Conceptual Development of Pre-Service Teachers through Verification versus Guided-Inquiry Physical Science Laboratories

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Abstract

Verification laboratory instruction lacks opportunities for students to pose questions, generate hypotheses, and/or determine experimental procedures. Students in such settings often follow prescribed instructions towards a predetermined outcome. However, the Next Generation Science Standards (NGSS) calls for more inquiry-based approaches through science and engineering practices. This pre/post comparison study investigates the impact of a new guided inquiry-based laboratory curriculum versus an existing verification-based laboratory curriculum on the physical science content knowledge of 98 preservice elementary educators. The results show no differences in disciplinary chemistry/physics items but show a significant difference in integrated items for the guided-inquiry laboratory. Such findings indicate the value of guided versus verification-inquiry for integrated explanations and have important implications for teacher education in light of NGSS.

Objectives

Laboratory activities vary in the level of student input in asking questions, determining data collection methods, and interpreting of results (Blanchard et al., 2010). On one end, laboratories are completely teacher driven (verification) and on the other end, laboratories are completely student driven (open-inquiry) with structured and guided approaches in between (Blanchard et al., 2010; see Table 1). With the implementation of the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), educators need to make a shift in their teaching to accommodate more student-driven inquiry based approaches aligned with science and engineering practices (SEPs).

Table 1: Levels of Inquiry (Blanchard et al., 2010, p. 581)

	Source of the Question	Data Collection Methods	Interpretation of results
Level 0: Verification	Given by teacher	Given by teacher	Given by teacher
Level 1: Structured	Given by teacher	Given by teacher	Open to student
Level 2: Guided	Given by teacher	Open to student	Open to student
Level 3: Open	Open to student	Open to student	Open to student

Due to the dramatic shifts from the previous state standards to NGSS, teacher education programs need to evaluate and make changes to their current programs to meet the changing demands on teachers. Bybee (2014) suggests three ways that these shifts could be made including revising small elements of the program currently being taught over time, replacing/overhauling whole parts of a program, or completely reforming the teacher education program. This project focuses on the second of Bybee's suggestions through a replacement of the existing verification laboratory structure with a guided-inquiry structure. In the new guided-inquiry structure, the topic is provided, but students decide their hypothesis, plan and conduct their investigation, and analyze their results (Blanchard et al., 2010). This study investigates if this guided-inquiry approach has a significant effect on future teachers' physical science content knowledge, both disciplinary and integrated.

The research literature provides several definitions of the term inquiry, but there are common features to inquiry education across studies:

> *"including questioning and generating hypotheses, experimenting, designing, and planning, predicting, modeling/visualizing, observing and data collection, analyzing data, interpreting and explaining, developing/evaluating/arguing, reaching conclusions, and communicating findings"* (Donnelly et al., 2014, p. 2)

To better explain and extend their interpretation of inquiry, the NGSS use the science and engineering practices to outline the ways that students need to engage in and approach science content, i.e., analyzing and interpreting data, asking questions and defining problems, and arguing from evidence (NGSS Lead States, 2013).

Using Blanchard et al. (2010)'s, the new laboratory structure for the redesigned course is a level two, guided-inquiry. This level of inquiry gives students the question while students are responsible for designing the data collection method and interpreting their own results (Blanchard et al., 2010). The questions provided to the students align with anchor phenomenon (Deverel-Rico & Heredia, 2018) questions as well as investigative phenomena questions that elicit both chemistry and physics concepts throughout the semester.

The lecture portion of this course has previously gone through a redesign (Hinde & Donnelly, 2018). It has shifted from a disciplinary approach where chemistry and physics concepts are taught separately, splitting the semester between two lecture instructors from the Chemistry and Physics Departments, to an integrated approach. In the integrated approach, each lecture instructor teaches their own section for the entire semester, both covering all of the physical science content. Thus far, the study has shown no significant difference between the two types of lecture approach. The focus of this study is the redesign of the laboratory structure to support greater student inquiry.

The focus of the paper is to answer the following research questions:

1. Is there a significant difference in student understanding of disciplinary science content knowledge in a guided-inquiry laboratory and a verification laboratory structure?
2. Is there a significant difference in student understanding of integrated science content knowledge in a guided-inquiry laboratory and a verification laboratory structure?

Theoretical Framework

This study uses the knowledge integration framework to design pre/post assessments and rubrics. The knowledge integration framework is based on the constructivist ideas of making science accessible, making thinking visible, helping students learn from others, and promoting autonomy (Linn & Eylon, 2011). Since the pre/post assessment uses open ended, phenomena-based questions, we scored them to demonstrate the range of student ideas from non-normative to partial to total mastery of scientific concepts. Typically, science understanding is measured using multiple choice questions which do not fully elicit student ideas or allow for students to explain their responses (Liu, Lee, Hofstetter, & Linn, 2008). Knowledge integration items "pose a dilemma and require the respondents to generate an argument"(Liu et al., 2008, p. 37). Previous science education research has taken advantage of the knowledge integration framework to allow for more thorough student responses that show even small gains in mastery (Linn, Lee, Tinker, Husic, & Chiu, 2006).

We reviewed each student's responses and scored them from zero to five using rubrics created through the Knowledge Integration framework (Table 2). A score of zero is for a response left blank, and a score of one when students state that they do not know or are off task. An incorrect response receives a two, which is a non-normative idea. A score of three is for partially normative scientific ideas as the answer lacks a link between ideas. A four is for a complete normative scientific idea with one link between ideas. When students are able to apply ideas and make a more complex scientific link between ideas they score a five (Liu et al., 2008). Table 3 provides an example rubric for one of the integrated questions.

Table 2 - KI Rubric for Northern Lights Assessment Question

Score	KI Level	Criteria (Prompt: What causes the northern lights (aurora borealis)?
0	**No Answer**	**No answer**
1	**Off Task**	**I don't know** • Repeats question- Rephrasing question as answer • Irrelevant ideas- Nonscientific about the question • Invented Scenario- Imagined scenario/making up a situation instead of explaining what is given
2	**Non-Normative**	**Scientifically Non-Normative Ideas- A scientific idea that doesn't make sense.**
3	**Partial-Normative Idea**	**Part of a normative idea.** **Can also be part non-normative idea** **Isolated ideas with valid connection** • The sun emits high energy charged particles. • The sun emits solar wind. • The earth has a magnetic field (magnetosphere) • The air in the atmosphere absorbs energy. • The air in the atmosphere gives off energy. • The suns energy goes to the north pole.
4	**Normative Idea**	**Complete normative idea** • The sun emits charged particles that interact with earth. • The charged particles are directed to the poles (north polar region) by the earth's magnetic field. • The charged particles collide with the oxygen and nitrogen in the atmosphere. • Energy is transferred from the charged particles to the oxygen/nitrogen molecules, causing their electrons to be excited (or for the atoms to be in a higher energy state). • When the oxygen/nitrogen molecules lose energy, the energy is emitted in the form of a photon of light.

		• Depending on the height and composition of the atmosphere, as well as how much energy the oxygen and nitrogen molecules absorb, different colors of light are given off.
5	**Disciplinary Link**	**One Scientifically valid link between normative ideas.** • The sun emits charged particles that are directed to the poles by the earth's magnetic field. • Energy from the charged particles from the sun is transferred to the oxygen. Nitrogen molecules in the atmosphere causing them to energy a higher energy state. When the energy is released, visible light is emitted in the form of a photon.

Table 3 - Content Assessment Questions

	Question	**Content Addressed**	**Topic Assessed**
1	If a driver not wearing their seatbelt slams on the brakes of a car, what happens to the driver and to the car? Explain your answer.	Physics	Newton's First Law
2	A pumpkin is dropped vertically from the window of a building and at the same time, a second pumpkin is thrown horizontally from the same window as the first pumpkin is dropped. Assuming no air resistance and the same mass for each pumpkin, do the pumpkins hit the ground at the same or different times? Explain your answer.	Physics	Motion
3	Should only water or should soap and water be used to clean animals after an oil spill? Explain your answer.	Chemistry	Polarity
4	Two liters (0.53 gallon) of a saltwater sample is left outside in an open container for a day. The next day only 1.5 liters (0.40 gallon) of the saltwater sample remains due to evaporation. Has evaporation caused the salt concentration in the sample to increase, decrease, or does it stay the same? Explain your answer.	Chemistry	Concentration
5	The pressure of when you push something you are applying force to an object and either making it move, or react. The pressure of gas is the amount of force within a limited area, or caged within a certain volume.	Integrated	Pressure
6	Why do the northern lights (aurora borealis) occur? Explain your answer.	Integrated	Bohr Model/ Magnetism
7	What is the difference between how hot air balloons function and how helium balloons function? Explain your answer.	Integrated	Density/ Buoyancy

Method

The study uses a quasi-experimental approach involving pre/post measure with a convenience sample. The students chose their lecture instructor, which placed them in one of the laboratory types. The verification group consisted of the students enrolled in the existing laboratory structure. The verification group did twelve laboratory activities, six physics and six chemistry. The guided-inquiry based laboratory structure provided in the redesigned course gives students an anchor phenomenon question and then possible investigative phenomena questions to explore. The activities support students to ask questions, generate hypotheses, and design investigations. The students, provided a list of materials present for the particular laboratory experiment session, designed their experiments before coming to class. They had to write the laboratory themselves including procedures, data tables, and analysis. Students participated in a four-week boot camp, before completing such laboratories, that involved discussions and activities on high-quality experimentation, conducting a sample investigation involving a pendulum, and analyzing, presenting, and discussing data through graphs.

Ninety-eight preservice elementary teachers completed both pre and post-assessments with 63 students in the verification laboratory and 35 in the guided-inquiry laboratory. We gave students the option of providing demographic information. The makeup of the classes was predominantly female with 83% (n=76) of respondents identifying as female and 17% of respondents identifying as male. Six students did not provide a gender. Of the 82 students who provided an answer to the ethnicity question 62% identified as Hispanic (n=51,) 26% identified as Caucasian (n=21), and 12% identified as Asian (n=10). All students signed ethical consent forms before participating.

Data Sources

To address the research questions, students answered seven content-based open-ended pre and post-assessment questions as well as two questions pertaining to science and engineering practices to support a separate research study. The seven content questions included two chemistry, two physics, and three integrated questions as outlined in Table 3. Two raters did separate scoring on all student responses for each question and a comparison of scores was done to determine agreement and address inconsistencies in the rubric. Inter-rater reliability was calculated for each item (Table 4) and found and all were in the near perfect (0.81- 0.99) to perfect agreement range (1.00). Responses with differing scores were then discussed to find agreement.

Participants answered the questions using the WISE online platform for data collection. We gave students 30 minutes in the first laboratory session for the pre-assessment and again in the last laboratory for the post-assessment. We removed any students from the data set who did not have responses for both the pre and post-assessment, along with students who began and did not finish one or both of the assessments. We removed 20 participants from the study for these reasons.

Table 4 – Inter-rater Reliability

Question	Kappa	Percent Agreement
1	.973	99.1
2	.905	93.8
3	.828	91.2
4	.923	95.6

5	.856	90.3
6	.857	92.9
7	.956	97.3

Results

The results for the pre and post-tests are summarized by laboratory section in Table 5 below as well as the results by question type and laboratory type in Table 6. Both laboratory types showed significant gains from pre- to post-test. A one-way within subject repeated measures ANOVA showed no significant difference between the verification and guided-inquiry laboratory sections (F(1, 96)=3.469, p=.066) for the total pre and post-test scores on the conceptual questions.

Table 5 - Descriptive Statistics by Laboratory Type

Lab Type	n	Pre (SD)	Post (SD)	Gain (SD)	p	d
Verification	63	17.13 (2.59)	19.17 (3.09)	2.04 (3.09)	.001	0.74
Guided-inquiry	35	16.06 (2.65)	19.40 (3.57)	3.34 (3.64)	.001	0.28
Total	98	16.74 (2.65)	19.26 (3.25)	2.51 (3.34)	.001	0.85

The questions were broken down into three subsets to analyze further. Questions one and two are physics, three and four are chemistry and five, six and seven are integrated questions. Each question type was analyzed using a one-way within subject repeated measures ANOVA.

The analysis performed was to test whether there was a difference in Physics content knowledge by laboratory type. There is a significant difference in physics pre and post scores for all participants (F(1, 96)=14.196, p<.001). There is not a significant difference based on verification versus guided-inquiry laboratory (F(1, 96)=2.982, p=.087). Participants average a non-normative to partial normative score on the pre-test and a partial normative score on the post-test.

A test for difference in Chemistry content knowledge by laboratory type show a significant difference in chemistry pre and post scores for all participants (F(1, 96)=8.879, p=.004) but there is not a significant difference in chemistry content based on verification versus guided-inquiry laboratory (F(1, 96)=3.273, p=.074). Participants average a non-normative score on the pre-test and a partial normative score on the post-test.

Finally, a test for difference in Integrated content knowledge by laboratory type resulted in a significant difference in integrated pre and post scores for all participants (F(1, 96)=58.194, p<.001) and a significant difference in integrated content based on verification versus guided-inquiry laboratory (F(1, 96)=11.379, p=.001) in favor of the guided inquiry laboratory. This is also evidenced by the high effect size (d=1.32) for the guided-inquiry laboratories though this could be skewed high due to a small sample size (n=35). Participants are averaging a non-normative score on the pre-test for both laboratory structures. Participants are averaging a partial normative score on the post-test for the verification laboratory and a partial-normative to normative score on the post-test for the guided-inquiry laboratory. This result demonstrates the guided-inquiry laboratory having an impact on participant’s ability to integrate the physics and chemistry content.

Table 6 - Descriptive Statistics for Question Type by Laboratory Type

Domain	Lab Type	n	Pre (SD)	Post (SD)	Gain (SD)	P	d
Physics	Verification	63	5.62 (1.07)	6.62 (1.57)	1.00 (1.67)	.001	0.74
	Guided-inquiry	35	5.51 (1.25)	5.89 (1.43)	0.38 (1.83)	.001	0.28
	Total	98	5.58 (1.13)	6.36 (1.55)	.78 (1.74)	.001	0.58
Chemistry	Verification	63	5.49 (1.31)	5.67 (1.30)	0.18 (1.44)	.004	0.14
	Guided-inquiry	35	5.17 (1.32)	5.89 (1.30)	0.72 (1.36)	.004	0.56
	Total	98	5.38 (1.31)	5.74 (1.29)	.37 (1.43)	.001	0.28
Integrated	Verification	63	6.02 (1.41)	6.89 (1.56)	0.87 (1.67)	.001	0.59
	Guided-inquiry	35	5.37 (1.59)	7.63 (1.83)	2.26 (1.37)	.001	1.32
	Total	98	5.79 (1.50)	7.15 (1.69)	1.37 (2.05)	.001	0.85

Scholarly Significance of the Study

The results show the guided-inquiry laboratory structure results in a significant increase in integrated content knowledge with non-significant results for the disciplinary items. Such results are promising given it is only the first semester of the new guided-inquiry laboratory structure.

Overall, this study indicates that even after a semester of the physical science course, students continue to have only partial normative ideas overall. Given that they have limited prior knowledge, movement across all laboratory structures toward more normative ideas is promising.

Lin, Lin, and Tsai (2014)'s comprehensive review of four-science education journals suggest a lack of studies on the conceptual understanding of teachers. The focus of research was far greater in learning context, student conceptual learning and teaching strategies (ibid). This indicates that this study can contribute more to an area that is lacking in the literature. In light of NGSS, this continuing research can give insights as to how inquiry might affect both integrated and disciplinary content knowledge for preservice teachers. Szyjka (2012) found that "a series of recent content analysis studies indicates that there has been a significant shift in paradigms from the quantitative to the qualitative" (p.114). This study uses a quantitative approach instead of qualitative to gain insights into the content areas in which participants are making gains, and how the guided-inquiry laboratory structure contributes to those gains.

This research, along with related research into participant ownership of learning, will help to further the understanding of preservice teacher content knowledge growth through the laboratory setting. There is also continuing research on the impact of integration of physical science content in the lecture sections.

References

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability?: A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education, 94*(4), 577-616. doi:10.1002/sce.20390

Bybee, R. W. (2014). NGSS and the Next Generation of Science Teachers. *Journal of Science Teacher Education, 25*(2), 211-221. doi:10.1007/s10972-014-9381-4

Deverel-Rico, C., & Heredia, S. (2018). THE NGSS-IFICATION OF TOO SLOW TO NOTICE. *Science Scope, 41*(6), 45-54.

Donnelly, D. F., Linn, M. C., & Ludvigsen, S. (2014). Impacts and Characteristics of Computer-Based Science Inquiry Learning Environments for Precollege Students. *Review of Educational Research, 84*(4). http://doi.org/10.3102/0034654314546954

Hinde, A., & Donnelly, D.F. (2018). Impact of disciplinary and integrated approaches in Physical Science lectures for future K-8 teachers. Paper presented at the annual meeting of the American Educational Research Association (AERA), New York City, New York, April 13-17.

Lin, T.-C., Lin, T.-J., & Tsai, C.-C. (2014). Research Trends in Science Education from 2008 to 2012: A systematic content analysis of publications in selected journals. . *International Journal of Science Education, 36*(8), 1346-1372.

Linn, M., & Eylon, B.-S. (2011). Science Learning and Instruction: Taking advantage of technology to promote knowledge integration. In (pp. 102). New York: Routledge.

Linn, M., Lee, H.-S., Tinker, R., Husic, F., & Chiu, J. L. (2006). Teaching and Assessing Knowledge Integration in Science. *Science, 313*(5790), 1049-1050. doi:10.1126/science.1131408

Liu, O. L., Lee, H.-S., Hofstetter, C., & Linn, M. C. (2008). Assessing Knowledge Integration in Science: Construct, Measures, and Evidence. *Educational Assessment, 13*(1), 33-55. doi:10.1080/10627190801968224

States, N. L. (2013). *Next Generation Science Standards: for states, by states*. Washington, D.C.: Washington, D.C. : National Academies Press.

Szyjka, S. (2012). Understanding Research Paradigms: Trends in Science Education Research. *Problems of education in the 21st century, 43*, 110.