Supporting Comprehension in Computer-Based Science Simulations

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Abstract

Computer simulations can pose a number of comprehension challenges for science students. This study explored methods of improving students learning from a simulation. Undergraduates (*n* = 415) were randomly assigned to a 2(agency: active, passive) × 2(strategy: control condition, control of variables [CVS] strategy) between-subjects design. Students completed photosynthesis and general science prior knowledge tests and a post-simulation comprehension test. Results indicated that the students had relatively good comprehension of the simulation content and that performance on these outcomes was strongly driven by prior knowledge. Although there were no significant effects of the agency or strategy manipulations, exploratory interactions suggest a need to further investigate which types of simulation supports might be most beneficial for different learners.

Keywords: science comprehension; prior knowledge; multimedia comprehension

Supporting Comprehension in Computer-Based Science Simulations

Science simulations have become a common tool in the science classroom (Rutten et al., 2012). Simulations support interactive learning and are particularly useful because they allow students to examine phenomena that cannot be observed with the naked eye (Baltzis & Koukias, 2009; de Jong et al., 2013). However, simulations can pose a number of challenges for students. One concern with simulations is that they are often self-guided and require both reading about the phenomena and interacting with the simulation. However, little work has been done to understand computer simulations as a comprehension task. Multimedia comprehension requires the coordination of a number of higher order processes and skills in order to construct a coherent mental model that includes information from the text as well as information from the visualization (Wiley et al., 2014; Mayer, 2014). For example, Figure 1 shows a screenshot of the Concord Consortium simulation about photosynthesis. The student must read the text, which includes a number of topic-specific terms, as well as map the colors and shapes in the image to the text content. They then must use this information to manipulate the simulation in meaningful ways that will help them to investigate and understand the scientific concept. This example also highlights two principles of multimedia learning that might influence the effects of science simulations. The first is the *prior knowledge principle* (Kalyuga, 2015), which suggests that the effects of multimedia learning activities will be dependent on a learner's prior knowledge. The second is the *learner control principle* (Scheiter, 2014) which suggests that agency plays a critical role in multimedia learning. We examine both prior knowledge and agency in this study.

A concern with science simulations is that many students lack experience with good experimental practices, such as manipulating one variable at a time (e.g., *control of variables*

(CVS) strategy, Chen & Klahr, 1999; Renken & Nuñez, 2013). This is particularly problematic for students who have inaccurate or naïve conceptions. Although simulations are often designed to help students to confront "anomalous data" (Clark & Chinn, 1993), students often rerun an experiment until they get the result they expect (Renken & Nuñez, 2013). Thus, in the current study, we examined the potential benefits of providing a pre-activity instruction about CVS prior to completing a science simulation and the extent to which this effect might vary as a function of both prior knowledge and agency.

Current Study

This study is part of a larger investigation into how to best implement science simulations in undergraduate biology. Participants were randomly assigned to a 2(instruction: control, CVS) x 2(agency: passive, active) between-subjects design. Learning was measured in two ways: 1) a pre to posttest gain on six standardized items about photosynthesis and 2) an 8-item comprehension test that probed from information specific to the text and tasks within the simulation activity.

Method

Participants

415 undergraduates from an introductory biology course completed the study for extra credit.

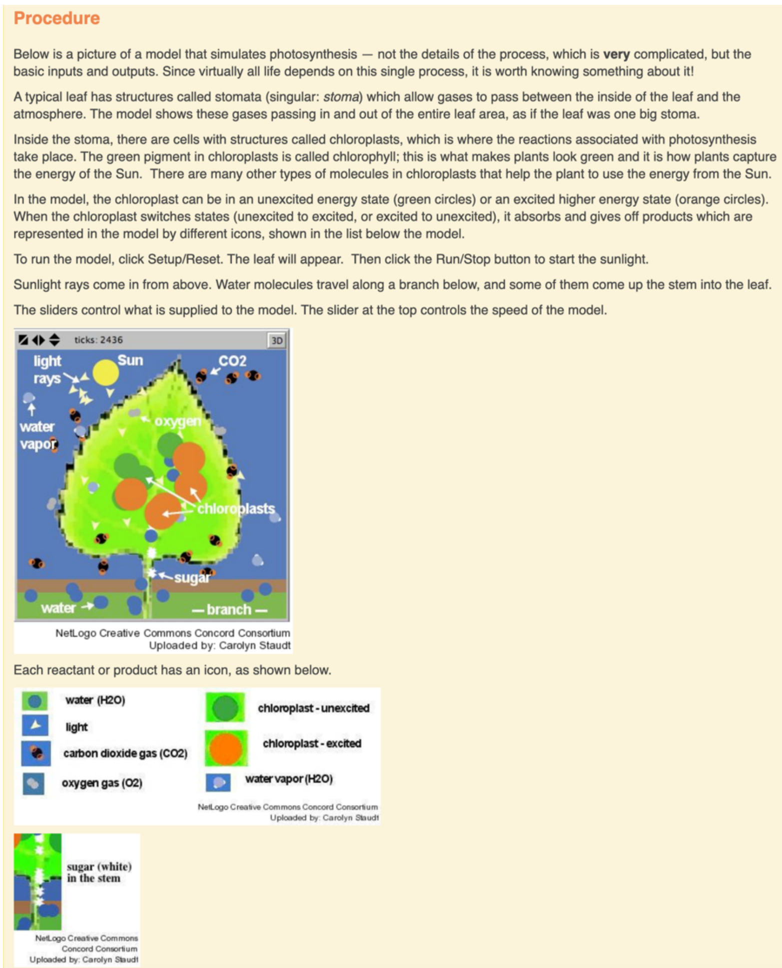
Materials

Photosynthesis Activity

Participants completed a common computer-based photosynthesis simulation (NetLogo, Concord Consortium) in which they read a short introduction about photosynthesis and worked with simulations to examine how different variables (water, sunshine, and carbon dioxide) influence the production of chemical energy (Figure 1). The simulation with changeable buttons and sliders is shown in Figure 2.

Figure 1

Section of the NetLogo Concord Consortium Simulation Leaf Photosynthesis.



Procedure

Below is a picture of a model that simulates photosynthesis — not the details of the process, which is **very** complicated, but the basic inputs and outputs. Since virtually all life depends on this single process, it is worth knowing something about it!

A typical leaf has structures called stomata (singular: *stoma*) which allow gases to pass between the inside of the leaf and the atmosphere. The model shows these gases passing in and out of the entire leaf area, as if the leaf was one big stoma.

Inside the stoma, there are cells with structures called chloroplasts, which is where the reactions associated with photosynthesis take place. The green pigment in chloroplasts is called chlorophyll; this is what makes plants look green and it is how plants capture the energy of the Sun. There are many other types of molecules in chloroplasts that help the plant to use the energy from the Sun.

In the model, the chloroplast can be in an unexcited energy state (green circles) or an excited higher energy state (orange circles). When the chloroplast switches states (unexcited to excited, or excited to unexcited), it absorbs and gives off products which are represented in the model by different icons, shown in the list below the model.

To run the model, click Setup/Reset. The leaf will appear. Then click the Run/Stop button to start the sunlight.

Sunlight rays come in from above. Water molecules travel along a branch below, and some of them come up the stem into the leaf.

The sliders control what is supplied to the model. The slider at the top controls the speed of the model.

NetLogo Creative Commons Concord Consortium
Uploaded by: Carolyn Staudt

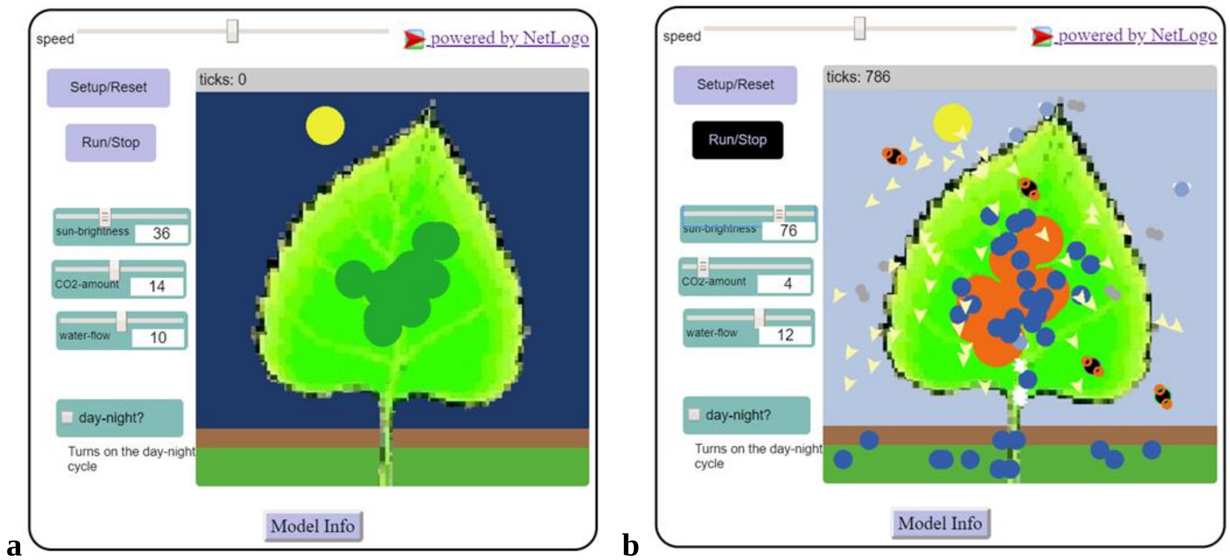
Each reactant or product has an icon, as shown below.

NetLogo Creative Commons Concord Consortium
Uploaded by: Carolyn Staudt

NetLogo Creative Commons Concord Consortium
Uploaded by: Carolyn Staudt

Figure 2

NetLogo Creative Commons Concord Consortium Simulation display of default leaf setting and display after manipulation of independent variables.



In the active condition, participants were able to move the various sliders and run the simulations themselves. In the passive condition, participants watched a screen recording of an example student running the simulation.

Instructions: Control, CVS

All participants received a brief passage that explained what they were going to do in the learning activity. The CVS instruction was adapted from the intervention developed by Chen and Klahr (1999). The instructions provide the participants with guidance on useful and systematic experimentation methods highlighting the value of manipulating one variable at a time.

AAAS Items

Students completed multiple-choice items from the American Association for the Advancement of Science (AAAS) Project 2061 Science Assessment. This included 6 items to measure photosynthesis knowledge and 6 unrelated (filler) items, both of which we administered at pretest and posttest, as well as 5 items that were specifically about the *control of variables strategy*. These items were included only at posttest.

Comprehension Test

An 8-item multiple-choice comprehension test was developed to evaluate students' learning from the activity. The test included four memory items and four inference items based on information that could be learned from the photosynthesis activity. This test was administered after completing the simulation.

Procedure

The study typically took students 60-90 minutes to complete. All data were collected online and asynchronously as an extra credit activity. Participants first completed the AAAS items and prior knowledge measures. They then received the appropriate task instruction (control, CVS). After reading and summarizing the instructions, they were then transitioned to the photosynthesis activity in which they read about photosynthesis and then either watched or actively engaged in a series of simulations. Once they completed the activity, they completed the posttest that included the comprehension test and the AAAS knowledge measure.

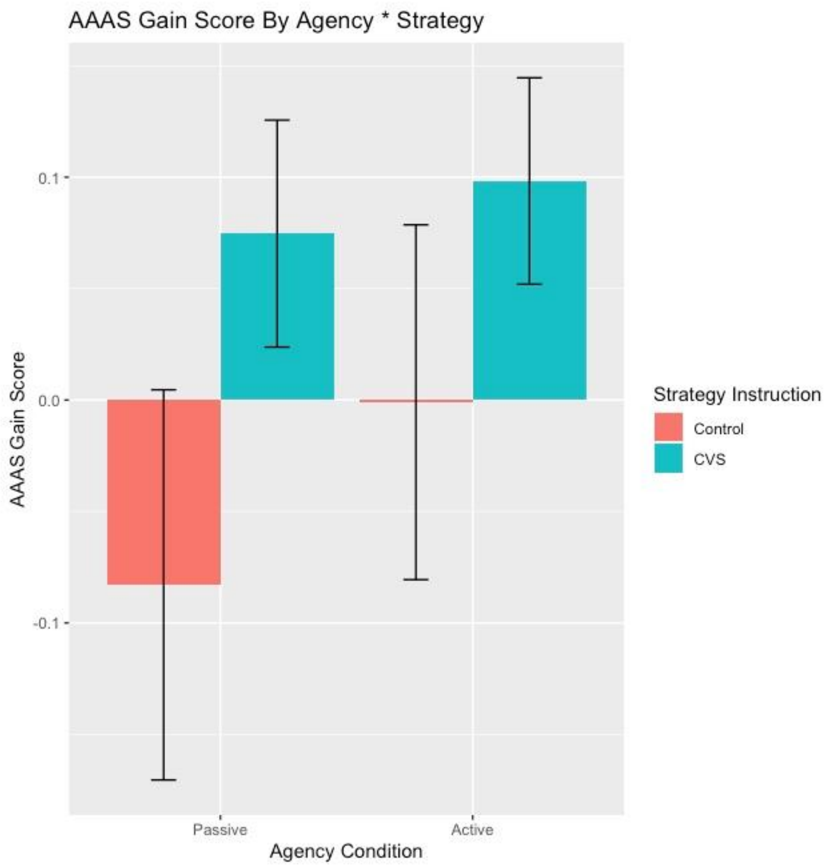
Results

AAAS Gain Score

We first examined the effects of the strategy and agency manipulation on students' performance on the AAAS items related to photosynthesis. During item scoring, it was revealed that one item in the AAAS filler assessment was omitted in the posttest. Thus, we removed the item from the pretest and yielded a AAAS filler score range from 0-5 instead of 0-6. Rather than conducting a repeated-measures analysis of variance (ANOVA), we elected to calculate a gain score. Students who produced perfect scores (n = 19) on the pretest were removed from this analysis because their AAAS score could not improve. Figure 3 displays the means and standard deviations of students' AAAS gain scores.

Figure 3

AAAS Photosynthesis Gain Scores as a Function of Agency and Strategy Conditions.



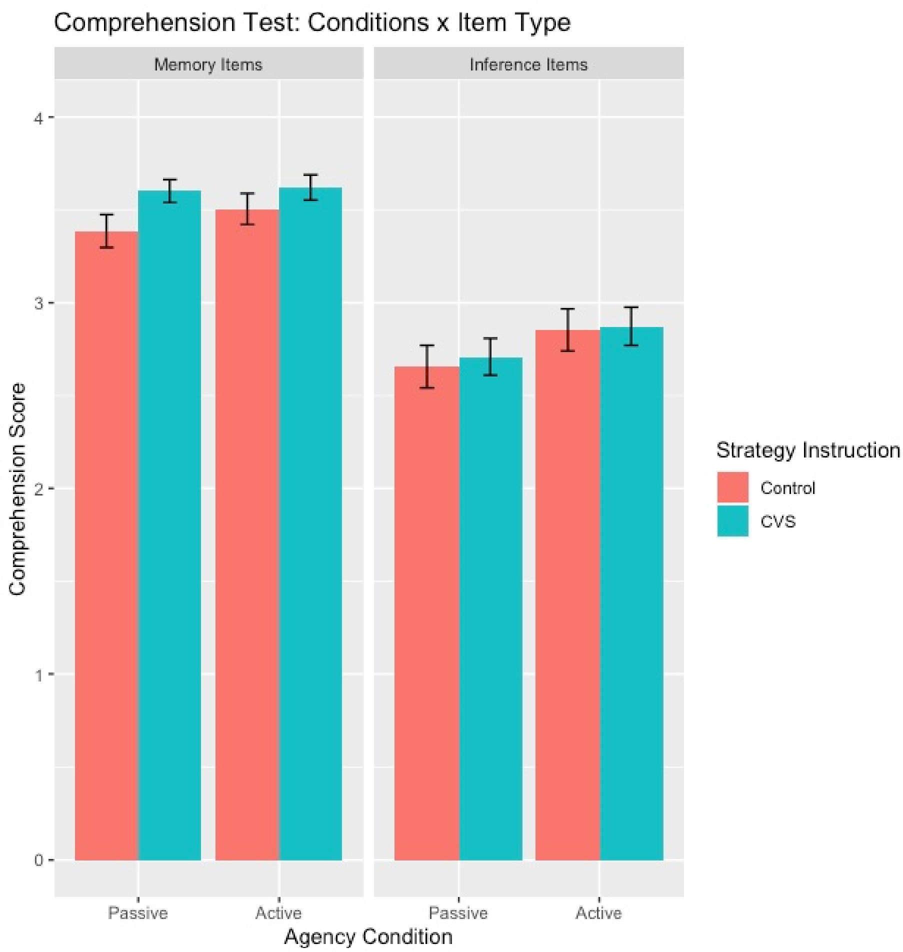
A 2(agency: active, passive) × 2(strategy: control, CVS) ANOVA revealed no main effect of agency, $F(1, 392) = 0.44$, $p = 0.51$, a marginal effect of strategy, $F(1, 392) = 3.64$, $p = 0.06$. There was no significant interaction, $F < 1.00$.

Comprehension Test

Performance on the comprehension test as a function of the agency and strategy manipulations is shown in Figure 4.

Figure 4

Comprehension Test Score as a Function of Agency and Strategy Conditions.



We conducted a series of linear mixed effects models, and significance was determined using likelihood ratio tests between each model and a reduced model. Significant chi-square (χ^2) tests indicate that adding the additional variable(s) improved fit as compared to the previous model. The baseline model (m0) included student and item as fixed effects. Adding in item type (memory, inference) significantly improved model fit, $\chi^2 = 7.71$, $p < .01$. A follow-up t-test confirmed that participants answered more memory items correctly ($M = 3.53$, $SD = 0.77$) than inference items ($M = 2.77$, 1.09), $t(414) = -14.27$, $p < 0.01$ Inconsistent with our predictions, there were no significant effects of the agency or strategy manipulations (m2), $\chi^2 = 3.72$, $p < .29$.

By contrast, Model 3 significantly improved model fit, indicating that performance on the comprehension test was driven by students' prior topic knowledge as measured by AAAS score, $\chi^2 = 7.92$, $p < .001$. Finally, an exploratory model (m4) that included all possible interaction terms failed to reach significance. The best fit model (m3) is shown in Table 2. Coefficients indicate that both item type and prior knowledge were significant predictors of comprehension test performance.

Table 1

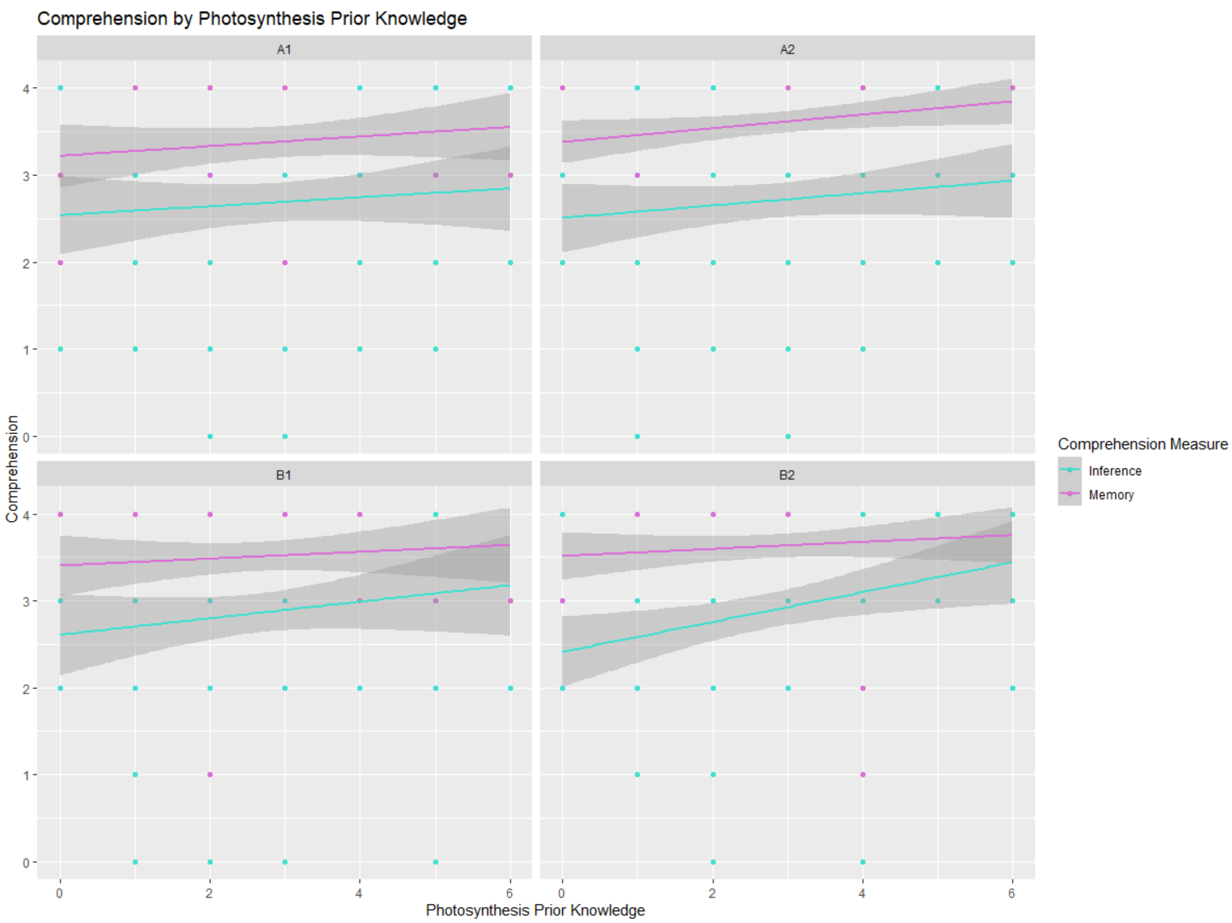
Coefficients for Best Fit Model (M3).

	Model 3 (M3)			
	AIC	**BIC**	**χ^2**	***p***
	2987.70	**3042.60**	**7.92**	**0.00**
	B	***SE***	**t**	***p***
Intercept	0.66	0.05	14.30	0.00
Item type	**0.19**	**0.06**	**3.13**	**0.02**
Strategy Condition	0.03	0.03	0.93	0.35
Agency Condition	0.04	0.03	1.54	0.12
Strategy x Agency	-0.01	0.04	-0.36	0.72
AAAS pretest score	**0.03**	**0.00**	**2.82**	**0.01**

Despite a nonsignificant model, we further explored M4 to examine possible (underpowered) three and four-way interactions. Figure 8 shows the correlations between AAAS score and comprehension score as a function of item type and the manipulations. Although there were no significant interactions, these graphs reveal some interesting trends within the four-way interaction. Those in the active condition (B1, B2) appear to show a slightly stronger correlation between AAAS pretest score and comprehension test score than their peers who passively watched the simulation video. More specifically, those with higher prior knowledge as measured by AAAS scores seem to be doing equally well on the memory and inference items, whereas those with less knowledge show a greater disparity between the two types of items. In particular, the students who were given the CVS instruction and were then able to actively manipulate the simulation appear to show a slightly stronger correlation on the more difficult inference items.

Figure 5

Comprehension scores by photosynthesis prior knowledge scores between item types and conditions.



Note: A1: Passive, Control; A2: Passive, CVS; B1: Active, Control; B2: Active, CVS

Discussion

Contrary to our predictions, there was little effect of the agency or strategy manipulations on students' AAAS gain nor comprehension test performance. After examining student performance through multiple analyses, the results of this study show that student performance is best predicted by individual differences, specifically students' photosynthesis knowledge prior to participating in the activity. Students who had a strong understanding of photosynthesis prior to completing the activity performed better on posttest comprehension measures than those with less topic knowledge. These results are consistent with research in prior knowledge suggesting a "rich get richer" effect. This is because students who have a richer knowledge base to draw upon are able to more quickly active relevant information, integrate with the current task, and organize that information more efficiently and effectively (see McCarthy & McNamara, 2021). The exploratory interactions suggest more complex relations between the activity manipulations and individual differences in knowledge. We suspect that less skilled or knowledgeable learners in the treatment condition may not be able to leverage information about control of variables effectively and, conversely, more skilled learners in the control condition may be spontaneously engaging in the strategy (e.g., Chi et al., 1994; see also Bumbacher et al., 2018). Thus, we need to more deeply explore process data to understand how the manipulation affected the way the students engaged with the simulation to examine potential mediating effects.

This study suggests that students who engaged with a computer simulation were able to adequately comprehend the content. However, performance on the tasks seemed to be driven by preexisting individual differences rather than on any of the educational scaffolds. Teachers should be aware of the role that prior knowledge can play and use caution when introducing computer simulations in the classroom. Although the manipulations showed little direct effects, there are some suggestions that researchers should more deeply explore what types of supports and scaffolds work best for which learners.

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