JOURNAL OF CHEMICAL EDUCATION

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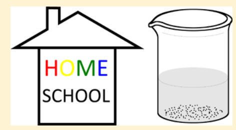
Evaluating a College-Prep Laboratory Exercise for Teenaged Homeschool Students in a University Setting

Daniel A. Hercules,* Cameron A. Parrish, and Daniel C. Whitehead*

Department of Chemistry, Clemson University, Clemson, South Carolina 29634, United States

S *Supporting Information*

ABSTRACT: We devised a half-day laboratory exercise for a group of 10th grade homeschooled students enrolled in an honors-level high school general chemistry course organized by a collective of homeschooling families associated with local Christian churches. Anecdotal evidence suggested that the students met the learning objectives of the exercise. The influence of the exercise on the students' perception of laboratory experimentation was assessed quantitatively by means of a brief pre- and post-encounter Likert-scale survey.



KEYWORDS: *High School/Introductory Chemistry, Laboratory Instruction, Aqueous Solution Chemistry*

■ INTRODUCTION

Over the last three decades, the number of families electing to homeschool their children has increased dramatically. For instance, the number of homeschooled students soared from between 250 000 to 300 000 in 1990 to over 2 million in 2010, representing about 5% of school-age Americans.[1] From 1999 to 2007, the number of homeschooled children nationwide grew by 74%.[2] Factors that motivate parents to pursue homeschooling include the following: a desire to provide religious or moral instruction, peer pressure concerns, worries about drugs and safety in public schools, dissatisfaction with the local availability of quality instruction, a desire for increased family time, financial constraints, travel plans inconsistent with public school schedules, distance to public schools, a desire to provide a nontraditional approach to their child's education, and health-related issues.[3]

Despite the marked increase in the number of homeschooled children in the U.S., the availability of data evaluating the educational outcomes of the endeavor is scarce, likely due to the absence of established mechanisms for reporting such data to state agencies. The *Science and Engineering Indicators: 2010* report published by the NSF decried the lack of any available national data that allows for an analysis of involvement and achievement of homeschoolers in science and mathematics.[4]

One potential limitation of homeschool science education is the relative lack of access to experimental exercises conducted in a laboratory setting.[5−9] Similarly, laboratory exercises that can be feasibly and safely conducted at home are difficult to design and execute, especially for high school science courses.[5] Indeed, parents of the children who participated in the study described herein decried the lack of access to exercises in laboratory facilities similar to large public high schools. In part to address this issue, we established an outreach program, Clemson Chemistry Connection for Homeschoolers (C^3H), geared toward providing access to laboratory exercises in a university setting. Described herein is a brief account of our first pilot endeavor, which was to conduct a half-day laboratory exercise with a group of 10th grade homeschooled students enrolled in an honors-level high school general chemistry course organized by a collective of homeschooling families. Further, we attempted to assess the effects of the exercise on the students' confidence in their lab skills and their perceptions of college-level laboratory coursework.

To the best of our knowledge, no studies concerning the effectiveness of science outreach programs in the context of homeschooled students have appeared. Nevertheless, there are a number of studies that have focused on evaluating the effectiveness of short-term, so-called informal science education opportunities (such as university outreach programs) in the context of public school education. Therefore, we made the assumption that the documented positive educational impacts of such programs in the context of public education might be reasonably expected with homeschool students as well. With respect to public school students, the benefits of university outreach interactions include the improvement of science content knowledge of participating students,[10−16] positive impacts on the students' perception of scientific inquiry,[17,18] and gains in participants' scientific reasoning skills.[19] Also, in some more prolonged encounters, the epistemological beliefs of the students are positively influenced by allowing them to begin to visualize and entertain a career in the sciences.[9,20,21]

Short and long-term follow-up studies evaluating scientific outreach programs demonstrated that student participation in such activities can greatly increase the likelihood that they will study science in college and pursue a career in science thereafter. Immediate benefits include increasing the students' confidence in future laboratory encounters and in future science classes.[9,20−25] Importantly, lasting student learning gains are evident even after a single, short-term (i.e., 3−4 h) laboratory encounter in a university setting.[9,20−25]

Received: September 7, 2015
Revised: February 4, 2016
Published: March 8, 2016

DOI: 10.1021/acs.jchemed.5b00733
J. Chem. Educ. 2016, 93, 870−873

■ PROGRAM OVERVIEW

The participants in the pilot program were six 10th grade homeschool students from the vicinity of Clemson, SC, a small university town (~14 000 permanent residents) located in rural upstate South Carolina, U.S.A. The six students who comprised the cohort for our pilot program were enrolled in a honors-level high school general chemistry course that was organized by a local collective of homeschooling families associated with several Christian churches. Anecdotal evidence suggested that the motivation for homeschooling among the participating families involved several factors including a desire for more flexibility in their daily schedules, more intimate control over the curriculum, and religious motivations. Despite the course organization arising from church message boards, the course was taught from a secular perspective, and no effort was made to incorporate religious doctrine into the course curriculum.

The course was certified as honors-level by meeting curriculum guidelines established by the Foothills Accountability homeschool association in upstate South Carolina. The course itself was not associated with Clemson University in any official capacity, but was taught by one of the coauthors of this manuscript (D.A.H.), who is a fifth year graduate student (Ph.D. candidate) in the CU Chemistry department. D.C.W. is an assistant professor of synthetic organic chemistry at CU and has hosted several elementary and preschool groups for laboratory tours and lab exercises previously.

The present exercise and study arose from a collaborative effort between the coauthors as a means to provide this homeschool cohort with an opportunity to conduct an experiment in a college teaching laboratory setting. The six participants in our pilot program were all taking their first high-school level chemistry course and none of the participants had ever conducted an experiment in a laboratory prior to the encounter described herein. We organized and executed this laboratory exercise toward the end of the course.

The homeschool outreach program included a half-hour lecture period followed by a 2.5-h hands-on experiment in a university teaching laboratory. The lecture and laboratory exercise was designed to allow the students to investigate the solubility properties of common inorganic salts utilizing "unknown" salt samples. The lecture portion of the encounter was spent detailing the basic principles of solubility and the solubility rules of inorganic salts in water. Additionally, the students were given a brief safety lecture that emphasized laboratory best practices, general lab safety, and the requisite personal protective equipment (PPE). The safety presentation was modeled after a similar presentation that is made to incoming college freshmen at the inception of their laboratory course.

The laboratory experiment was similar to that carried out routinely in college freshmen laboratory courses nationwide, including at our home institution (Clemson University). A detailed description of the lab exercise and the lab handout presented to the students is available in the Supporting Information. The students selected an "unknown" inorganic salt and deduce the chemical composition of the sample by means of a series of laboratory experiments that allowed the student to probe the nature of the cation and anion of the salt (see Supporting Information for specific details). The students were then tasked with choosing an experiment or two that would further confirm the identity of their unknown salt sample.

We chose this particular exercise for several reasons. First, from a practical standpoint, the exercise is routinely conducted at Clemson University in the freshman chemistry lab sequence. Thus, we were familiar with the exercise and two of us (D.A.H. and C.A.P.) had conducted the experiments several times with college freshmen. Additionally, the required reagents and supplies were readily available for use in our departmental teaching stockroom free of charge. Further, this type of experiment is routinely conducted in most freshman lab courses across the country. These operational benefits allowed us to plan, organize, and execute the exercise with the homeschoolers on a fairly rapid time frame (i.e., less than one month from initial discussions and planning to execution), which was particularly advantageous given the time demands of our other teaching and scholarly activities during the semester.

More importantly, we chose this particular experiment for several pedagogical reasons. First, we wanted to expose the homeschoolers to a series of experiments that could not be conducted feasibly in the home or in a classroom setting. Given that none of the six students within our cohort had worked in a laboratory setting previously, this encounter would likely represent their first exposure to nonhousehold chemicals (i.e., a series of inorganic salts) and strong concentrated acids (e.g., nitric acid, sulfuric acid, and hydrochloric acid). Further, the requisite series of solution-phase reactions that were necessary to determine the identity of the unknown sample would provide an opportunity for the students to practice basic laboratory techniques including making analytical measurments (i.e., balance operation, solution preparation, use of graduated cylinders), pipetting, glassware manipulation, and safe Bunsen burner use. Finally, and perhaps most importantly, the deductive reasoning required to ascertain the identity of the unknown salt sample is a relatively unique exercise for freshman chemistry laboratory experiments, and to us hearkens to the hypothesis driven study inherent to academic research. We hoped that this challenge might provide the homeschoolers with a brief snapshot of the allure of inquiry-driven research!

Each student worked independently on the exercise under the supervision of their course instructor (D.A.H.) and another fifth-year graduate student with prior general chemistry laboratory TA experience (C.A.P.). The experiments were conducted by the students with relatively little scaffolding after the brief lecture period. When the students moved from the lecture room to the laboratory, the instructors briefly highlighted the relevant safety features of the laboratory and emphasized some common laboratory etiquette. Next, the students were provided with the laboratory procedure presented on pages S4−S6 in the Supporting Information. Then, the instructor demonstrated a positive outcome for each test reaction (described in detail in the Supporting Information). If the homeschoolers encountered a roadblock during the exercise, the instructors provided some real-time feedback by attempting to lead the student to the proper conclusions or next steps by asking a series of leading questions.

Our learning objectives for the exercise included a desire for the students (1) to execute a series of experiments in a college laboratory setting, (2) to understand inorganic salt solubility rules in aqueous media, (3) to gain basic operational laboratory skills, (4) to apply solubility rules to ascertain the identity of an unknown sample, and (5) to design an experiment to confirm the suspected identity of the unknown sample.

DOI: 10.1021/acs.jchemed.5b00733
J. Chem. Educ. 2016, 93, 870−873

Table 1. Comparisons of Students' Averaged Pre- and Post-Encounter Responses

	Students' Pre-encounter and Postencounter Scores[a] in Response to the Survey Statements													
	Student 1		Student 2		Student 3		Student 4		Student 5		Student 6		Mean (N = 6)	
Survey Statement	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	2	4	3	5	4	4	4	4	4	5	5	5	3.7	4.5
2	2	4	2	5	4	4	4	5	4	5	5	5	3.5	4.7
3	3	3	3	1	1	1	3	1	1	1	1	1	2.0	1.3[b]
4	3	3	3	5	5	5	4	4	5	4	5	5	4.2	4.3
5	3	2	4	1	5	1	3	1	2	1	1	1	3.0	1.0[b]
6	1	1	1	1	1	1	1	1	1	1	1	1	1.0	1.0

[a]Likert-scale scores based on 1 = Strongly Disagree; 2 = Disagree Somewhat; 3 = Neutral; 4 = Agree Somewhat; 5 = Strongly Agree. [b]Increased student efficacy is reflected by a lower score for items 3 and 5.

■ OUTCOME OF THE EXERCISE

On the basis of our anecdotal observation of the students during and after the lab period, they appeared to meet most of the learning objectives. All six students successfully completed all aspects of the exercise including the correct identification of their respective unknown samples. Further, they all successfully designed an experiment to confirm the suspected identity of their unknown sample. On the basis of our observations, the homeschoolers performed relatively similar to Clemson University college freshmen, who navigate essentially the same laboratory exercise. In one or two cases, the homeschool students arguably outperformed the typical college freshman in the exercise based on the apparent ease with which they completed the experiments. Anecdotal feedback from the students after the exercise was uniformly positive. The students commented on their excitement for conducting scientific experiments and for their first opportunity to conduct work in a "real" laboratory. Several students remarked that the exercise was "easier than we expected".

In an effort to assess the effect of the exercise on the students' perception of laboratory exercises, the students were presented with a brief, six-question pre-encounter Likert-scale survey during the lecture period before the laboratory exercise. The same assessment was presented to the students 2 weeks after the laboratory encounter.

1. I have a good idea of what to expect in a college freshman laboratory course.
2. I feel like I have the necessary laboratory skills to succeed in a college freshman laboratory course.
3. I am not comfortable handling laboratory chemicals.
4. I can confidently follow an experimental protocol.
5. I am apprehensive about conducting a chemistry laboratory exercise.
6. Conducting laboratory exercises is not a very important component of learning chemistry.

The survey was designed to assess the student's perception of (1) the importance of laboratory experimentation, and (2) their level of preparedness and self-confidence to successfully navigate a college-level laboratory. Table 1 depicts the individual and averaged responses from the students for each question pre- and post-encounter.

The students unanimously acknowledged the importance of laboratory study as an integral part of learning chemistry (i.e., 100% selection of "Strongly Disagree" for statement 6 before and after the encounter). Nevertheless, despite understanding the importance of the endeavor, the homeschool students were marginally confident in their laboratory skills (average response to statement 2, 3.5 ± 1.2) and noted some apprehension toward conducting chemistry laboratory experiments prior to the laboratory exercise (average response to statement 5, 3.0 ± 1.4). Conversely, the homeschoolers maintained a moderately high level of confidence in their ability to handle laboratory chemicals (i.e., pre-encounter response to statement 3, 2.0 ± 1.0; postencounter response, 1.3 ± 0.8) and to follow an experimental protocol (i.e., pre-encounter response to statement 4, 4.2 ± 1.0; postencounter response, 4.3 ± 0.8) before and after the laboratory encounter. These two results may suggest that this cohort of homeschool students have conducted some science experiments in their previous homeschool curriculum despite never visiting a laboratory. When asked whether they had "a good idea of what to expect from a college freshman laboratory course", the students in general reported high levels of confidence both before and after the encounter (3.7 ± 1.0 prior to the exercise to 4.5 ± 0.5 afterward). The upward trend after the encounter, however, fell outside of statistical significance (P = 0.056). Nonetheless, two individuals (i.e., Students 1 and 2) did report notable changes in their perception of what a college laboratory course would entail after the exercise.

Statistically significant gains in the homeschool students' perception of their laboratory skills were evident in the postencounter responses 2 weeks after the laboratory session. When asked to respond to statement 2: "I feel like I have the necessary laboratory skills to succeed in a college freshman laboratory course", the average postencounter response increased to 4.7 ± 0.5 from the pre-encounter average of 3.5 ± 1.2 at >95% confidence (P = 0.029). Nonetheless, one cannot ignore that several of the students entered the exercise with a high degree of confidence in their laboratory skills. The most striking result from the pre- and postencounter surveys was a highly statistically significant decrease in their level of apprehension toward conducting a laboratory experiment. Specifically, the averaged pre-encounter response to statement 5: "I am apprehensive about conducting a chemistry laboratory exercise" fell from 3.0 ± 1.4 to 1.2 ± 0.4 after the on-campus exercise (P = 0.006). Further, only Student 6 reported no apprehension about conducting a laboratory exercise prior to the encounter, while the remaining five homeschoolers self-reported reduced apprehension toward conducting laboratory experiments.

■ CONCLUSION

A laboratory exercise was conducted with six 10th grade homeschool students enrolled in an honors-level high school general chemistry course organized by a collective of home-schooling families. The coauthors facilitated an outreach

DOI: 10.1021/acs.jchemed.5b00733
J. Chem. Educ. 2016, 93, 870–873

activity that allowed the students to participate in a half-hour lecture followed by a 2.5-h laboratory exercise investigating inorganic salt solubility rules in aqueous media. Anecdotal evidence suggests that the students met most of the learning objectives for the encounter. Additionally, a brief Likert-scale survey was conducted before and after the encounter to assess changes in the students' perceptions of laboratory exercises. The results of this survey suggest that our on-campus laboratory exercise led to positive gains in the homeschool participants' perception of their laboratory skills and reduced their anxiety level about conducting chemistry experiments. Nevertheless, the small sample size of our pilot program certainly necessitates further investigation in future studies with larger cohorts in order to substantiate these trends. Additionally, our subsequent efforts will attempt to obtain a more quantitative assessment of the learning gains of the exercise as opposed to the anecdotal evidence presented in this pilot study. The results of these studies will be reported in due course. Successfully improving the students' self-confidence in their own ability to navigate a college-level laboratory course may be beneficial to high school and perhaps middle school-aged homeschooled students given that they often lack ready access to chemistry experiments that are conducted in a laboratory setting. Subsequent efforts with the C^3H program will focus on facilitating further university laboratory interactions with area homeschooled students and assessing their benefit in terms of both learning gains and changes in the students' perceptions of laboratory exercises.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00733.

Brief description of the laboratory exercise, laboratory protocol, and assessment quiz (PDF, DOCX)

■ AUTHOR INFORMATION

Corresponding Authors

*E-mail: dhercul@clemson.edu.
*E-mail: dwhiteh@clemson.edu.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We wish to thank Ms. Barbara Lewis and Mr. Will Wannamaker and the Clemson University Department of Chemistry for allocating laboratory teaching space and supplies for the outreach program. We also wish to thank Prof. Gautam Bhattacharyya (Missouri State University) for extremely helpful insight and prudent suggestions.

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DOI: 10.1021/acs.jchemed.5b00733
J. Chem. Educ. 2016, 93, 870−873