Long-term Benefits of Direct Instruction with Reification for Learning the Control of Variables Strategy

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Abstract. We compare three learning conditions on 57 middle school students' short- and long-term retention at applying the control of variables strategy. Collapsing over time, direct instruction with reification yielded more robust learning than either direct instruction without reification or discovery learning conditions as measured by skill at constructing unconfounded experiments.

Keywords: microworlds, virtual instruction, science education

1 Introduction and Method

Currently, there is a debate in the science education community on the effectiveness of discovery versus direct instruction (e.g. [1]). In our previous work [2], we compared the effectiveness of two types of direct instruction, with and without reification (self-explanation), and discovery learning on middle school students' acquisition and transfer of the Control of Variables Strategy (CVS), a procedure for conducting controlled scientific experiments. Students in our study practiced CVS by designing experiments with two virtual ramp apparatus to determine if a given factor affected how far a ball would roll down a ramp. Ramp setups could initially be *singly confounded* (one extraneous variable is not controlled) or *multiply confounded* (more than one extraneous variable is not controlled), and were initally *uncontrasted* (the factor to test is unchanged). Students had to modify ramp setups to test a specified factor while controlling for the others. We found that in an immediate posttest, both direct conditions designed significantly more unconfounded experiments starting from a multiply confounded setup than the discovery condition. However, the direct conditions did not significantly differ from each other. In the present study, we examined if these findings were robust by retesting participants 6 months after our original study. We hypothesized participants in the direct+reify group would outperform the other conditions even though the direct conditions showed no significant differences at the immediate posttest, since self-explanation supports deep learning [3] and knowledge integration [4].

We used the Science ASSISTment System [5], a web-based intelligent tutoring system, to host our materials and run randomized controlled experiments. The pretest, immediate posttest, and delayed 6 month posttest required students to construct 4 unconfounded ramp setups, without receiving feedback, to determine different factors' effects on the outcome. Between the pretest and immediate posttest, students

practiced CVS in a randomly assigned learning condition. In both direct conditions, students were first taught CVS in the context of the ramp and asked to evaluate if different ramp setups tested "for sure" that a factor affected the outcome. However, direct+reify students explained their reasoning whereas direct-no reify students did not. Discovery students continued attempting to construct unconfounded experiments receiving no feedback. For more details on the original procedure, see [2].

2 Results

We analyzed 57 students' immediate and delayed posttest scores to determine which condition(s) yielded better performance on skill in constructing unconfounded ramp setups using a repeated measures ANCOVA with pretest score as a covariate. Four students who did not take the original ramp pretest were excluded from this analysis. Means and standard errors for ramp performance over time are shown in Figure 1. Ramp setups demonstrating CVS for a given factor were scored 1 point, 0 otherwise. Within-subjects tests revealed no significant main effects for time, Wilks λ=.97, $F(1,49)$=1.36, p=.249, partial η^2=.027 and no significant interaction between time and condition, Wilks λ=.92, $F(2,49)$=2.03, p=.143, partial η^2=.076. However, condition was a significant between-subjects factor, $F(2,49)$=3.26, p=.047, partial η^2=.117, controlling for ramp pretest score. Post hoc comparisons revealed that the direct+reify condition constructed significantly more unconfounded experiments than the discovery condition (M=0.92, SE=0.43, p=.037, 95% CI=[0.06, 1.79]) and the direct-no reify condition (M=0.98, SE=0.45, p=.033, 95% CI=[0.84, 1.88]). No significant difference was found between the direct-no reify and discovery conditions, p=.903.

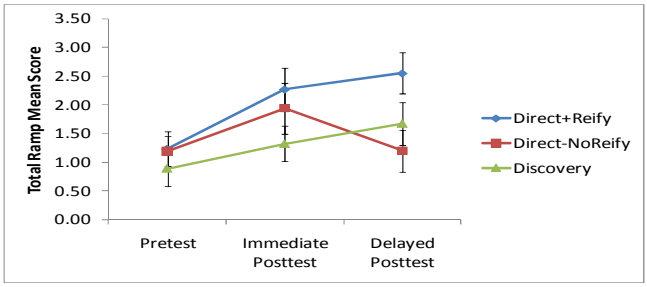

Fig 1. Means and standard errors for total ramp score by condition, maximum score = 4.

Since there was a significant between-subjects effect on condition, we analyzed group differences solely at the delayed posttest using an ANCOVA with ramp pretest score as a covariate. We found a main effect on condition, $F(2,49)$=3.36, p=.043, partial η^2=.121 with ramp pretest not being a significant covariate, $F(1,49)$=1.38, p=.247. Post hoc tests revealed that the direct+reify condition constructed significantly more unconfounded experiments in the delayed posttest than the direct-no reify condition (M=1.34, SE=0.53, p=.014, 95% CI=[0.29, 2.40]). There were no significant differences between direct+reify and discovery, p=.131 nor direct-no reify

and discovery, p=.306. As shown in Figure 1, the direct+reify condition maintained its higher performance at the immediate and delayed posttest. Though the direct-no reify condition improved at the immediate posttest compared to the pretest, the improvement is lost 6 months later at the delayed posttest. Also, the discovery condition's skills on this CVS authentic inquiry task increased as time progressed.

3 Conclusions and Future Work

On the Science Assistments project [5] we aim to assess inquiry skills such as hypothesizing, designing controlled experiments, collecting and analyzing data and formulating conclusions as they engage in inquiry using microworlds across different domains such as physics, chemistry, biology, and earth science. As a start, we researched the acquisition of a particular skill, CVS, which we feel is a necessary cornerstone for reasoning via inquiry. Our research suggests that the best way to attain timely and long-term skill in constructing unconfounded experiments is to combine direct instruction with reification. On a broader scale, we are using student action log files to create detectors of haphazard inquiry behavior as students engage in more open-ended inquiry tasks requiring the use of many inquiry skills. Example behaviors include running uncontrolled experiments and not testing stated hypotheses. These detectors will enable us in real-time to auto-score inquiry and determine those students requiring support. Leveraging these detectors, we can compare scaffolding strategies to identify those that are most effective for different kinds of students.

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