Development of Student Abilities in Control of Variables at a Two-Year College

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Scientific reasoning skills are necessary for scientific literacy. The control of variables (COV) sub skill is foundational for developing scientific reasoning skills. This study investigated student development of Low, Intermediate, and High COV skills in a first semester algebra-based introductory physics lab at a two-year college. Nine COV questions were utilized to determine students' development at the three COV skill levels. Findings indicated students' overall COV skills improved, but the increases varied according to the COV skill level assessed. These findings provide a baseline for a two-year college population for which scientific reasoning is largely unstudied. Future research will explore COV development at a four-year institution where a larger sample is available in order to inform future lab curriculum development.

Scientific reasoning (SR) is a set of abilities required to conduct scientific investigations and includes the collection and analysis of evidence, as well as the generation of evidence-based arguments (Koenig, Schen, & Bao, 2012). Some studies have shown that college students do not necessarily improve their SR skills within a one-semester physics course (Moore & Rubbo, 2012) or even over the course of their undergraduate education (Ding, 2013; Ding, Wei & Mollohan, 2016). Because a curriculum focused on content contributes little to the development of SR skills, many have called for inquiry-based science instruction that promotes the development of SR skills (Bao et al., 2009; Ding, 2013). A curriculum that specifically targets the development of SR skills has been shown to help students improve in some areas of scientific reasoning (Koenig, Schen, & Bao, 2012).

Control of variables (COV) is a fundamental skill necessary for the development of SR skills. Chen and Klahr (1999) defined the control of variables strategy as varying one variable between experimental conditions, being able to make valid inferences from unconfounded experiments and being able to identify the indeterminacy of confounded experiments. But not all outcomes are influenced by only one variable. Kuhn, Ramsey, and Arvidsson (2015) argue that COV skills need to be developed for more complex experiments involving multiple variables that may affect an outcome. Several categories of factors can contribute to the complexity of COV skills (Zhou et al., 2016). Understanding the factors that contribute to the complexity of COV skill levels is essential for developing students' COV skills. **It is important for curriculum to focus on developing this skill at various complexity levels** (Zhou et al., 2016; Wood, 2015)**.**

Specific COV skills have been assessed for pre-college students (Chen & Klahr, 1999; Penner & Klahr, 1996; Kuhn, 2007) and college students (Boudreaux, Shaffer, Heron, & McDermott, 2008; Zhou et al., 2016) with a variety of instruments targeting individual COV skills. Lawson (1978) proposed his Classroom Test of Scientific Reasoning (LCTSR) that was revised in 2000 and has been used in a variety of classroom settings (Bao et al., 2009; Coletta & Phillips, 2005). The LCTSR measures a variety of SR skills, but only contains three COV scenarios involving designing a controlled experiment and determining if experimental results indicate variables have an impact. Based on the definition of control of variables proposed by Chen and Klahr (1999), Schwichow et al. (2016) argue for four sub categories of COV skills–designing controlled experiments, interpreting controlled experiments, identifying controlled experiments, and understanding the indeterminacy of confounded experiments. While this framework incorporates important aspects of COV skills, a finer grain is needed to distinguish the various COV skill complexity levels. Zhou et al. (2016) proposed a progression of COV skills that incorporated a variety of factors that contribute to COV complexity, including number of variables, context (real-world vs. physics context), inclusion of experimental results, testability and influence. Building on their work, we tested a set of COV questions that incorporated a wide range of COV complexity and classified their level based on student data in a naturalistic setting (Wood, 2015).

The purpose of this study was to investigate student development of Low, Intermediate, and High COV skills at a two-year college (TYC) in an introductory physics lab course that targets the development of SR skills. The research questions were:

1. Do students' COV skills improve in an introductory physics lab course that targets the development of scientific reasoning skills?
2. At what complexity levels do students' COV skills improve?

This article discusses how the instrument used addresses the COV skill levels and the development of students' COV skill levels in an inquiry-based lab at a TYC.

Methods

Data Collection and Analysis

This study was conducted during Fall 2016 and Spring 2017 semesters in a first semester, algebra-based introductory physics lab at a Midwest two-year college (TYC). The lab met for two hours each week in a 15-week semester. The lab curriculum utilized guided-instruction that targeted the development of students' SR skills. Students were given a research question and were guided through designing and conducting controlled experiments in order to make valid claims based on experimental evidence. There were twelve labs, many which focused on one topic over two weeks. This allowed students to explore a topic using valid experimental design to create mathematical models from experimental data and then to apply their mathematical model to a similar situation. The lab topics included a Pendulum, Projectile Motion, Newton's Laws, Simple Harmonic Motion, Momentum & Energy, Rotation, and a Windmill Design Challenge.

Three full-time physics instructors taught the seven lab sections. Students in this course were predominately in the health sciences, including pre-pharmacy, pre-med and a variety of health fields. A total of 78 students were enrolled in the labs, but only 65 students completed both the pre- and post-tests and are included in this study. The pre-test was administered during the first week of the lab course prior to instruction and the same post-test during the last week of the course. The lab curriculum specifically targeted scientific reasoning skills, including COV skills (Koenig, Wood, Bao, Fabby, & Owens, 2016).

Nine COV questions were analyzed using two-tailed t-tests on the mean scores for all COV questions combined, as well as for each COV question to determine statistical significance at a 95% confidence level between matched pre- and post-tests. The effect size was calculated to determine the size of the difference between pre- and post-test scores. The effect size was calculated using Cohen's $d = \frac{(M_1 - M_2)}{SD}$ where M_1 is the post-test score, M_2 is the pre-test score, and SD is the standard deviation. We use the effect size to determine a practical significance of the results. In other words, the effect size gives us more information about whether the lab curriculum had a small (less than 0.3), medium (0.5) or large (0.8) effect on students' development of COV skills.

Instrumentation

We determined COV complexity by measuring student reasoning skills on questions that incorporated a variety of factors known to contribute to COV complexity (Zhou et al., 2016; Wood, 2015). Our measurement-based COV levels were categorized into Low, Intermediate, and High COV skill levels. The most basic COV skill level involved the identification of variables and simple relations. At this level, students should be able to distinguish between a controlled and confounded experiment in a variety of settings. At the Intermediate COV skill level, in order to increase the complexity level, experimental results were added which have been found to interfere with student understanding of controlled experiments (Zhou et al., 2016). In addition, students were expected to determine if variables were testable and influential even when the experiments may or may not be controlled. At the highest COV skill level, students were expected to determine testability and impact with multiple variables and to bridge into higher-level dimensions, including applying COV skills to causal relations and hypothesis testing.

Nine COV multiple-choice questions were used to measure low, intermediate, and high COV skills - some from the literature (Zhou et al., 2016) and some developed by authors. The complexity of each question was varied by incorporating a variety of factors that contribute to COV complexity, including number of variables, context (real-world vs. science context), inclusion of experimental results, testability and influence. Each COV skill level had three questions with slightly different factors to assess at a finer grain of COV skills as described below.

Low COV Level Questions
No experimental results provided

- Simple Pendulum: Design controlled experiment with 2 variables (Lawson, 2000)
- Freeze Milk: Design controlled experiment with 3 variables (developed by authors)
- Fishing: Determine if a variable is testable given 3 variables (Zhou et al., 2016)

Intermediate COV Level Questions
Experimental results provided

- Flies-Impact: Interpret evidence for impact given two variables (modified from Lawson, 2000)
- Flies-Testable: Determine if variable is testable given 2 variables (modified from Lawson, 2000)
- Pendulum-Not Testable: Determine if any variables are testable given 3 variables when none are testable (Zhou et al., 2016; Boudreaux et al., 2008)

High COV Level Questions

- Elastic Rod-Impact: Given experimental results, determine which variables have impact given 3 variables when hidden relations exist (developed by authors)
- Elastic Rod-Testable: Given experimental results, determine which variables are testable given 3 variables when hidden relations exist (developed by authors)
- Roses: Use control of variables to determine if necessary conditions exist in casual relations (developed by authors)

The lowest level COV question involved a *simple pendulum* with three strings that had two different masses. This question was from the LCTSR (Lawson, 2000). Given two variables, students were asked to design an experiment to determine if length has an effect on the period of oscillation. This question was considered to be at a Low COV level because no experimental results were provided and only two variables were involved in a physics context. The correct response required students to identify the appropriate independent variable and control variable in order to select the two strings that could be used in a controlled experiment. The alternative responses involved the use a single string, so the independent variable did not change; failing to control the second variable; or utilizing the incorrect independent and control variables.

Another Low COV question, developed by authors of this paper, involved *freezing milk* and determining whether or not initial temperature impacts the time it takes to freeze. Students were asked to design a controlled experiment by selecting the type and amount of soy milk to use as control variables when initial temperature varies. This was a Low COV question because no experimental results were provided and only two variables were involved in a chemistry context. The correct response was to hold constant both the type and amount of soy milk. Alternative responses involved various selections that would cause the experiment to be uncontrolled by varying the type, amount, or both.

Tom, Jerry and Dan are good friends and go fishing together most weekends. They often use the same type of fishing tools and have similar skills in fishing (that is, they typically catch about the same number of fish as one another every time). On their last fishing trip, they used a variety of fishing rods and fishhooks, and chose between two different locations to fish (see the conditions given in the table below).

		Tom	Jerry	Dan
Variables	Fishing rods	long	long	Short
	Fishhooks	thick	thin	thin
	Locations	Point A	Point A	Point B

Ignoring other possible influences and using the conditions as listed in the table, which of the following variables can be tested for possible impact on the number of fish caught?

Select ALL that apply.

a. Length of the fishing rod
b. Thickness of the fishhooks
c. Location of fishing
d. None of the above

Figure 1. Low COV *Fishing* question modified from Zhou et al. (2016). Determine if a variable is testable given three variables in a real-world context.

The last Low COV question involved *fishing* and determining which variables could be tested for impact given three variables and no experimental results in a real-world context (See Fig. 1). This was a Low COV question because no experimental results were provided, but it was more difficult than the first two questions due to having three variables and a real-world context. Real-world contexts tend to be not as well defined and more difficult for students than the more narrowly defined physics or chemistry contexts (Zhou et al., 2016). We modified the *fishing* question from Zhou et al. (2016) by asking students to determine the testability of three variables, instead of only one of the variables, and omitted experimental results. The correct response involved identifying the two conditions that represented a controlled experiment, and then reporting the sole testable variable in that experiment. The alternative responses involved varying the other variables, but not controlling the remaining variables, thus creating uncontrolled experiments. This question was more difficult than the other Low COV questions because students were instructed to select all options that apply.

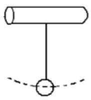
The first Intermediate COV question involved *flies* and determining if two different variables–red light or gravity–have impact on them. This question was modified slightly from the LCTSR (Lawson, 2000) to focus solely on determining impact of variables. This was considered an Intermediate COV skill because experimental results were provided, which increased the COV complexity level. The correct response identified the testable variable–gravity–as having an impact. The alternative responses included the variable that was testable but not influential; confusing testable with influential; and considering a variable not testable if it was not influential.

The next Intermediate COV question involved designing an experiment to determine if *flies* respond to blue light. We modified this *flies* question from the LCTSR (Lawson, 2000) by changing from determining impact to determining if a variable–blue light–is testable. This was considered an Intermediate COV skill because experimental results were provided, which increased the COV complexity level (Zhou et al., 2016). The correct response identified the two tubes that could be used to test if blue light is influential. The alternative responses involved not changing the independent variable; changing the wrong variable; and changing both variables.

The last Intermediate COV question involved a *pendulum* and determining which of three variables could be tested given three sets of data with experimental results when none of the variables were testable (See Fig. 2). This question, from Zhou et al. (2016), which was modified from Boudreaux et al. (2008), had a higher COV complexity because experimental results and three variables were provided (Zhou et al., 2016). The correct response was that no variable was testable due to all experiments being confounded. The alternative responses involved each variable in an uncontrolled experiment with other combinations of variables.

As shown below, a string hangs from a bar and has a small ball attached to its end. The string (and the attached ball) can be made to swing back and forth, and the number of complete swings during a certain time interval can be counted. A student wants to know whether or not the number of swings in 10 seconds is affected by the length of the string, the mass of the ball, and/or the angle the string is pulled away from the vertical at the time of release.

The student carried out several experiments to investigate what factors affected the number of swings in 10 seconds. The conditions and results are shown in the table below.



		Trial 1	Trial 2	Trial 3
Variables	length of string	10cm	10cm	40cm
	mass of ball	20g	30g	30g
	angle at release	15°	30°	15°
Number of swings in 10 seconds		16	16	8

Ignoring all other variables, which variable or variables do you think **can be tested** using the information shown in the table above?

a. the length of the string
b. the mass of the ball
c. the angle at release
d. "a" and "b"
e. "b" and "c"
f. "a" and "c"
g. "a", "b", and "c"
h. No variable can be tested using the information provided in the table.

Figure 2. Intermediate COV *Pendulum – Not testable* question from Zhou et al. (2016). Determine if any variable is testable given three variables when none are testable.

The first High COV question, developed by two authors of this paper, involved an *elastic rod* and determining which of three variables–length, distance rod is pulled, and mass of ball on rod–were influential. This question was more complex because experimental results and three variables, some not testable, were provided. The correct response used only two trials to determine that one variable, mass, was influential. The alternative responses involved a variable that was not testable; a variable that was testable, but not influential; no variables identified as having impact; and any combination of the possible responses.

The second High COV question, developed by authors of this paper, involved an *elastic rod* and determining which variables were testable when two variables were testable but only one had an impact on the number of oscillations per minute (see Fig. 3). The alternative responses included identifying a variable as testable when it did not change; identifying only one of the testable variables; indicating that no variables were testable; and any combination of responses.

A small ball of mass M is placed on one end of an elastic rod that is mounted vertically on a platform. Given an initial pull towards one side, the ball will oscillate back and forth as shown below. The number of complete oscillations during a certain time interval can be counted. A student wants to know whether or not the number of oscillations in 1 minute is affected by the length of the rod, the distance the ball pulled from equilibrium at the time of release, and/or the mass of the ball.

The student plans to carry out several different experiments to investigate which factors affect the number of oscillations in 1 minute. The conditions are shown in the table below.

		Trial 1	Trial 2	Trial 3
Variables	Length of the rod	50 cm	50 cm	50 cm
	Distance the ball is pulled from equilibrium at the time of release	4 cm	3 cm	6 cm
	Mass of the ball	49g	25g	25g
Results	Number of oscillations in 1 minute	27	38	38

Which of the following factors can be tested based on the information shown in the table above? You may choose more than one answer.

a. The **length** of the rod
b. The **distance** the ball is pulled from equilibrium
c. The **mass** of the ball
d. None of these

Figure 3. High COV *Elastic Rod –Testable* question developed by authors. Given experimental results, determine which variables are testable given 3 variables when hidden relations exist.

The last High COV question, also developed by authors of this paper, involved a scenario of growing *roses* and using COV to determine if necessary conditions existed in casual relations. This question was at the highest COV complexity level because it involved a real-world context and required students to apply COV skills to a higher scientific reasoning skill–causal reasoning.

Results

Student development in Overall COV skills indicated statistically significant improvement (p = 0.000) with a small effect size (Effect size = 0.23) for students in this TYC algebra-based physics lab (see Fig. 4). While there was a significant increase in students overall COV skills, the effect size indicates a relatively small effect. Looking at each COV question separately, we see that student improvement varied at different COV skill levels (see Table 1).

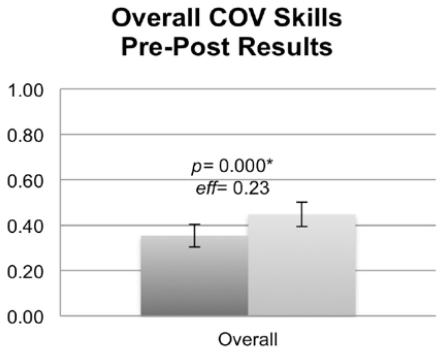


Figure 4. Mean scores on Overall COV questions. Error bars represent the standard errors. *Indicates p<0.05 determined with 2-tailed t-test

Table 1
COV Question Means, Significance Level, and Effect Size.

Question	Pre-Test Score (Week 1)	Post-Test Score (Week 14)	p-value	Effect size
Low COV				
Simple Pendulum	0.80	0.85	0.443	0.12
Freeze milk	0.74	0.80	0.321	0.15
Fishing	0.08	029	0.000*	0.60
Intermediate COV				
Flies-Impact	0.25	0.45	0.004*	0.43
Flies-Testable	0.20	0.34	0.028*	0.32
Pendulum-Not Testable	0.25	0.35	0.034*	0.24
High COV				
Elastic Rod-Impact	049	0.48	0.849	-0.03
Elastic Rod-Testable	0.31	0.42	0.163	0.23
Roses	0.08	0.06	0.742	-0.06

Note. Mean scores, significance levels for each 2-tailed t-test between assessments, and effect size. * Indicates p<0.05 which means is likely not due to chance but instead due to treatment.

At the Low COV skill level, there were not statistically significant improvements for the mean scores for the first two questions (*simple pendulum* p = 0.443 and *freeze milk* p = 0.321) that focused on designing controlled experiments, but the pre-test scores were high with little room for improvement. For the third Low COV question (*fishing* p = 0.000), which asked about determining which variables were testable, students improved significantly with a medium effect size (Effect size = 0.60) (see Fig. 5). The most common alternative response included all three variables as testable, even though two of the three variables could not be tested because the experiments were confounded. Students' pre-test scores were below the level of chance, but they improved significantly after instruction. The difference between these Low COV questions is that the *fishing* question involved a real-world context. Zhou et al. (2016) found that students used different patterns of reasoning when considering real-world contexts. The open-endedness of the *fishing* question may have triggered a variety of real-world knowledge such that students may have considered variables not given in the question (Zhou et al., 2016).

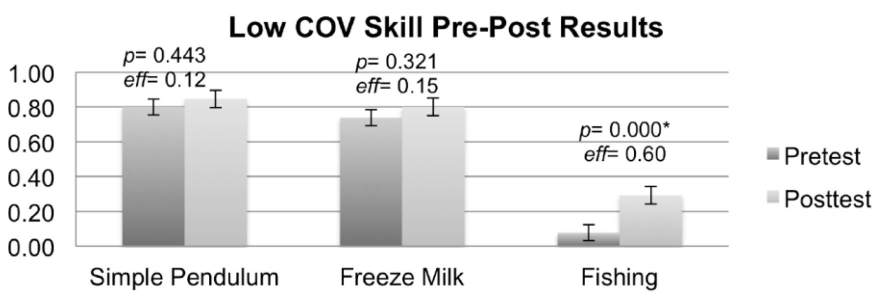


Figure 5. Mean scores on Low COV questions. Error bars represent the standard errors. *Indicates p<0.05 determined with 2-tailed t-test.

At the Intermediate COV skill level, students demonstrated statistically significant increases for all three COV questions (*flies-impact* p = 0.004*, flies-testable* p = 0.028*, pendulum-not testable* p = 0.034). There was a medium effect size for *flies-impact* (Effect size = 0.43) and low effect sizes for *flies-testable* (Effect size = 0.32) and *pendulum-not testable* (Effect size = 0.24) (see Fig. 6). For the *flies-impact* question, the most common alternative response indicated that students confused testable with having

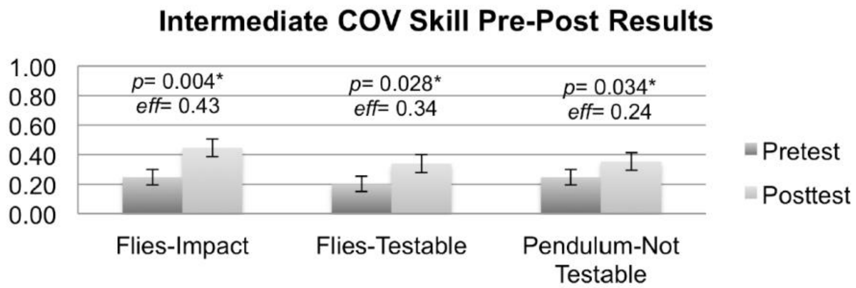


Figure 6. Mean scores on Intermediate COV questions. Error bars represent the standard errors. *Indicates p<0.05 determined with 2-tailed t-test.

impact. For the *flies-testable* question, the most common alternative responses were either using an uncontrolled experiment or changing the wrong variable to determine testability. Zhou et al. (2016) tested questions with and without experimental results and found that students tend to include experimental results in their reasoning and have difficulty distinguishing between testability and impact. For the *pendulum-not testable* question, the highest alternative response was using confounded experiments to determine testability. Being able to determine that an experiment is confounded is more challenging than identifying a controlled experiment (Schwichow et al., 2016).

At the High COV skill level, students exhibited no statistically significant improvement for the three COV questions (*elastic rod-impact* p = 0.849*, elastic rod-testable* p = 0.163*, roses* p = 0.742) (see Fig. 7). For the *elastic rod-impact* and the *roses* question, the post-test scores were lower than the pre-test scores. The overlapping error bars indicate that no difference can be detected due to the variation measured by the standard

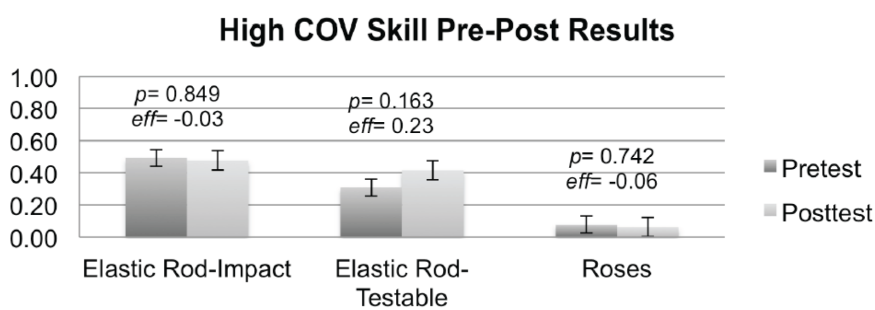


Figure 7. Mean scores on High COV questions. Error bars represent the standard errors. *Indicates p<0.05 determined with 2-tailed t-test.

error of the data. The practical significance of the results for these questions is that the lab curriculum did not effectively develop students' High COV skill levels. For the *elastic rod-impact* question, the most common alternative response was not recognizing that any variable had impact. For the *elastic rod-testable* question, the most common alternative response was to confuse testability with impact. For the *roses* question, the most common alternative response suggested that students assumed causation when a causal factor was undetermined. At the highest COV skill level, which required students to *apply* COV skills to determine if necessary conditions existed in causal reasoning, students had pre- and post-test scores below the level of chance. Future research will investigate the reasoning patterns used by students at this High COV skill level, so that these can be addressed in the lab curriculum.

Conclusion

The purpose of this study was to investigate student development of Low, Intermediate, and High COV skills in a first semester algebra-based introductory physics lab at a two-year college. Students were enrolled in an inquiry-based introductory physics lab that targeted the development of SR skills. Findings indicate that students' overall COV skills improved, but the increases varied according to the COV skill level assessed with the most improvement occurring at the Intermediate COV skill level. This suggests that the lab curriculum impacted student COV skills at the Intermediate COV skill level the most effectively, but was unable to develop student abilities at the higher COV skill levels. These results can be used to revise the lab curriculum to develop exercises and additional scaffolding to push students beyond the Intermediate COV skill level and to develop more complex COV skills assessed with the High COV questions. Note that these results are for a two-year college population and may not be comparable to other populations.

These findings provide a baseline for COV skills at a two-year college for which scientific reasoning is largely unstudied. Future research will explore COV skill development at a four-year institution where a larger sample is available in order to better inform future lab curriculum development. The ultimate goal is to develop a lab curriculum that effectively targets the development of multiple SR skills, with an emphasis on developing all levels of COV skills, which are the foundation for higher levels of scientific reasoning.

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For those who are interested in learning more about the full assessment tool, Inquiry for Scientific Thinking and Reasoning (iSTAR), used to measure gains in scientific reasoning skills or interested in our iSTAR Labs, please contact the first author.

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Personal Biography

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