Control of variables strategy across phases of inquiry in virtual labs

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Introduction

Control of Variables Strategy (CVS) is the process of isolating the effect of single variables when conducting scientific inquiry [1, 2, 3].
148 students worked with minimally-guided inquiry activities using virtual labs on two different physics topics. The virtual labs allowed for exploration, data collection, and graphical analysis. Using student log data, we assess how CVS can help students achieve different levels of understanding when implemented in these phases of students' inquiry process [4]. We pose the following research questions.

Research Questions

1. What is the relationship between a student's final scientific model and the use of **control variable strategy** in different parts of their inquiry process?
2. Does the relationship depend on the simulated underlying mathematical relationship?

Inquiry Activity

The students engaged with two virtual labs: light-lab and charge-lab (Figure 1). Both have one outcome variable (absorbance or charge) and similar underlying mathematical relationships: outcome variables are proportional to the sim variables with the exception of plate separation:

$$Absorbance = f(wavelength) * concentration * width \quad (1)$$

$$Charge = voltage * area * \frac{1}{separation} \quad (2)$$

The inquiry labs consisted of a 5 minutes pre-worksheet assessing incoming knowledge (**pre-score**) and a 15 minutes activity with a main-worksheet and the virtual lab assessing scientific models (**main-score**).

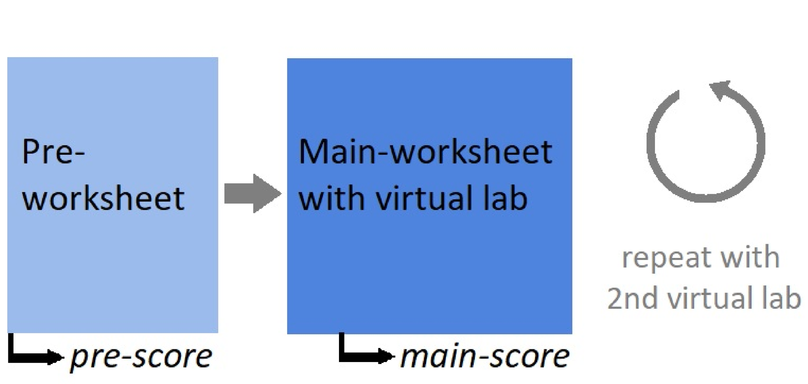

Figure 1: The study procedure.

The virtual lab activity

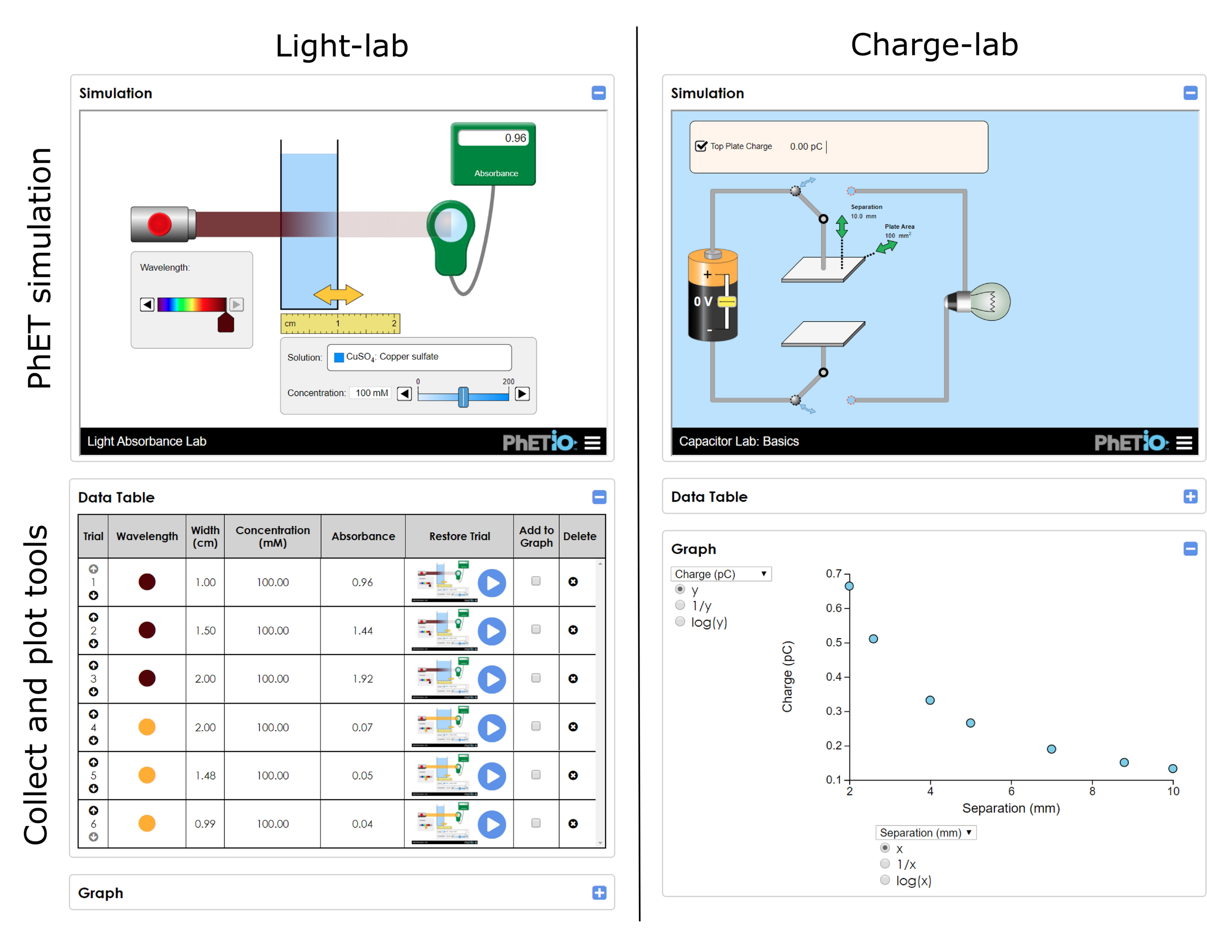

Figure 2: The light-lab and charge-lab with two collapsible tools: a table to record data (left) and a graph to plot data (right).

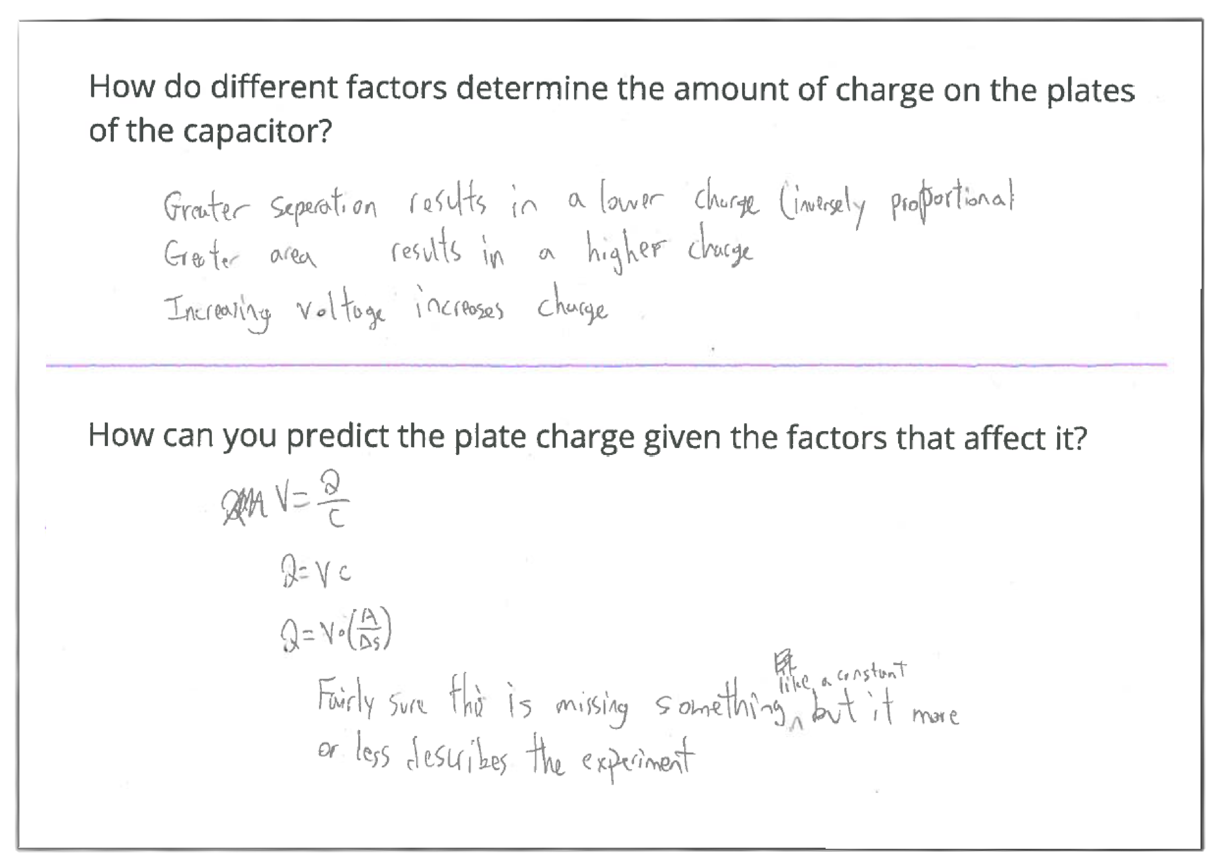

Figure 3: A student's main-worksheet for the charge-lab. The questions asked in the pre-worksheet are identical.

Assessment Methods

For each student, we code the highest level of CVS done per variable (**CVS_context**):

- CVS-explore changing a variable using a slider in the virtual lab
- CVS-collect collecting 3+ unconfounded trials sequentially
- CVS-plot adding these trials to a graph with appropriate axes

We code the mention of variables:

- (score=3) Quantitative description "when width doubles, the absorbance doubles"
- (score=2) Qualitative description "when width increases, absorbance increases"
- (score=1) Identified variable "width of beaker affects absorbance"
- (score=0) All above incorrect.

Results

Table 1: Average pre and main scores for CVS-explore,-collect,-plot and activity order

	CVS-explore	CVS-collect	CVS-plot	1^{st} activity	2^{nd} activity
pre	1.11±0.74	1.24±0.87	1.31±0.85	1.19±0.84	1.26±0.79
main	2.05±0.66	2.16±0.69	2.55±0.64	2.20±0.72	2.39±0.67

Regression model

We compare students' scientific model and CVS-context level for each variable by predicting their final model scores using a linear regression:

$$main\_score = \beta_1 \cdot CVS\_context + \beta_2 \cdot pre\_score + \beta_3 \cdot activity\_order + \beta_4 \cdot sim\_variable + \beta_5 \cdot student\_id \quad (3)$$

Use of CVS and learning

For a given variable, 53.3 to 64.9% of students do CVS-collect, and 43.2 to 50% do CVS-plot.
Students generally improve their models from simply identifying (score=1) to gaining a qualitative (score=2) or quantitative understanding (score=3) of the relationship between sim variable and outcome ($Z = -19.28$, $p < 0.001$, effect size=1.59).

Modeling student understanding

The ANOVA on EQ 3 returns CVS_context ($F(2,154) = 10.49$, $p < 0.001$, $\eta^2 = 0.02$) and activity order ($F(1,154) = 12.00$, $p < 0.001$, $\eta^2 = 0.01$) as significant predictors. Specifically, the final scores for a student doing CVS-plot were generally higher than students doing CVS-collect which were higher than doing CVS-explore (Table 1). The second activity had higher final scores (Table 1).
We run an ANOVA on a similar linear regression model but for each sim variable separately (c.f. EQ 3; with Bonferroni-Holmes correction). We find that CVS-plot remains a predictor of the final model score for all variables except for Separation:

- Width $F = (2,8) = 13.05$, $p < 0.001$
- Concentration $F = (2,8) = 12.81$, $p < 0.001$
- Area $F = (2,8) = 7.85$, $p < 0.001$
- Separation $F = (2,8) = 1.88$, $p = 0.16$

Conclusion

We found that students using CVS during data collection and plotting was associated with students achieving more qualitative and quantitative models, respectively, across two different science virtual labs and topics. This did not hold, however, for more complicated mathematical relationships (i.e. inversely proportional), emphasizing the importance of mathematical and graphical interpretation skills when doing CVS.

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