Which of the following has a greater perimeter/area?" (2) "What is the area of the [composite] figure?" and (3) "What is the area of the shaded region?" Each correct answer earned one point, resulting in a maximum of 12 points on the pretest and 10 points on the posttest.

Cognitive Load Measure. This study used an adapted version of Paas' (1992) subjective rating scale to assess cognitive load. Instead of a 9-point rating scale, the adapted cognitive load scale consisted of a 7-point scale where students had to indicate how *difficult* they found the task to be. The scale ranged from (1) *not at all to* (7) *extremely difficult*. Students were presented with this scale after every question on the post-test ($\alpha = .84$), for a total of 10 responses.

Procedure

The experiment was conducted in a computer laboratory at the middle school with students seated individually in front of computer monitors. Each class attended the session during their normal mathematics class period, which lasted approximately 70 minutes. At the beginning of the study, students were encouraged to participate in the experiment independently without any external help from peers or notes.

Students were randomly assigned to one of the four experimental conditions (Process + Menu-based, Process + Focused, Product + Menu-based, Product + Focused). Students were given 15 minutes to complete the 12 pre-test questions. Following the pretest, students were informed that they had 20 minutes to study materials on how to calculate the area of a right-angle triangle. They were also told that they had to answer five practice problems during this time. After each practice problem, students were prompted to self-explain their answer via menu-based or focused self-explanations.

All students received accuracy feedback during the practice problems in the form of process- or product-oriented worked examples based on the conditions they were assigned to. After the learning intervention, students had 35 minutes to complete the 10 posttest questions. The pretest, learning intervention, practice problems, and the posttest were all administered online.

Results

Preliminary Analyses

Prior to data analysis and testing the hypotheses, all variables were examined for accuracy of data entry, outliers, and normality of distributions. Distributions were normal and within acceptable levels of skewness and kurtosis (below ±2; Tabachnick & Fidell, 2006). Across all four conditions, all dependent variables were missing at random (Little's MCAR $p > .05$); therefore, a decision was made to impute missing data values using the Expectation Maximization imputation. We eliminated data for five participants, of which three spent more than 20 minutes studying the materials and two did not complete the posttest, leaving 117 participants' data for all subsequent analyses. Table 1 shows the descriptive statistics for the pretest, practice problems, self-explanations, posttest and cognitive load for the four experimental groups. The four experimental groups did not differ significantly on the pretest of calculating the areas of triangles and composite figures, $F(3,113) = 0.76, p = .76, \eta^2 = .010$. As a result, pretest was not included as a covariate in all subsequent analyses.

A 2x2 between-subjects multivariate analysis of variance (MANOVA) was conducted with worked examples (process vs. product) and self-explanation (menu-based vs. focused) as independent variables and practice problem, self-explanation, posttest scores, and cognitive load scores as the dependent variables. The assumption of equality of covariance matrices was met, Box's M = 45.22, $F = 1.41$, $p = .07$. There was a significant main effect for self-explanation, (Wilks' Lambda = .69, $F = 12.45$, $p < .001$, $\eta_p^2 = 0.31$). The main effect for worked examples (Wilks' Lambda = .97, $F = .78$, $p = .54$, $\eta_p^2 = 0.03$) and worked examples x self-explanation interaction (Wilks' Lambda = .98, $F = .63$, $p = .64$, $\eta_p^2 = 0.04$) were not significant. Univariate tests revealed a statistically significant effect of learning with menu-based self-explanations on self-explanation scores, $F(1,113) = 34.29, p < .001, \eta_p^2 = 0.23$.

Are Menu-Based Self-Explanations More Effective for Learning Than Focused Explanations?

Contrary to hypothesis 1, menu-based self-explanations were not more effective for learning than focused explanations on posttest scores. However, analysis of variance (ANOVA) showed a significant main effect of treatment, $F(1,113) = 34.29$, $p < .001$, $\eta_p^2 = 0.23$ on self-explanation scores. Approximately 23% of the self-explanation score variance could be attributed to the treatment. Bonferroni adjustments for multiple comparisons found significant differences between the Process + Menu-based vs. Process + Focused ($d = 1.23, p < .001$), Process + Menu-based vs. Product + Focused ($d = 0.85$, $p = .008$), Product + Menu-based vs. Process + Focused ($d = 1.33$, $p < .001$), and Product + Menu-based vs. Product + Focused ($d = 0.92$, $p = .006$).

Is Process- or Product-Oriented Worked Examples More Effective for Learning Than the Other?

In line with hypothesis 2, the process-oriented worked examples conditions did not outperform the product-oriented worked examples on learning. This indicates that the process-oriented worked examples were not more superior than the product-oriented worked examples on posttest scores ($d = 0.05$, $p > .05$), self-explanations ($d = 0.19$, $p > .05$) and practice problem scores ($d = 0.05$, $p > .05$).

Are Process-Oriented Worked Examples More Effective in Prompting Menu-Based or Focused Self-Explanations Than the Respective Process-Oriented Worked Examples?

Contrary to hypothesis 3, there were no significant differences between the respective process-oriented and product-oriented worked examples in prompting menu-based or focused self-explanation. Bonferroni adjustments for multiple comparisons found no differences for Process + Menu-based vs. Product + Menu-based ($d = 0.08$, $p > .05$) and Process + Focused vs. Product + Focused ($d = 0.38$, $p > .05$).

Are There Differences in Cognitive Load Between the Conditions?

Contrary to hypothesis 4, there were no significant differences between the conditions for cognitive load. Bonferroni adjustments for multiple comparisons found no differences for Process + Menu-based vs. Process + Focused ($d = 0.28$, $p > .05$), Process + Menu-based vs. Product + Menu-based ($d = 0.11$, $p > .05$), Process + Menu-based vs. Product + Focused ($d = 1.61$, $p > .05$), Process + Focused vs. Product + Menu-based ($d = 0.27$, $p > .05$), Process + Focused vs. Product + Focused ($d = 0.18$, $p > .05$), and Product + Menu-based vs. Product + Focused ($d = 0.18$, $p > .05$).

Discussion

In this study, we examined whether a learning environment that utilized both worked examples and self-explanations was beneficial in helping sixth-grade students acquire a new mathematical skill of calculating the area of a triangle. Empirical evidence suggests that worked examples are superior to general problem-solving strategies in several areas such as less acquisition time (van Gog et al., 2006; van Loon-Hillen et al., 2012), lower cognitive load (Atkinson et al., 2000; Paas & van Gog, 2006) and increased learning performance (Huang & Reiser, 2012; Chen et al., 2015). Findings from the current study provide the following contributions to existing research: (1) Menu-based self-explanation prompts may be more beneficial for eliciting accurate self-explanations across prior knowledge levels compared to written focused self-explanation prompts in an ecologically valid context, and (2) Process-oriented and product-oriented worked examples provide similar learning benefits towards learning in an ecologically valid context.

Effects of Menu-Based Self-Explanations on Learning Outcomes

Contrary to hypothesis 1, menu-based self-explanation prompts were not more beneficial than focused self-explanation prompts on posttest scores. One advantage of menu-based self-explanations, a strongly cued self-explanation prompt, is

Assessment Components	Process-oriented and menu-based ($n = 29$)		Process-oriented and focused ($n = 31$)		Product-oriented and menu-based ($n = 25$)		Product-oriented and focused ($n = 32$)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pretest	7.66	2.72	7.81	2.27	8.00	2.14	7.38	1.88
Practice Problems	2.14	1.43	1.87	1.67	2.20	1.38	1.97	1.26
Self-Explanation	3.86	1.36	1.90	1.78	3.96	1.21	2.56	1.68
Posttest	5.79	2.43	5.13	2.62	6.08	2.14	5.19	2.25
Cognitive load	24.92	10.39	27.57	8.43	25.99	8.90	27.73	10.45

Table 1. Descriptive Statistics (Means, Standard Deviations and n) of Dependent Measures for the Four Experimental Groups.

that it is more beneficial during initial skill acquisition as it provides learners with more instructional guidance and reduces faulty self-explanations (Atkinson, Renkl, & Merrill, 2003; Wylie, Koedinger, & Mitamura, 2009). Low-prior knowledge learners who lack the knowledge to generate complete self-explanations on their own may more likely benefit from this self-explanation format. One reason that we may have failed to find significant differences between the two self-explanation formats could be that learners in the study had a moderate to high prior knowledge of the learning material even before the learning intervention. However, our results did indicate that menu-based self-explanation prompts were more beneficial for eliciting immediate self-explanations, compared to focused explanation prompts in an ecologically valid context. While this is a first step towards addressing Bisra et al.'s (2018) call for more direct comparisons between different self-explanation formats, the large effect sizes (range: d = 4.63 to 7.05) obtained between the conditions have to be interpreted with caution. Menu-based self-explanations typically provide a handful of self-explanations in a drop-down menu for learners to select what they consider to be an accurate explanation. Unlike focused self-explanation prompts, learners are more susceptible to guessing the correct explanation. Future research should examine the effects of different self-explanation formats with learners of varying levels of prior knowledge. Additionally, future research should consider opportunities to control for learners' guessing the menu-based self-explanation responses. This might include measuring the amount of time taken to select a response or assessing the number of clicks on the measures.

Effects of Process- and Product-Oriented Worked Examples on Learning Outcomes and Self-Explanations

Consistent with hypothesis 2, there were no significant differences between process- and product-oriented worked examples on learning outcomes, and contrary to hypothesis 3, there were no significant differences between the respective process- and product-oriented worked examples in prompting menu-based or focused self-explanation. In this study, both process- and product-oriented worked examples were paired with either menu-based or focused self-explanation prompt. The results are consistent with the explanation that the effects of learning from process-oriented worked examples may be diminished when self-explanations are also provided (Schworm & Renkl, 2006). Based on this, it may be unhelpful to provide additional instructional explanations to worked examples when learning with self-explanation prompts to enhance understanding of the learning material (Wittwer & Renkl, 2010). Furthermore, since pretest scores revealed that students had moderate to high prior knowledge of the learning material, it may be likely that students did not benefit from such guided instructional material.

Differences in Cognitive Load Across Conditions

Contrary to hypothesis 4, there were no significant differences between the conditions on cognitive load. Research on worked examples and self-explanation prompts suggests that low prior knowledge learners are more likely to benefit from these instructional strategies because the structure of worked examples eliminates extraneous cognitive load (Sweller & Cooper, 1985; van Gog et al., 2006; Renkl, 2014a), and self-explanations increases germane cognitive load. However, again, given that students had moderate to high prior knowledge, it is likely that a measure of level of difficulty to represent students' cognitive load during learning is insufficient, and also that the majority of students were unlikely to find the materials difficult. Furthermore, the cognitive load scale was administered after the learning intervention and not during the intervention, therefore it might not provide a good representation of cognitive load experienced from the learning materials. Given that studies are lacking on the effects of process-oriented and product-oriented worked examples on cognitive load, future research should explore the impact of such instructional strategies on students' cognitive load.

Practical Implications

There are several plausible explanations for the results obtained in this study. First of all, given the lack of significant difference between pretest and posttest scores across the conditions, it is possible that the students started the present study with a good understanding of the learning material. According to Kalyuga's expertise reversal effect (2014), instructional techniques that are traditionally effective for low prior knowledge learners become ineffective with high prior knowledge learners, potentially causing negative learning consequences (Kalyuga, Ayres, Chandler & Sweller, 2003). In the context of worked examples, the expertise reversal effect occurs when worked examples lose their effectiveness for learners with high prior knowledge (Kalyuga et al., 2001). When high prior knowledge learners' view worked examples, the detailed solution steps may induce greater cognitive load on the high prior knowledge learner instead of minimizing the load, because of conflicts between the previously acquired schemas and the incoming instructional support. As a consequence, if the learner is provided with the worked examples, he or she will have to engage in a manner that integrates both sets of information thus resulting in a cognitive overload, and potentially a decrease in learning outcome scores. On the other hand, if the learner were a novice, then previous research suggests that the worked examples would have been more effective in helping the learner acquire information. Therefore, one way to maximize the effectiveness of learning from worked examples is to ensure that the materials are used with learners who have low prior knowledge, or to offer faded steps in the worked examples for learners with high prior knowledge (Renkl & Atkinson, 2003).

Theoretical Implications

In this paper, we had hoped to extend the benefits of the CLT principles for instructional design in a K-12 population where initial mathematics skills acquisition is imperative for future academic success. Although it has been established that worked examples and self-explanations are supportive and generative learning strategies for college students, those findings were not replicated in this study. While a plausible explanation might be due to the expertise reversal effect experienced by learners, an alternative explanation might be that cognitively developing students may not know how to utilize metacognitive learning strategies as effectively yet. With the inconsistency in the effectiveness of learning with worked examples and self-explanation with middle school students and the findings from this study, more research with K-12 populations is necessary to establish the role of worked examples and self-explanations in K-12 learning.

Limitations

The interpretation of the results of this study is subject to several limitations. First, the study was conducted only with sixth-graders from the same middle school. To generalize the effects, more studies should be conducted students from different K-12 populations. Second, students' mathematics teachers were consulted on the appropriateness of the learning materials, however, they were concerned that students would be too discouraged if learning materials were too tough, or the topic was completely new to students. As a result, the topic in this study was something somewhat familiar to students, and most students in this study had moderate to high prior knowledge of the learning material. Future studies should consider students of varying levels of prior knowledge or implementing the study's design with more challenging materials. Third, this study was conducted in a single day at the middle school. Due to restrictions on how much time researchers had with students and the University's IRB protocols, it was impossible to use the pretest to gauge how well students already understood the learning material. As a result, researchers were unable to alter the difficulty of the learning materials before the study. While future studies should take this into consideration, this study also highlights the complexity of drawing huge inferences from classroom-based studies. Fourth, students were expected to provide self-explanations for their answers during the learning intervention, the learning intervention did not focus on teaching students how to self-explain, and the quality of focused self-explanations produced were not analyzed. This presents a limitation because it is unclear if the self-explanation prompts were sufficient or suitable in helping students learn from the material. Future research should include a segment on training students to self-explain before requiring students to provide self-explanations. Finally, we used a self-reported measure of cognitive load in line with previous studies. However, this was implemented after the learning intervention and not during the learning intervention. Furthermore, since the cognitive load scale in this study was assessed by students' perceived levels of difficulty, it is possible that students did not make accurate judgments of their own learning. It was noted during data analysis that several students reported low cognitive load scores even though their responses were incorrect. Future research should consider either utilizing a secondary task to capture students' speed of responses, or recording duration spent on each question to provide a more accurate representation of the perceived amount of difficulty on the task.

The findings from the study suggest that while a combination of worked examples and self-explanation might work for college students, these learning interventions may not work as effectively for younger students who might not yet know how to utilize metacognitive learning strategies. From a developmental perspective, this could be explained via the differences in working memory resources between middle school students and college students, as well as individual differences in attention span (Raghubar, Barnes, & Hecht, 2010; Vuontela et al., 2013). In addition, the implications from the findings of this study are clear. Instructional designers should take into consideration appropriate ways to incorporate learning tools that provide sufficient scaffolding for low prior knowledge learners and cater to the needs of high prior knowledge learners who do not need as much guidance. Perhaps one way to do this with worked examples and self-explanation prompts would be to provide faded-out worked examples for high prior knowledge learners, and self-explanations that have less scaffolding, for example, open-ended or focused explanations.

Conclusions

The purpose of this study was to extend previous research done on computer-based learning from worked examples and self-explanation to different populations of learners in ecologically valid educational contexts. Previous research on worked examples and self-explanation have focused primarily on the effects of these learning strategies on learning effects with convenience samples of college populations. Additionally, researchers have only focused on a single self-explanation format in those studies. In contrast, this study compared the effects of learning from two worked examples formats, as well as menu-based and focused self-explanations with a middle school population in a classroom study. In addition, building off the critiques of previous studies, the present study included an independent cognitive load measure with a 7-point scale that accounts for greater response sensitivity.

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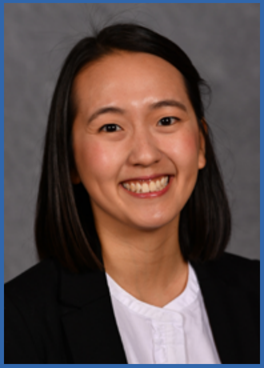

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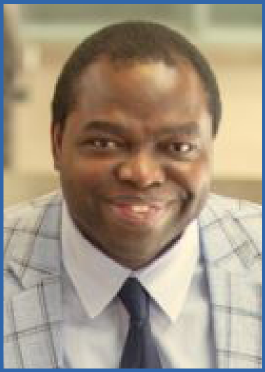

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