Improving Students' Scientific Reasoning Skills via Virtual Experiments and Worked Examples

Shiyu Liu and Keisha Varma
University of Minnesota, 56 East River Road, Minneapolis, MN 55455
Email: 1iux0631@umn.edu, keisha@umn.edu

Abstract: This work looks at how to improve students' scientific reasoning. The findings suggest that neither worked examples alone nor interactive visualization experiences alone are as helpful as the combination. While worked examples are effective instructional devices to assist learning, due to students' limited self-explanation skills, virtual experiments are needed to elicit more metacognitive efforts when studying the examples. At the same time, worked examples provide direct guidance that can prevent potential frustration with the visualization.

Introduction

Successful learning in science classrooms requires scientific reasoning skills involved in experimentation, evidence evaluation, theory and evidence coordination and so on (Zimmerman, 2005). National science standards mandate that they are taught to students beginning in early elementary grades and continuing through high school (NRC, 1996). While interactive visualizations may facilitate the learning of these skills, additional support is needed so that students are able to apply them appropriately (Varma & Linn, 2011).

Worked examples are effective instructional device to assist learning, as they demonstrate expert problem solving strategies in a step-by-step fashion to avoid overtaxing learners' cognitive resources (Renkl, Stark, Gruber, & Mandl, 1998). The cognitive load theory (Sweller, 1988) suggests that, learning from worked examples can more efficiently prevent cognitive overload during initial knowledge acquisition than problem solving. Accumulating research has been studying this worked example effect (e.g., van Gog, Kester, & Paas, 2011), but mainly focused on conceptual learning in well structured domains such as algebra and physics (e.g., Caroll, 1994). The present work transitions the focus of worked examples research to explore the learning of scientific reasoning in authentic classroom contexts. In particular, we investigate the following research questions: (1) How does learning from worked examples influence students' understanding of scientific experimentation? (2) What is the role of inquiry activities with interactive visualizations in the learning process? and (3) How will the combination of worked examples and inquiry activities impact students' learning?

Methodology

Over a span of six weeks, 69 seventh-grade students (42 females and 27 males; mean age=12) were randomly assigned to three conditions: only studying worked examples (Example/Practice Only Group), only interacting with the visualization (Visualization Only Group), or learning via both worked examples and visualization activities (Combination Group) (see Table 1). A pre-and posttest (Cronbach's α reliability is 0.717) was administered to examine students' knowledge of scientific experimentation. Worked-example learning sessions occurred during regular class time (two sessions each week and approximately 15 minutes each session), when students were asked to study a worked example (see Figure 1) and solve a practice problem. Besides, the Combination and Visualization Only Groups participated in three virtual experiments, where they investigated the role of a particular variable in the greenhouse effect by manipulating the interactive visualization (see Figure 2).

Results and Conclusions

Results show that students who both reflected on worked examples and interacted with the computer visualization significantly outperformed others in designing scientific experiments [$F(2,66)=5.166$, $p<.01$]. Across the six weeks, they had notable improvement in applying the control-of-variable strategy when asked to evaluate and refine experimental designs [$F(1,16)=22.07$, $p<.001$]. In contrast, only learning from worked examples or interacting with the visualization resulted in much less progress in students' performance, and there was no significant difference between these two approaches [$F(1,42)=.731$, $p=.397$]. Rasch Model is used to measure the practice problems' item difficulty and preliminary results indicate that the questions in general tap well into the distribution of students' scientific reasoning abilities.

Our findings indicate that combining worked examples with visualization inquiry activities is a promising approach to facilitate the learning of scientific reasoning. Although computer visualizations are helpful tools to enhance learning, students are found often tempted to manipulate variables randomly when direct guidance is not provided, and fail to recognize the importance of controlling variables in a systematic manner. Worked examples can serve to encourage their reflection on the specific knowledge and motivate them to devote more metacognitive efforts when interacting with the visualization. On the other hand, without additional exploratory experience, learning from worked examples is less effective than would be expected. Due to limited self-explanation skills, students may only focus on the superficial features of the examples and pay little attention to possible deficiencies in their learning (Chi & Lewis, 1989). This lack of sufficient mental effort thus makes it difficult for them to transfer what have been learned from the examples to new scenarios. In this sense, interacting with the visualization provides valuable opportunity for students to try out the reasoning strategies they have learned from the worked examples, which in turn will greatly elicit their deep understanding of them. Although we cannot ignore the possibility that the different learning time across groups may have impacted students' performance, our follow-up study will adopt relevant tasks to make sure that participants in all the conditions spend equal time learning the topic so as to eliminate the confounding effect there may exist.

References

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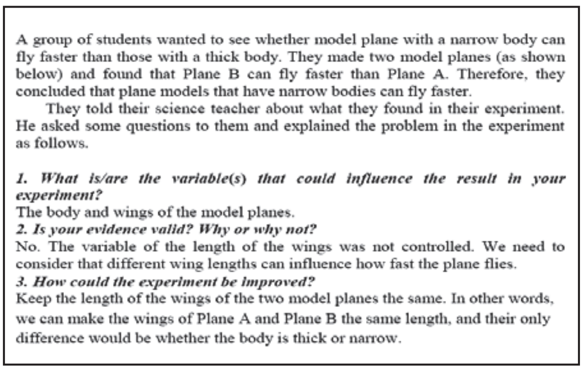
Table 1: Group Assignment and Schedule.

Group	Pre-test	Vis.	WE	Vis.	WE	Vis.	Post-
	Week 1	Week 1	Week 2 & 3	Week 3	Week 4 & 5	Week 5	Week 6
Combination	X	X	X	X	X	X	X
Visualization Only	X	X		X		X	X
Example/Practice	X		X		X		X

Note: 1. WE: worked-example learning; Vis.: activities with the visualization
2. Shaded boxes indicate that the group did not participate in the particular activity.


A group of students wanted to see whether model plane with a narrow body can fly faster than those with a thick body. They made two model planes (as shown below) and found that Plane B can fly faster than Plane A. Therefore, they concluded that plane models that have narrow bodies can fly faster.

They told their science teacher about what they found in their experiment. He asked some questions to them and explained the problem in the experiment as follows.

1. What is/are the variable(s) that could influence the result in your experiment?
The body and wings of the model planes.
2. Is your evidence valid? Why or why not?
No. The variable of the length of the wings was not controlled. We need to consider that different wing lengths can influence how fast the plane flies.
3. How could the experiment be improved?
Keep the length of the wings of the two model planes the same. In other words, we can make the wings of Plane A and Plane B the same length, and their only difference would be whether the body is thick or narrow.

Figure 1. Screenshot of a sample worked example.

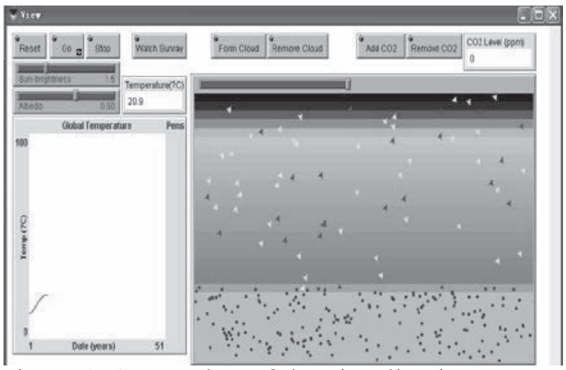


Figure 2. Screenshot of the visualization.