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of

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DOCTOR OF PHILOSOPHY

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ABSTRACT

UNDERGRADUATE STUDENTS TEACHING CHEMISTRY IN INFORMAL ENVIRONMENTS: INVESTIGATING CHEMISTRY OUTREACH PRACTICES AND CONCEPTUAL UNDERSTANDING

by

Justin M. Pratt

This study was designed to explore the chemistry outreach practices of college students associated with the American Chemical Society (ACS) and Alpha Chi Sigma (ΑΧΣ). Students affiliated with these organizations are heavily involved with the chemistry-specific informal science education practice of chemistry outreach. Despite reporting that they reach almost 1 million people every year through outreach, little is known about their outreach practices. Two investigations were conducted to address the gap in understanding of college students conducting outreach. The first investigation involved an open-ended survey administered nationally to students (N = 206) and their faculty/staff advisors (N = 107) to characterize the outreach practices of these two populations through the lenses of 1) purposes of doing outreach, 2) activities commonly used, and 3) evaluation practices. Results indicated that audience learning is the most frequently discussed purpose of outreach, followed by affective goals (*e.g.,* interest, enjoyment). The most prevalently facilitated activities include the elephant toothpaste reaction and making liquid nitrogen ice cream. Lastly, results showed little evidence to support that students evaluate their outreach practices, and whether or not they are meeting their goals.

Using these results, the second investigation was an in-depth qualitative study (N = 37 students) conducted remotely using multimedia-based software. The goals were to explore college student understandings of the chemistry content underlying elephant toothpaste and liquid nitrogen ice cream, their teaching and learning beliefs that they bring into outreach, and the training experiences students had prior to facilitating events. Multiple theoretical lenses were used to interpret findings, including Meaningful Learning theory, the role of content knowledge in teacher pedagogical content knowledge, the impacts of teacher beliefs on their practices, and Cognitive Apprenticeship Theory. Findings evidence significant misunderstandings of thermodynamics, kinetics, and catalysis, as well as teaching/learning beliefs that are contrary audience learning. Lastly, descriptions of training experiences revealed little chapter advisor involvement, and students informally using modeling and coaching techniques. These findings suggest that targeted outreach practitioner training is needed that focuses on conceptual chemistry understanding, as well as the mechanisms behind how humans naturally learn. These findings also provide evidence to support ACS and ΑΧΣ in making data-driven decisions to improve outreach practices.

UNDERGRADUATE STUDENTS TEACHING CHEMISTRY IN INFORMAL ENVIRONMENTS: INVESTIGATING CHEMISTRY OUTREACH PRACTICES AND CONCEPTUAL UNDERSTANDING

A DISSERTATION

Presented to the Faculty of

Miami University in partial

fulfillment of the requirements

for the degree of

Doctor of Philosophy

Department of Chemistry & Biochemistry

by

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The Graduate School
Miami University
Oxford, Ohio

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Dissertation Director: Dr. Ellen J. Yezierski

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DEDICATION

To my grandfather, Papa Bob. Thank you for always believing in me, and being so excited to tell others that you had a future doctor in the family.

* * *

To my parents. Thank you for supporting me throughout all of my education. Without your tireless support through 20 credit hour semesters, moving, and five years of graduate school, I would not have been able to succeed or accomplish all that I have been able to.

* * *

To my husband, Hunt. We met at the beginning of graduate school, and you saw me through all the highs and the lows. Being there to lend an ear, let me vent, and practice presentations means the world to me.

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CHAPTER 1:
INTRODUCTION

Informal science education takes place in a range of learning environments where over 80% of K-12 science learning occurs; once a student progresses past secondary education, 95-100% of science learning occurs in informal environments (National Research Council, 2009). While formal science learning environments (*e.g.*, classrooms) are typically characterized by cognitive learning outcomes, informal learning environments are much more diverse. Learning goals/strands of learning associated with informal learning environments also include understanding science content, as well as engaging in science practices, sparking interest and excitement, reflecting on science, using the tools and language of science, and even scientific identity formation (National Research Council, 2009, 2010). On top of the variety of learning outcomes, informal learning environments are also varied in terms of location; they include formalized science institutions (such as zoos, aquariums, and museums), interactions with the media (games, television, internet), structured out-of-school programs (clubs, youth programs), and even just everyday experiences (National Research Council, 2009; National Science Teachers Association, 2012).

Chemistry-specific informal science education has been a part of the chemical enterprise since 1989 (and likely earlier) when the first peer-reviewed publication about informal chemistry education was published in the *Journal of Chemical Education*. While this is limited only to publications across the suite of ACS Publications and is United States-centric, it encapsulates the long-standing tradition of teaching chemistry in informal environments. Since then, the number of publications dramatically increases, including a report by the National Academies in 2016 titled, *Effective Chemistry Communication in Informal Environments* (National Academies of Sciences Engineering and Medicine, 2016). This report summarized informal chemistry education practices of chemists and provided a framework for designing effective informal chemistry events. However, this report failed to include the perspectives of college students who conduct a significant amount of informal chemistry education (termed *chemistry outreach*).

College students associated with the professional chemistry societies, American Chemical Society (ACS) and Alpha Chi Sigma (ΑΧΣ), report reaching approximately 1 million people every year through their chemistry outreach (Connelly, 2015; Pratt, 2017). Despite such a wide reach, little investigation of the chemistry outreach practices of students involved with these collegiate organizations has occurred. Additionally, the majority of publications focusing on chemistry outreach describe procedures and models for events, rather than scholarly investigations of the efficacy and impacts of events on facilitators and/or audiences (*e.g.,* Carpenter, Phillips, & Jakubinek, 2010; Flynn, 2005; Houck, Machamer, & Erickson, 2014; Koehler, Park, & Kaplan, 1999; Kuntzleman & Baldwin, 2011; Laursen, Liston, Thiry, & Graf, 2007; Louters & Huisman, 1999; Swim, 1999). With little investigations of chemistry outreach, this study was designed to characterize chemistry outreach practices in order to seed future scholarly investigations of informal chemistry education.

Purpose & Research Questions

With the goal of characterizing chemistry outreach practices, the purpose of this study was two-fold: 1) to provide a cursory overview and characterization of the goals and foci of chemistry outreach conducted by members of ACS and ΑΧΣ collegiate chapters and 2) using data from the initial characterization, to design an in-depth qualitative study to further explore the nuances of college student chemistry outreach practices. With little scholarly research to guide the development of these two investigations, a data-driven approach was used such that an initial, exploratory investigation (Investigation 1) was conducted to provide data to support the decisions and focus of the second investigation (Investigation 2). The data analyses across both investigations can be characterized as descriptive qualitative research and were guided by multiple theoretical frameworks/lenses, including a variety of principles and recommendations for electronic data collection (across education, business, sociology, and health sciences), the role of teacher content knowledge on teaching and pedagogical content knowledge (*e.g.,* Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008; Shulman, 1986, 1987), the impacts of teacher beliefs on instruction and student learning (*e.g.,* Bryan, 2012; Clark & Peterson, 1986), and Cognitive Apprenticeship Theory (*e.g.,* Collins, Brown, & Holum, 1991; Collins, Brown, & Newman, 1989). The research questions which framed and were answered in these investigations were:

<u>Investigation 1:</u>

1. What are collegiate students' and faculty/staff's ideas about the purpose(s) of chemistry outreach?
2. What activities are most commonly practiced in chemistry outreach?

3. What evaluation methods do collegiate chemistry organizations use during outreach?

Investigation 2:

1. How effectively can technological solutions provide access to interview participants across an entire country to diversify samples and improve the transferability of findings?
2. How can in-person interview tasks be adapted to function in an online multimedia platform to elicit rich description commensurate with traditional face-to-face interviews?

3. For college students conducting chemistry outreach, what is the nature and extent of their content knowledge associated with
   a. the elephant toothpaste reaction?
   b. making liquid nitrogen ice cream?
4. What beliefs about teaching and learning were expressed by college student outreach practitioners?
5. How do college students' teaching and learning beliefs about outreach vary (if at all) depending on audience age level?
6. What are the training experiences and perceptions of gaps in training expressed by college student outreach practitioners?
7. What alignment (if any) is there between training experiences expressed by college students and Cognitive Apprenticeship Theory?

To answer these research questions, qualitative research methods were used. For Investigation 1, an electronic, open-ended survey was administered to college students and faculty/staff members associated with ACS and/or AΧΣ student chapters. Findings from this investigation seeded Investigation 2, which involved developing and using a novel qualitative method. This novel method took the form of semi-structured interviews conducted over multimedia-based programs (such as Skype), and combined audio, video, and instant messaging communication with electronic survey software, student drawings/artifacts, and screen capturing techniques. Additionally, a novel elicitation technique was also developed and employed that was comprised of written, partially inaccurate student explanations of common outreach activities. These explanations incorporated ideas discussed during a pilot study as well as published misconceptions.

Boundary Conditions

Informal chemistry education is a very diverse field practiced by many different people. As such, boundary conditions were set to focus and frame this study. This study primarily examined college students associated with ACS and/or ΑΧΣ student chapters who had previous experience conducting chemistry outreach prior to participating in the study. While faculty/staff members and chapter advisors associated with these two organizations were included as part of Investigation 1, Investigation 2 only focused on the college student members of these organizations. Additionally, based on results from Investigation 1, the study was narrowed to only examine student ideas related to the elephant toothpaste reaction, making liquid nitrogen ice cream, and/or making slime. Sampling criteria required students to have had previous experience facilitating at least one of these three activities with children/an audience prior to being interviewed. Due to the exploratory nature of these investigations, questions to students focused entirely on their reflections on what they do during outreach (their stated practices), and the rationales for their decisions. The study did not seek to characterize enacted practices during outreach events, or any impacts of outreach conducted by college students on their audiences.

Organization

The results from these two investigations have been featured in three published papers and two manuscripts, corresponding with the research questions above. Of the manuscripts, one has been revised and resubmitted, and one is in review. These manuscripts are divided among the next three chapters of the dissertation. Chapter 2 features an ACS Editor's Choice publication discussing Investigation 1. Chapter 3 describes the development of the novel qualitative method, and the evaluation of its efficacy, as part of Investigation 2. Chapter 4 is composed of the remaining paper and manuscripts that detail the results of Investigation 2, including student conceptual understanding of chemistry content underlying elephant toothpaste and making liquid nitrogen ice cream, the teaching and learning ideas expressed by college student outreach practitioners, and a characterization of the training experiences these students had to conduct chemistry outreach. For clarity, the structure of the body of the dissertation is summarized in the table below. Since the dissertation is composed of compiled publications and manuscripts, there are no separate chapters focused on reviewing previous literature or describing the research methods; these are distributed across the individual papers/manuscripts. The final chapter, Chapter 5, summarizes and synthesizes the conclusions and implications for both investigations.

Table 1. Structure of the body of the dissertation

Chapter	Research Questions Addressed (RQs)	Title of Publication/Manuscript	Publication Status*
2	Investigation 1: RQs 1-3	Characterizing the landscape: Collegiate organizations' chemistry outreach practices	Published
3	Investigation 2: RQs 1 & 2	A novel qualitative method to improve access, elicitation, and sample diversification for enhanced transferability applied to studying chemistry outreach	Published
4	Investigation 2: RQ 3	College students teaching chemistry through outreach: Conceptual understanding of the elephant toothpaste reaction and making liquid nitrogen ice cream	Published
	Investigation 2: RQ 4 & 5	"You lose some accuracy when you're dumbing it down": Teaching and learning ideas of college students teaching chemistry through outreach	Revised
	Investigation 2: RQ 6 & 7	Goodwill without guidance: College student outreach practitioner training	In review

*At time of submission of the dissertation

CHAPTER 2:

INVESTIGATION 1 – CHARACTERIZING THE LANDSCAPE: COLLEGIATE ORGANIZATIONS' CHEMISTRY OUTREACH PRACTICES

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Characterizing the Landscape: Collegiate Organizations' Chemistry Outreach Practices

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Supporting Information

ABSTRACT: Little scholarly investigation of chemistry outreach carried out by undergraduate students in schools and communities has occurred despite widespread practice and monetary investment by large national and international organizations. This study provides the first investigation of these fairly uncharted waters by characterizing expected outcomes of outreach events, the types of activities and chemistry content widely practiced, and how outreach practitioners evaluate the success of events. Results from an open-ended survey deployed nationally to college students and faculty/staff members involved with collegiate chapters of the American Chemical Society and Alpha Chi Sigma are presented. Students and faculty/staff members reported that the most prevalent purposes of chemistry outreach are learning and having fun as a result of attending events, and that events typically involve demonstrations using liquid nitrogen, making slime, and the elephant toothpaste reaction. Differences between students and faculty/staff members are also presented as well as potential future investigations of chemistry outreach practices, which are needed to fully understand this unique chemistry teaching and learning environment.

KEYWORDS: *Chemical Education Research, Public Understanding/Outreach, General Public*

FEATURE: Chemical Education Research

INTRODUCTION

Informal Science Education

Informal Science Education (ISE) encompasses the learning experiences that occur outside of the formal classroom.[1,2] Research on characterizing and improving ISE rests on the idea that only 18.5% of K−12 learning occurs inside the formal classroom with the rest of learning occurring in informal environments. Additionally, the percent of learning occurring in the formal classroom dramatically diminishes once a student is no longer in grades K−12.[2] These informal settings include formalized institutions for learning science (e.g., museums and zoos) as well as everyday experiences and interactions with the media (see Figure 1).[1,2]

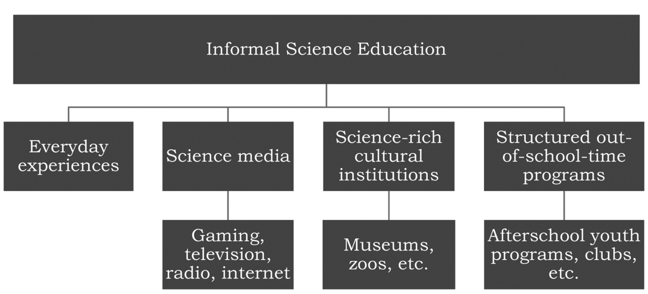

Figure 1. Overview of the main areas of informal science education.

Interest in researching ISE has grown over the past decade embodied by the National Science Foundation's Advancing Informal STEM Learning (AISL) program[3] and multiple National Academies of Sciences, Engineering, and Medicine reports.[2,4,5] The Center for Advancement of Informal Science Education (CAISE) was also established to support the informal science community and create an online space to network and share resources.[6]

Chemistry-Specific Informal Education

Chemistry-specific informal science education has become a recent focus via a report by the National Academies in 2016 titled *Effective Chemistry Communication in Informal Environments* which summarizes current practices for communicating chemistry to the public (i.e., demonstration shows, science cafés, public lectures) as well as proposes a framework for designing effective informal chemistry education events.[5] As noted in the report, it was written to "enhance the effectiveness of public communication by chemists at activities that foster engagement and learning outside the classroom setting" (page ix) and therefore grouped all types of informal chemistry education events under a single umbrella: communication events.[5] Two important sets of findings are presented in the

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report related to *chemists* who conduct these events. One set of findings describes the goals chemists have for events:

1. Increasing public appreciation of and excitement for chemistry
2. Developing scientifically informed consumers
3. Empowering informed participation in democratic processes
4. Encouraging workforce development in the chemical sciences

Another finding describes the chemistry content chemists focus on during these communication events. While the report admits that the list is not exhaustive, it presents four categories of content:

1. Core principles and applications of chemistry (primarily biochemistry and materials chemistry)
2. The role of chemistry in the everyday (including food and cooking, health/medicine)
3. Environmental science (such as climate change and global warming, natural resources)
4. Interdisciplinary connections between chemistry and other disciplines (such as biotechnology, forensic science)

The report also presents a framework for communication events that is composed of five elements/steps to make an effective event; of note is the emphasis placed on setting goals/purposes for the event and evaluating the attainment of those goals.

While these findings are crucial to seeding future research in informal chemistry education, they only reflect the viewpoints of practicing chemists. Additionally, these findings (and framework) are generalized to apply to all types of chemistry communication events. Little details are provided about the differences among event types (e.g., demonstration shows, science cafés, museums) or the perspectives of chemists-in-training (i.e., college students). These limitations are important when we consider that a significant amount of chemistry communication to the public occurs by college students carrying out specialized events through national and international chemistry organizations.

American Chemical Society and Alpha Chi Sigma

The American Chemical Society (ACS) and Alpha Chi Sigma (AΧΣ) are two large organizations which are heavily involved with one type of chemistry communication: chemistry outreach. Chemistry outreach typically includes demonstration shows and hands-on activities performed by chemists and/or chemistry students for varying audiences (e.g., elementary, middle, and high school students, the general public) in out-of-school-time programs. The ACS organizes two large outreach events each year in which members participate, National Chemistry Week and Chemists Celebrate Earth Day, with the goal of promoting chemistry and communicating what chemists do to the public.[7] Additionally, outreach events have been held at ACS National Meetings as part of Presidential Symposia and Events.[8] Similarly, AΧΣ encourages outreach participation as it is included in one of three objects or purposes of the organization and its members.[9] Both organizations also include outreach event ideas and resources on their Web sites.[7,10]

When considering the chemists-in-training, the student/collegiate chapters of these two organizations reach almost 1 million event attendees each year through their outreach events.[11,12] With such a large reach, an investigation of this collegiate population is necessary to better understand chemistry outreach practices. Additionally, both national organizations emphasize and support these chapters in participating in chemistry outreach. The ACS Office of Undergraduate Programs offers ACS Student Chapters funding opportunities to support outreach endeavors[13] and includes outreach events as a criterion in awarding annual student chapter awards.[14] They also facilitate the sharing of outreach activity ideas and procedures for demonstrations among student chapters and host outreach-focused workshops at National Meetings.[15] Similar programs exist for AΧΣ chapters/colonies/groups where individual members can apply for multiple awards for their outreach participation and chapter-organized outreach events are considered in determining annual chapter awards.[10] AΧΣ National Meetings also include discussions about outreach practices.[16] The large number of programs and resources dedicated to chemistry outreach demonstrates that chemistry outreach is very important to these two organizations, and is emphasized as a valuable part of the college student experience.

Chemistry Outreach

Research investigating specific chemistry outreach practices is lacking (e.g., what are the goals of outreach events, what activities are conducted at events). Most publications in this area seek to share ideas/procedures for demonstrations or models for programs rather than investigations of goals or measurements of efficacy.[17−24] Fusion Science Theater (FST) is one exception that has shown that conceptual learning can occur during a demonstration show via their specific model, and measurement of conceptual learning can be successfully conducted via pre-/post-tests as well as short interviews.[25−27] While more recent publications have evaluated event attendees' perceptions of the facilitator's practices, the overall event implementation, and their perceived gains,[28,29] no research has investigated *why* chemistry outreach is conducted (and promoted) nor what practices look like for the college students involved with outreach.

■ RESEARCH QUESTIONS

Despite the findings from the National Academies' report, there clearly is a gap in the literature regarding the nuances of chemistry outreach; of particular interest is the focus on publishing activities without measurements of efficacy, and the time and resources committed by national organizations in conducting these events without any investigation of outcomes. The viewpoints of college students are also of interest, considering the large number of people they reach each year and the monetary support and rewards provided to them by these national organizations. Therefore, the goal of this study is to characterize the chemistry outreach practices of these collegiate organizations by addressing the following research questions (RQs):

1. What are collegiate students' and faculty/staff's ideas about the purpose(s) of chemistry outreach?
2. What activities are most commonly practiced in chemistry outreach?
3. What evaluation methods do collegiate chemistry organizations use during outreach?

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METHODS

The study was conducted during the spring semester of 2015 when almost 1,100 chapters of these two organizations were actively hosting events.[30,31]

Data Collection and Recruitment of Participants

To address the above research questions, an anonymous, open-ended survey was developed and approved by the Institutional Review Board (IRB). The survey included 27 questions (two multiple-choice and 25 free response). Sample questions from this survey are shown in Figure 2, and the full survey is available in the Supporting Information. The survey items were input into Qualtrics[32] and administered electronically.

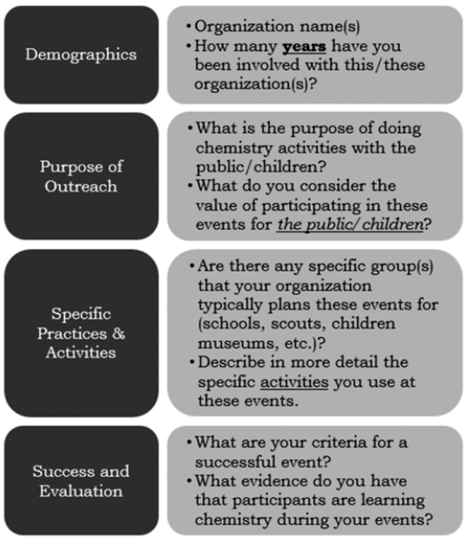

Figure 2. Phases of survey and example survey items.

With the goal of understanding the facilitators of teaching and learning within chemistry outreach, both students and faculty/staff members involved with these organizations were targeted. With aid from the ACS Office of Undergraduate Programs and the Supreme Council of AXΣ, participants were recruited via e-mail sent directly from the national organizations to registered chapter advisors and by social media posts. Chapter advisors acted as gatekeepers[33,34] and were requested to forward the e-mail on to the students (and other faculty/staff members) of their individual chapters. To increase participation in this voluntary survey, an incentive was offered; participants who completed the survey voluntarily could provide contact information to be included in a drawing for one $50 Amazon gift awarded for every 50 survey responses received.

Data Cleaning and Analyses

Preliminary analyses of surveys showed that some participants seemed only interested in the gift card drawing and did not answer the survey questions; these participants were able to use spaces, periods, and/or random words to "trick" the survey validation criteria requiring responses to questions. Additionally, some respondents did not finish the entire survey. As such, those who did not answer the questions were excluded; only responses from completed surveys were included in the analysis.

Content analysis was performed on the data in order to address the research questions.[35,36] To address RQ 1, word clouds were initially used to explore the data, as is common in qualitative studies.[37,38] To construct the word clouds, the responses were first spell-checked before using R (a language and environment for statistical computing)[39] to remove punctuation, numbers, and common words (e.g., is, the). Words were then merged together on the basis of similarity and meaning (e.g., "student" merged with "students", "children" merged with "kids", "liquid" and "nitrogen" merged to "liquid nitrogen"). A frequency table was then constructed of the words and visualized into a word cloud using Wordle.net.[40] Multiple iterations of the word clouds were constructed in order to elucidate meaningful findings by iteratively removing words which skewed the word clouds and hindered interpretation. The skewing words removed included words that were part of the question prompt and those discussed so prevalently that the word clouds became uninterpretable (e.g., chemistry, science, demonstration).

To interpret the meaning of the word clouds related to the purpose of outreach, context was necessary and warranted a more rigorous analysis. As the population differed from those studied in the National Academies' report and no previous studies existed to provide context, inductive coding was performed where codes emerged from the data itself.[36,41] To ensure trustworthiness of the codes,[36,42] the first author independently developed the initial codebook based on 50% of the student data, and the second author independently applied the initial codebook on a random sample composed of 10% of the coded student responses. The two authors negotiated any disagreements and collaboratively revised the codebook. The revised codebook was then used to code the entire student data corpus by the first author, and any unique cases were discussed and agreed upon by both authors. The faculty/staff data were analyzed after the student data. While the majority of the codes generated during the analysis of the student data still applied to the nonstudent responses, the faculty/staff brought new perspectives. Additional codes were generated to capture the unique perspectives of the faculty/staff. Establishing trustworthiness for the codebook for the faculty/staff data followed the same procedure as with the student data including independent development of codes by the first author, independent application of the codes by the second author, and negations/revisions to the codebook until 100% agreement was obtained. Patterns in code application were investigated by visualizing co-occurrence of codes as well as groups of responses using Dedoose, a qualitative data analysis software.[43]

To address RQ 2, word clouds were constructed following the same procedure described above. However, the results were conclusive and did not warrant further analysis, as the responses were typically lists and context was not necessary. Data pertaining to answering RQ 3 were shallow (short and lacked description about criteria, tools, and mechanisms for evaluation). As a result, only meaningful quotes are presented.

RESULTS AND DISCUSSION

Student Sample

After data cleaning, student responses ($N = 206$) were obtained and analyzed. Of the sample, 61.7% identified themselves as part of an ACS chapter (127 students), 31.6% as part of an AXΣ chapter (65 students), and 6.8% identified belonging to both organizations (14 students). The majority of the students also provided their university/school ($n = 200$, 97%). In Figure 3, the locations of each institution provided are plotted and

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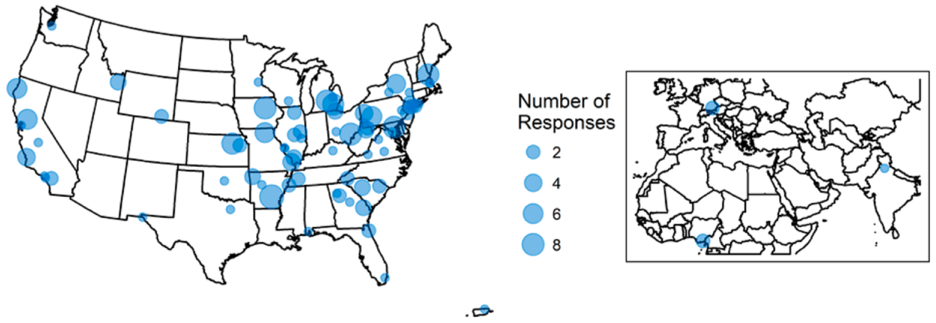

Figure 3. Maps showing locations and responses of students (n = 200 of 206 represented on maps).

scaled by the number of responses received from each location. As ACS is an international organization, five students from three locations outside of the United States are included.

The range of experience reported by the students is from 1 to 12 years in the organization with the median number of years being 2. In addition, 55% of the students were in some sort of leadership position in their chapter (e.g., president, vice-president, outreach coordinator), while 45% were general members.

Faculty/Staff Sample

After data cleaning, faculty/staff responses (N = 108) were obtained and analyzed. Of the sample, 89.8% identified themselves as part of an ACS chapter (n = 97), 7.4% as part of an AXΣ chapter (n = 8), and 2.8% identified belonging to both organizations (n = 3). The majority of the faculty/staff participants provided their university/school (n = 106, 99%). The locations of the faculty/staff are shown in Figure 4; no faculty/staff responses were received from outside of the United States.

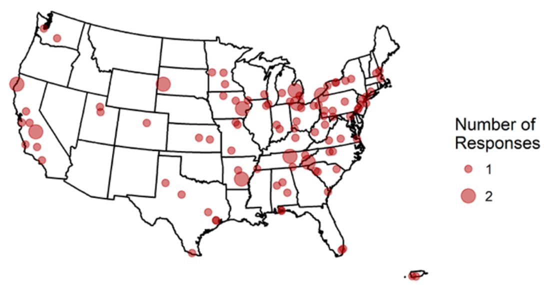

Figure 4. Map showing locations and responses of faculty/staff (n = 106 of 107 represented on map).

The range of experience reported by the faculty/staff members is from brand new to the organization (zero years) to 53 years in the organization with the median number of years being 7.5. Not surprisingly, the faculty/staff members report being involved with their organization (and outreach) longer than the students. In addition, 89% of the faculty/staff members were in the role of advisor to the student organization while 11% were general faculty/staff members involved with the student organization.

Research Question 1: Purpose of Chemistry Outreach

Initial word clouds of student responses related to the purpose of outreach are shown in Figure 5.

The responses from the students showed a focus on *fun*, *interest*, and *education* in relation to children/the public attending their events. Similar responses came from the

A B

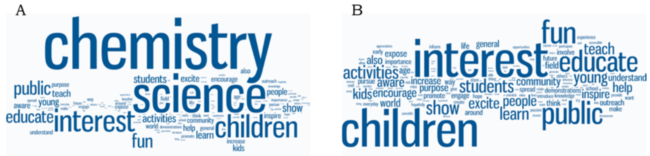

Figure 5. Word clouds representing student responses about the purpose of chemistry outreach; the size of the word corresponds to the number of instances it appeared in the data. Part A shows the raw responses while part B has skewing words "chemistry" and "science" removed.

faculty/staff members as shown in Figure 6. However, faculty/staff also placed an emphasis on the *students* running the events.

While some inferences can be made from these word clouds, such as students only talk about purposes related to children while faculty/staff also include college students in their purposes, context was necessary to effectively interpret what these two groups communicated as the purpose of chemistry outreach.

A B

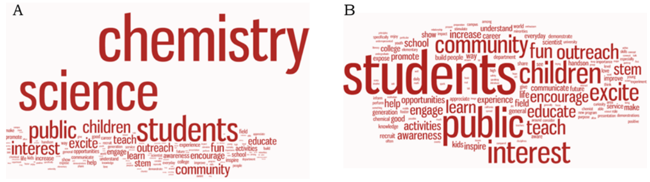

Figure 6. Word clouds representing faculty/staff responses about the purpose of chemistry outreach; the size of the word corresponds to the number of instances it appeared in the data. Part A shows the raw responses while part B has skewing words "chemistry" and "science" removed.

The results from inductive coding of student responses are shown in Table 1. Since no differences between students involved with ACS versus AXΣ were apparent, results are presented in aggregation. For students, eight broad purposes emerged from the data with the median number of purposes discussed by each participant being three. The most commonly mentioned purpose was "audience learning" as the result of the outreach events (which matches the education focus found in the word cloud analysis). Other cognitive learning-oriented purposes included making the audience *aware that science is a fun discipline* (#2), what the *field of science* actually entails (#5), *who scientists actually are* (#8), and just general *awareness of science* (#7).

Purposes more aligned with the affective domain of learning, which are similar to the results from the world clouds ("fun"

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Table 1. Comparative Student Responses on the Purposes of Outreach

	Purpose of Outreach	Representative Quote(s) from Students	Students, *N*	Percentage of Sample
1	Audience learning	"To educate children"	123	60
		"They learn"		
2	Awareness that science is fun	"See the fun of chemistry"	82	40
		"Get excited about chemistry"		
3	Generating interest/curiosity in audience	"Get them more interested in science"	81	39
		"To inspire a curiosity of science"		
4	Audience enjoyment	"Having fun"	78	38
		"They enjoy it!"		
5	Awareness of what science is and its place in the world	"They see that chemistry is more than words on a textbook and has a diverse number of practical applications even in their daily lives."	69	33
6	Motivating for future study	"Inspire younger students to pursue the science field"	68	33
		"To inspire future chemists"		
7	Awareness of and exposure to science	"Expose them to science!"	46	22
		"Awareness of chemistry"		
8	Accessibility to science and who scientists are	"They learn that science is accessible and it's also showing children that they can also do science."	32	16
		"Awareness of what a chemist does"		

Table 2. Comparative Faculty/Staff Members' Responses on the Purposes of Outreach

	Purpose of Outreach	Representative Quote(s) from Faculty/Staff Members	Faculty/Staff Members, *N*	Percentage of Sample
1	Audience learning	"Education"	50	46
		"They learn things"		
2	Awareness that science is fun	"To show them that chemistry is fun"	43	40
3	Generating interest/curiosity in audience	"It gets them interested in the basic science"	28	26
		"To activate their curiosity"		
4	Audience enjoyment	"It is fun! The kids really enjoy these activities."	27	25
		"We also make things fun"		
5	Awareness of what science is and its place in the world	"To allow them to appreciate the chemistry all around them!"	50	46
		"Get them to understand the importance of chemistry"		
6	Motivating for future study	"Want to encourage more of them to go into science"	41	38
		"To inspire the next generation of scientists"		
7	Awareness of and exposure to science	"They are introduced to science."	26	24
		"It exposes the public to chemistry"		
8	Accessibility to science and who scientists are	"Science is more than... people making drugs or mad scientists."	21	19%
		"Science is doable by everyone"		
9	College students developing into scientists	"They learn how to communicate with the public and describe science to the lay person."	77	71
		"Beginning to understand their role in society as a science professional"		
10	College students learning	"The students... get a better understanding of chemistry"	28	26
		"They learn the chemistry... they don't just memorize it for a test and forget it."		
11	College student enjoyment	"Rekindles their excitement for chemistry"	21	19
		"They have fun"		
12	Developing relationships within the organization	"Meet and make friends"	16	15
		"Builds community"		
		"They build a network"		
13	Institutional promotion and service	"Connect the community with the university."	14	13
		"Promote the institution and the department"		
14	Supplementing formal education of audience	"Experience something that they wouldn't have known"	11	10
		"They don't have any access to equipment or chemicals that would allow them to do even simple science"		

and "interest"), were also uncovered. Purpose 3 emphasized the audience becoming *interested in* and *curious about science* while purpose 4 specifically focused on the audience *having fun during an outreach event*. Interestingly, one purpose that was

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Figure 7. Word clouds representing student responses about the activities used in outreach events and their practices; the size of the word corresponds to the number of instances it appeared in the data. Part A shows the raw responses while part B has skewing words "chemistry," "science," "experiment," and "demonstrations" removed.

completely undiscoverable through the word cloud analysis was the desire to *motivate the audience to study science in the future* (#6). While the word clouds were useful, the results from the inductive coding better revealed the ideas the students have and why they conduct outreach. In general, these purposes showed a clear emphasis on educating their audiences, while considering both the cognitive and affective domains of learning, and recruiting them into the sciences.

As many students discussed multiple purposes in their responses, an analysis of co-occurrence (responses including multiple purposes) was warranted; the most common co-occurrence was between the *audience learning* and the *audience enjoying themselves* (purposes #1 and #4). There were 58 cases of this co-occurrence (28%) in the sample. This suggests that not only is learning a goal for these events, but also learning combined with enjoyment is very important. Quotes which exemplify this relationship include when a student said the events "should be both entertaining and educational" and a student who said "It helps local students learn, and more importantly, enjoy learning something new." No other patterns were found in the data based on purposes mentioned nor were any patterns apparent relating years of experience to the number or types of purposes discussed by participants.

When the student purposes were compared to those of practicing chemists reported by the National Academies,[5] some overlap existed. Purposes 2, 5, and 7 discuss ideas related to "increasing public appreciation of science" (chemist's goal #1). Additionally, purpose 1 reflects an ideal for "scientifically informed consumers" (chemist's goal #2), while purposes 6 and 8 both relate to "encouraging workforce in the chemical sciences" (chemist's goal #4). Interestingly, what separates the students from the practicing chemists are the affective goals of *audience enjoyment* and *interest* (purposes 3 and 4); these ideas were not discussed by the chemists in the report, yet students discuss these more prevalently than the purposes that do agree with the report's findings.

When examining responses from faculty/staff members, no differences were found on the basis of organization membership (ACS versus AΧΣ). The eight purposes uncovered from the analysis of the student responses were also in those of the faculty/staff (Table 2). These similar ideas expressed by the faculty/staff members, particularly those regarding the affective domain, further illustrate the differences between the population of chemists involved with collegiate organizations and those included in the National Academies' report.[5] However, additional purposes emerged that explain the finding from the analysis of the word clouds where faculty/staff members discussed purposes related to the college students (purposes #9–14). Like the students, the faculty/staff members also discussed multiple purposes of outreach in their responses; the median number of purposes discussed by faculty/staff members is four. This higher median value for the faculty/staff members is likely due to their focus on both the outreach audience and the college students in their responses.

As shown in Table 2, the most common purpose of the faculty/staff members was *college students developing into scientists* (including learning communication and leadership skills). Similar to the students, almost half of the faculty/staff members also stated that the *audience should be learning* as part of the events (#1). While the additional purposes explain why students were the focus of the faculty/staff members' responses, the applicability of the purposes derived from the student data (#1–8) shows that students and faculty/staff members have similar ideas regarding what the *audience* is supposed to gain from outreach events. The prevalent purposes of outreach uncovered by the survey only partially align with those in the National Academies' report (i.e., increasing public appreciation of science, creating scientifically informed consumers, and encouraging workforce in the chemical sciences);[5] the new ideas uncovered illustrate a gap in the National Academies' findings (i.e., affective goals and goals specific to college students).

Results of an analysis of co-occurrence for faculty/staff members' purposes showed the same result as those of the students: *the audience learning* and *the audience enjoying themselves* are most commonly discussed together. While the percentage of faculty/staff members with this co-occurrence was low (14%), it is still a meaningful similarity between students and faculty/staff members. More purposes were also discussed by faculty/staff members, which would mean a lower probability of co-occurrence. Across both demographic groups, no other patterns were detected in the responses when profiles of responses were investigated. Similarly, no relationships between years of experience and total number of purposes were apparent in the responses. This lack of patterns suggests that purposes of outreach are highly varied across individuals.

Overall, some differences exist between how students and faculty/staff members of these collegiate organizations describe the purpose of chemistry outreach. While both groups agree that the audience should be learning both cognitively and affectively, the faculty/staff members also emphasize college students developing in some way as a result of facilitating outreach events. Of interest are the ideas that faculty revealed that college students should develop professionally as scientists (#9) as well as cognitively (#10) during these events. The differences between students and faculty/staff, as well as the differences between the findings from this study and those from the National Academies' report,[5] suggest that each type of chemistry communication event may have different purpose(s). Additionally, each individual conducting the events, depending

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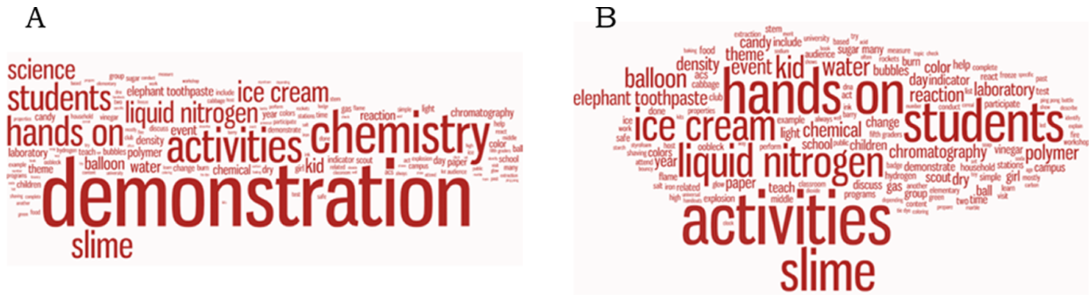

Figure 8. Word clouds representing faculty/staff responses about the activities used in outreach events and their practices; the size of the word corresponds to the number of instances it appeared in the data. Part A shows the raw responses while part B has skewing words "chemistry," "science," "experiment," and "demonstration" removed.

on their role in the field, may also have different goals, and generalized purposes for all types communication events fail to capture the nuanced differences among environments, audiences, and communication modalities.

Research Question 2: Activities at Events

Word clouds were also used to analyze responses related to the types of activities that occur at these outreach events, as most responses were written as lists of activities. Figure 7 shows the responses from students.

Clearly, a wide variety of activities and chemistry concepts are addressed during outreach events. Strikingly, demonstrations (in which the audience watches the activity) seem to be prevalent according to the student perspective. The top three most frequently mentioned activities included those using liquid nitrogen (including making ice cream),[44,45] the elephant toothpaste reaction (catalyzed decomposition of hydrogen peroxide),[46−48] and the creation of slime (gelation of polyvinyl alcohol with borax).[49,50]

Responses from the faculty/staff are shown in Figure 8. Similar to the responses from the students, demonstrations seem to be prevalent along with activities using liquid nitrogen (including making ice cream) and making slime.

However, the elephant toothpaste reaction was discussed less often. Additionally, the faculty/staff members discuss hands-on activities (where the audience actively participates in the activity) much more often than the students.

These responses show that outreach activities and practices for collegiate organizations vary greatly. Both the student and the faculty/staff responses agree that demonstration shows are very common for chemistry outreach events as well as using liquid nitrogen and making slime. When compared to the National Academies' report,[5] it seems that both students and faculty/staff discuss activities that may be categorized as "core principles and applications of chemistry" (chemist's content #1). However, no evidence was found to suggest a focus on biochemistry or materials science. This further distinguishes the population included in the National Academies' report[5] and those involved with collegiate organizations. Results also suggest that differences between outreach-specific chemistry content (for demonstration shows and hands-on activities) and generalized content goals for all communication events are not the same.

Research Question 3: Evaluating Events

Data related to the evaluation of outreach events were shallower than anticipated by investigators. The reasons for this are unclear and may be due to question wording or that data were collected before the framework suggested in the National Academies' report was published and had time to be adopted by organizations. Since the framework clearly calls for evaluation as a requirement for effective events, it is logical to conclude that respondents may not have thought about evaluating events prior to the publication of the report, as the survey was given prior to such a national focus on outreach. Additionally, while the chemistry-specific National Academies' report[5] calls for evaluation, the broader ISE reports[2,4] discuss the challenges of evaluation. Such challenges include difficulty developing and administering evaluations in informal environments as well as the worry that evaluation will diminish the impact of the event. Despite this, the responses that were meaningful across both students and faculty/staff members were similar: the most common way for evaluating the success of an outreach event was observation of the audience. These observations fall into two large categories: affective and cognitive. Positive affective observations include "I just look to the faces of our guests to see if they are enjoying themselves" and "the smiles on the faces!" Positive cognitive observations include "Did it appear that they learned something" and "We explain[ed] the chemistry." Obviously, the criteria used by these organizations do not explicitly correlate to the purposes they discuss. While there seems to be an attempt to evaluate whether or not the purposes of outreach were fulfilled on the basis of superficial evidence of affective and cognitive gains, details about how both students and faculty/staff collect data and use it to evaluate the efficacy of their events and programming are lacking. Respondents could lack a fluency in discussing the evaluation of their events because evaluation may not be a priority for the organizations as measures for event quality are currently not part of recognitions for outreach programming awarded by the organizations.[10,14] Additionally, the organizations may prescribe to the broader ISE's arguments[2,4] against evaluation rather than the chemistry-specific arguments supporting evaluation.[5]

■ CONCLUSIONS AND IMPLICATIONS

Research Question 1: What are Collegiate Students' and Faculty/Staff's Ideas about the Purpose(s) of Chemistry Outreach?

Both students and faculty/staff members of these collegiate organizations have varied ideas about why outreach is conducted and what the audience (and college students) is supposed to gain as a result of participation. Most commonly, emphasis was placed on the *audience learning*. Interestingly, people in both groups discussed multiple purposes for outreach events indicating that events are not designed to have a single measurable goal. When the goals of those involved with ACS

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and AXΣ are compared to the goals articulated by practicing chemists included in the National Academies' report,[5] few similarities are observed. Differences suggest that the sample under study may be representative of a distinct population of outreach practitioners whose interests are not represented in the National Academies' report.[5]

Results regarding the purpose of outreach have implications for practitioners of chemistry outreach. The variety of purposes suggest that the goals for outreach may not be unified and may not even be a topic for discussion within the organizations. The purposes generated by this study provide a data-derived collection of purposes native to the outreach environment. This compilation can serve organizations in implementing the framework proposed by the National Academies[5] while providing language for them to clearly articulate the purpose(s) for their events and provide more focus to their outreach programming. Not only can a well-articulated set of purposes better guide individual chapters in working toward their goals, but it can also provide an authentic and context- and research-based description of outreach goals to external stakeholders, such as funding agencies and the national organizations which support these chapters. Additionally, these purposes may help faculty in designing learning experiences and outcomes for service learning courses[51] and/or professional service experiences.[52]

For researchers, future investigations focused on *why* these purposes are important and how individual purposes are weighted across various outreach event types and settings are needed. Future studies that examine what prior knowledge and experiences influence students' and faculty/staff members' purpose(s) of outreach would shed light on the nature of outreach event design and implementation.

Research Question 2: What Activities Are Most Commonly Practiced in Chemistry Outreach?

Both students and faculty/staff members discussed specific activities used during outreach events including those using liquid nitrogen, the elephant toothpaste reaction, and the creation of slime. Some differences emerged between how students and faculty/staff members described the implementation/facilitations of these activities; both groups emphasized demonstration shows while faculty/staff members also highlighted hands-on activities. Now that there is a greater understanding of the prevalent activities carried out by the student chapters within these large organizations, ACS and AXΣ can focus outreach improvement efforts on these particular chemistry activities (e.g., curriculum development, facilitator training).

Findings regarding activities have implications for researchers since future investigations are needed to examine in more detail the pedagogical elements of outreach. Of particular research interest is the discrepancy between students' and faculty/staff members' discussion of demonstrations and hands-on activities uncovered in this study. Future studies could investigate the relationships among event goals, facilitation, activity choices, audience type, and event settings, and how these vary among students and faculty/staff members.

While findings regarding prevalent activities provide clear evidence that activities using liquid nitrogen, the creation of slime, and the elephant toothpaste reaction are common, understanding *why* these activities are used during outreach and what the audience is specifically supposed to gain are needed, especially given the heavy emphasis placed on *audience learning* (purpose #1) in this study. Additionally, participants discussed learning about *science's connection to everyday life* (purpose #5), which aligns with the findings from the National Academies' report.[5] However, participants did not suggest alignments between activities and everyday life. Further investigation is needed to understand how learning about science in everyday life connects to activities using liquid nitrogen, the creation of slime, and the elephant toothpaste reaction and the extent to which these connections are made during the facilitation of events. While these activities might align with *audience enjoyment* (purpose #4), it is unclear how they support purposes #1 and #5.

Research Question 3: What Evaluation Methods Do Collegiate Chemistry Organizations Use During Outreach?

Meaningful data about evaluating the success of outreach events were minimal. The shortage of data suggests a lack of specific and measurable criteria as well as a lack of participant fluency in discussing evaluation techniques. Additionally, it suggests that chemistry organizations may subscribe to the broader ISE philosophy that de-emphasizes evaluation[2,4] rather than the chemistry-specific philosophy of promoting it.[5] Data that were meaningful suggested *some* alignment between cognitive and affective purposes for events and evaluation via observations. However, the criteria are subjective (e.g., "Did it appear that they learned something"), and specifics about how these organizations collect and use evaluation data to inform future outreach events are deficient.

These findings have implications for outreach practitioners, as the findings stress the need to align outreach evaluation with the purposes/goals of an event which is called for by the National Academies' report.[5] The findings also suggest to national organizations that evaluation is not a common practice in outreach despite the organizations awarding recognitions for outreach programming. Organizations can promote more and better outreach evaluation by focusing awards criteria on event quality and alignment with the framework proposed by the National Academies,[5] which emphasizes evaluating events.

Implications for research include probing the connections between perceived purposes/goals of outreach events and ways that these organizations evaluate events. Additionally, there is a need to understand how the framework proposed by the National Academies' report[5] is viewed by outreach practitioners in terms of comprehension and utility, as well as to investigate the extent to which, and the ways in which, the framework is put into practice.

Limitations and Future Work

This study provides the first step in characterizing the chemistry outreach practices of organizations that heavily promote and conduct chemistry outreach events each year. Given the growing focus on informal science education, chemistry education researchers can respond by turning their attention to these informal environments, which has been called for before in this *Journal*.[53] Since chemistry outreach, one such informal science learning environment, drastically lacks scholarly investigation, this initial study was limited. The extant literature was lacking and could not provide a basis for developing the survey questions or a lens to analyze the data. The use of survey-only data collection also limited the type of responses obtained and the depth of analysis possible. The extended responses could only be analyzed via content analysis (i.e., *what* was said), since survey results do not provide thick descriptions. The short survey responses tended to lack context

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and supporting details that could aid in interpretation. Even with these limitations, the survey results provide a knowledge base from which researchers can begin to investigate outreach settings, events, facilitators, and participants.

In light of the limitations of this study, fully characterizing and understanding the outreach practices of collegiate chemistry organizations requires an in-depth qualitative study. As illustrated by the findings from this study, particular attention needs to be given to, at a minimum, why the purposes presented in this study are important and how events are designed to address these intended purposes (including the chemistry content included in events). Specifically, the teacher-centered nature of facilitating demonstrations, a prevalent pedagogy in outreach, warrants the investigation of the content knowledge and pedagogical expertise of college students running events. Such a study is underway, and reports on findings are forthcoming.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00627.

Full survey used to collect the data presented and a detailed codebook which provides complete descriptions for each code/purpose of outreach (PDF, DOCX)

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Notes

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Supporting Information

Characterizing the Landscape: Collegiate Organizations' Chemistry Outreach Practices

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1. National Survey Deployed to ACS/AXΣ Chapters

One survey was administered to both students and faculty/staff members. A beginning question separated respondents into two different lines of questioning based on demographic group; below are questions given to each demographic group once they self-identified themselves as students or faculty/staff members. Differences between the two surveys are minimal and focus on demographic questions and specifics related student or faculty/staff roles in the organizations.

Survey Questions for Students

These questions pertain to events planned/led by your group (or at which your group participates) that are aimed at teaching chemistry to the public. These events can be hosted at venues in the community, your own university, or place of business and can be diverse in nature (including demonstration shows at schools, science days at your university, after-school programs, scouting events, etc.). Please consider any and all events/experiences that teach chemistry to the public as you answer these questions.

Directions: Answer all questions as completely as possible. Please note that you will not be able to navigate backwards.

Demographic Questions

Institution Affiliation: ___________________

Organization name(s) (Chemistry Club, ACS Student Chapter, AXΣ, etc.): ____________________

How many **years** have you been involved with this/these organization(s)? __________

Position/Role in your organization:

- President
- Vice President
- Secretary
- Treasurer
- Other executive position (please specify)
- Member/No Leadership Position

How many times **per semester** do *you* attend/participate in these events? ___________

How many times **per semester** does *your group* attend/participate in these events? ____________

Which semester is your organization more active in these events?

- Fall Semester
- Spring Semester
- Equal participation during both semesters

Does your organization participate in these events during the summer? Yes / No
If yes: How many events do you/your organization participate in during the summer? ___________

<u>Main Survey</u>

1. What is the purpose of doing chemistry activities with the public/children?
2. What do you consider the value of participating in these events for *<u>you</u>*?
3. What do you consider the value of participating in these events for *<u>the public/children</u>*?
4. About how many participants attend a typical event? __________
5. Are there any specific group(s) that your organization typically plans these events for (schools, scouts, children museums, etc.)? Yes/No
    a. If yes, please describe these groups.
6. Do you have any role in planning your group's events? (yes or no)
    a. If no, Who is responsible in your group for scheduling/planning these events?
7. Please describe the <u>events</u> where you/your group teaches chemistry to the public.
8. Describe in more detail the specific <u>activities</u> you use at these events.
9. What is the source of your activities/resources used to plan and run these events?
10. Do you practice demonstrations and/or activities before events? (yes or no)
    a. If yes, Please describe how you practice for an event.
11. What are your criteria for a successful event?
12. Please describe how you evaluate the success of an event.
13. What skills or resources would help you improve the quality of your group's events?
14. What evidence do you have that participants are learning chemistry during your events?
15. What is the most challenging aspect of communicating chemistry to the public through these events?
16. How does teaching chemistry to others improve your <u>own</u> knowledge of the subject?
17. What resources would help you more effectively evaluate the success of an event?
18. What role (if any) does the American Chemical Society play in planning/implementing your events?
19. Please tell us anything else you would like us to know about communicating and teaching chemistry to the public (optional):

Survey Questions for Faculty/Staff Members

These questions pertain to events planned/led by your group (or at which your group participates) that are aimed at teaching chemistry to the public. These events can be hosted at venues in the community, your own university, or place of business and can be diverse in nature (including demonstration shows at schools, science days at your university, afterschool programs, scouting events, etc.). Please consider any and all events/experiences that teach chemistry to the public as you answer these questions.

Directions: Answer all questions as completely as possible. Please note that you will not be able to navigate backwards.

Demographic Questions

Institution Affiliation: __________________
Department: ________________
Organization name(s) (Chemistry Club, ACS Student Chapter, AXΣ, etc.). ___________________
How many **years** have you been involved with this/these organization(s)? __________
Position/Role in your organization:

- Faculty Advisor
- Faculty Member / Not Faculty Advisor
- Other (please specify)

How many times **per semester** do *you* attend/participate in these events? ___________
How many times **per semester** does *your group* attend/participate in these events? ____________
Which semester is your organization more active in these events?

- Fall Semester
- Spring Semester
- Equal participation during both semesters

Does your organization participate in these events during the summer? Yes / No
If yes: How many events do you participate in during the summer? ___________ events

Main Survey

20. What is the purpose of doing chemistry activities with the public/children?
21. What do you consider the value of participating in these events for *you*?
22. What do you consider the value of participating in these events for *your students*?
23. What do you consider the value of participating in these events for *the public/children*?
24. About how many participants attend a typical event? __________
25. Are there any specific group(s) that your organization typically plans these events for (schools, scouts, children museums, etc.)? Yes/No
    a. If yes, please describe these groups.
26. Please describe your role in scheduling/planning your group's events.
27. Please describe the events where you/your group teaches chemistry to the public.

28. Describe in more detail the specific activities you use at these events.
29. What is the source of your activities/resources used to plan and run these events?
30. What are your criteria for a successful event?
31. Please describe how you evaluate the success of an event.
32. What skills or resources would help you improve the quality of your group's events?
33. What evidence do you have that participants are learning chemistry during your events?
34. What is the most challenging aspect of communicating chemistry to the public through these events?
35. What resources would help you more effectively evaluate the success of an event?
36. What role (if any) does the American Chemical Society play in planning/implementing your events?
37. Please tell us anything else you would like us to know about communicating and teaching chemistry to the public (optional):

2. Codebook for Inductive Analysis of Purposes of Outreach

Code (Purpose of Outreach)	Description/Criteria
Accessibility to science and who scientists are	The focus is on scientists/chemists (the people who do science); The goal is to combat prejudice/stereotypes about who can be scientists and be role models in science.
Audience enjoyment	Affective goal of the audience having fun, enjoying themselves, being entertained, etc.
Audience learning	Goal of audience learning (including developing scientific literacy skills)
Awareness of and exposure to science	General awareness of (or engagement with) chemistry/science; Introducing audience to science/chemistry in general and/or exposing them to science, chemistry, or hands-on activities. No specifics given and does not discuss teaching/learning.
Awareness of what science is and its place in the world	Awareness of what constitutes the field of science/chemistry and how it applies to everyday life (its benefits to the world); Includes changing attitudes towards the field of science (seeing the good side of chemistry or combating the negative image of science).
Awareness that science is fun	Awareness of the fun/joy of chemistry/science; Goal of getting audience excited about chemistry/science, showing them that the science field is fun/interesting/cool/etc.
Generating interest/curiosity	Goal of getting audience interested in or curious about science
Motivating for future study	Goal of recruitment for future study (going to college, becoming the next generation of scientists, etc.)
College student enjoyment	Affective goal of college students having fun, enjoying themselves, being entertained, etc.
College student learning	Goal of college students learning (including principles they should have already learned in the formal classroom)
College students developing into scientists	College students developing the skills of scientists (talking to non-scientific audiences, appreciating the importance of service and helping the community, developing leadership and communication skills, and developing confidence in themselves).
Developing relationships within the organization	Develop relationships within the chemistry organization (between college students and with faculty/chapter advisor).
Institutional promotion and service	Promotion for and service to the institution; focus is on advertising the school or department/facilities and connecting/engaging the community with the institution.
Supplementing formal education of audience	Goal of supplementing the formal education of the audience by showing/teaching them things they would not normally get to see (due to facilities, cost, etc.)

CHAPTER 3:

INVESTIGATION 2 – A NOVEL QUALITATIVE METHOD TO IMPROVE ACCESS, ELICITATION, AND SAMPLE DIVERSIFICATION FOR ENHANCED TRANSFERABILITY APPLIED TO STUDYING CHEMISTRY OUTREACH

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A novel qualitative method to improve access, elicitation, and sample diversification for enhanced transferability applied to studying chemistry outreach

Justin M. Pratt and Ellen J. Yezierski *

Conducting qualitative research in any discipline warrants two actions: accessing participants and eliciting their ideas. In chemistry education research, survey techniques have been used to increase access to participants and diversify samples. Interview tasks (such as card sorting, using demonstrations, and using simulations) have been used to elicit participant ideas. While surveys can increase participation and remove geographic barriers from studies, they typically lack the ability to obtain detailed, thick description of participant ideas, which are possible from in-person interviews. Minimal research in CER has examined how to harness technology to synthesize traditionally diverse research approaches to advance the field. This paper presents a novel method for interviewing research participants employing freely available technology to investigate student ideas about the purposes of conducting chemistry outreach, how success of an outreach event is evaluated, and student understanding of the chemistry content embedded in activities facilitated at events. As the outreach practitioner population comes from numerous institutions and is therefore geographically diverse, technology is necessary in order to gain access to these students. To elicit their ideas and remove barriers associated with rapport, interview tasks are adapted and implemented electronically. The description of a novel set of methods is coupled with evidence from the interviews to illustrate the trustworthiness of the data obtained and to support the method as a means to improve qualitative data collection in chemistry education research. These methods create a unique data collection environment for off-site investigations and are applicable to all disciplines, as they shed light on how qualitative research in the 21st century can increase the diversity of samples and improve the transferability of findings.

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Background

This study employs novel methods to access and elicit ideas from chemistry outreach practitioners who are geographically diverse. Because the context of this study is outreach, a review of the extant literature on informal science education (ISE) is presented. This is followed by a review of the literature that informs methods in chemistry education research (CER) so the novel features of the methods in this study can be highlighted.

Informal chemistry education

Teaching and learning can be parsed by where it occurs: in formal environments (*i.e.*, schools) and informal environments (*i.e.*, anything outside of a school setting). In science, informal learning environments can include science-specific institutions (such as museums and zoos), science-related media, and structured programs that occur outside of school (National Research Council, 2009; National Science Teachers Association, 2012).

Research on ISE has grown in the past decade across the world including in the United States (U.S.), the United Kingdom (U.K.), and Australia, including government-support projects and funding (National Research Council, 2009, 2010; Parliamentary Office of Science & Technology, 2011; Sewry *et al.*, 2014; National Academies of Sciences Engineering and Medicine, 2016, 2017; National Innovation and Science Agenda, 2017; Australian Government, 2017a; National Science Foundation, n.d.). Such initiatives address growing concerns regarding the public's understanding of science (Funk and Goo, 2015; TNS BMRB and Royal Society of Chemistry, 2015) and the visibility of scientists (Wilsdon and Willis, 2004; Nisbet and Markowitz, 2015; National Academies of Sciences Engineering and Medicine, 2017). In chemistry, ISE is typically termed 'outreach' and involves college students and scientists engaging younger students and/or the public in chemistry activities (*e.g.*, demonstration shows, science cafés, and public lectures)

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(National Academies of Sciences Engineering and Medicine, 2016). Large chemistry organizations support chemists in developing and implementing outreach events: the American Chemical Society (ACS), Alpha Chi Sigma (ΑΧΣ), the Royal Australian Chemical Institute (RACI), and the Royal Society of Chemistry (RSC). All three of these large organizations encourage their members to participate in outreach and provide outreach resources on their websites (Royal Australian Chemical Institute Incorporated, 2017; Royal Society of Chemistry, 2017a; Alpha Chi Sigma, 2017b; American Chemical Society, 2017b). The ACS, Australian Government, and RSC even sponsor large science/chemistry-focused outreach events each year: National Chemistry Week, National Science Week, and Chemistry Week, respectively (American Chemical Society, 2017b; Australian Government, 2017b; Royal Society of Chemistry, 2017b).

Minimal research has investigated chemistry outreach practices (*e.g.*, practitioner goals and experiences, participant learning, long- and short-term impacts of events). While there are numerous publications discussing chemistry outreach, they primarily present ideas for outreach events and procedures for demonstrations (*e.g.*, Koehler *et al.*, 1999; Louters and Huisman, 1999; Swim, 1999; Flynn, 2005; Laursen *et al.*, 2007; Carpenter *et al.*, 2010; Kuntzleman and Baldwin, 2011; Houck *et al.*, 2014). The first scholarly investigation of outreach practices was on the Fusion Science Theater program, which uses a specific demonstration show model coupled with either pre/post-tests or short interviews to collect evidence on conceptual audience learning as a result of attending events (Kerby *et al.*, 2010, 2016; DeKorver *et al.*, 2017). Some recent publications have surveyed event attendees to understand their perceptions of event implementation and perceived cognitive and affective gains from attending the event (Sewry *et al.*, 2014; Ting *et al.*, 2017), but they do not shed light on why chemistry outreach is conducted or what events look like for those not involved with Fusion Science Theater.

In the U.S., the National Academies of Sciences, Engineering, and Medicine studied informal chemistry education practices and published a report in 2016 (National Academies of Sciences Engineering and Medicine, 2016). The scope of the report is broad and describes general ideas for all types of informal chemistry education events (*e.g.*, outreach events, science cafés, and public lectures). The report includes only perspectives of practicing chemists and presents generalized findings related to the goals chemists have for informal chemistry education events and the content areas they typically focus on during events. These goals include increasing the public's appreciation of science and encouraging people to enter the chemical sciences workforce. The goals that chemists in the U.S. have for conducting informal chemistry education align with U.K. outreach goals as evidenced by two ongoing outreach research studies by the RSC designed to understand public attitudes towards chemistry and how outreach can increase university enrollment (Royal Society of Chemistry, 2017c). The RSC even emphasizes its goal for increased university enrollment by stating on its website, *"The world needs more chemical scientists, and chemistry skills can lead our young people into a vast range of fulfilling careers"* (Royal Society of Chemistry, 2017e). This goal clearly aligns with U.S. chemists' goals for increasing the workforce in the chemical sciences. The report by the National Academies in the U.S. also presents a framework to guide planning and implementing informal chemistry events, which emphasizes setting goals and evaluating the success of achieving those goals. This framework is very similar to advice given by the RSC for planning chemistry outreach events, despite it being generalized to all event types, not just chemistry outreach (Royal Society of Chemistry, 2017d). With such an international focus on chemistry outreach, and the call from both chemistry education researchers (Christian and Yezierski, 2012) and the broader discipline-based education research community (National Research Council, 2012), it is timely to examine chemistry outreach practices using quality research approaches.

Methods in chemistry education research (CER)

Just as chemistry teaching/learning can be divided into two foci (formal and informal), so can the methods used in CER. The broadest distinction in methods is between quantitative and qualitative methods. When CER is focused on studying humans, researchers are limited by their ability to *access* research participants and the techniques that *elicit* the desired data from participants. Presented below are descriptions of various methods used in CER and the benefits and limitations associated with them, with respect to accessing participants and eliciting meaningful data.

Surveys. Surveys are one method used in CER that can generate both quantitative and qualitative data. Surveys are commonly used because they allow for quick data collection. Modern methods for survey research include using survey software to administer surveys electronically rather than on paper. This allows researchers to disseminate surveys to a large population at minimal cost, thus increasing sample sizes for studies and the generalizability or transferability of conclusions. For example, Raker and colleagues sent one email and disseminated a survey to over 5000 potential research participants (Raker *et al.*, 2015). Because of the ease of survey deployment *via* email, access to participants is maximized with email lists such as the Chemistry Education Research mailing list (Division of Chemical Education, 2016) and the National Association for Research in Science Teaching listserv (National Association for Research in Science Teaching, 2017). Limitations of survey research typically rest in the elicitation of participants' ideas. While both quantitative and qualitative data can be collected with surveys, there is the concern of whether or not a research participant understands the questions being asked on the survey. While cognitive pretesting/interviews can minimize this concern (Collins, 2003; Gehlbach and Brinkworth, 2011; Dean *et al.*, 2013), researchers are still limited to only analyzing the responses given by the participant when the survey is administered; follow-up questions to clarify the meaning of participant answers to free-response questions cannot be asked, thus limiting the depth of analysis. Additionally, there has been discussion about the validity and reliability of self-report data obtained *via* surveys (Mayer, 1999; Coughlan *et al.*, 2009) and minimizing limitations of self-reports *via* pilot testing survey questions and developing questions based on interviews or the literature (Kelly *et al.*, 2003; Desimone and Carlson le Floch, 2004; Bretz and Linenberger, 2012). No matter how the questions are developed, researchers are still limited in being unable to ask follow-up questions of participants to clarify survey responses without using additional research techniques.

Interviews. In contrast to surveys, interviews are also common in CER; interviews can generate rich, detailed descriptions of a research participant's ideas. Semi-structured interviews are common as they allow for follow-up/probing questions to be asked in an attempt to deepen the researcher's understanding of a participant's ideas (Drever, 1995; Patton, 2002). The issue of elicitation is a concern during interviews, since simply asking a participant to verbalize everything they know about a topic may not lead to rich, meaningful data. This is of particular concern when interviews are cognitive and focus on conceptual chemistry understanding; students often do not know what they do not know (Pazicni and Bauer, 2014). To increase elicitation during interviews, various tasks have been used in CER to obtain rich data necessary to answer research questions. Some common tasks include card sorting (*e.g.*, Krieter *et al.*, 2016), using demonstrations (*e.g.*, Nakhleh, 1994; Brandriet and Bretz, 2014), using multiple representations (*e.g.*, Linenberger and Bretz, 2012b; Kelly *et al.*, 2017), having participants draw (*e.g.*, Linenberger and Bretz, 2012a), and using think-aloud protocols (*e.g.*, Bowen, 1994; Herrington and Daubenmire, 2014). To this end, interviews have become common when research goals align with rich, detailed elicitation. However, the limitation that comes with interviews primarily revolves around access to participants.

The standard for interviews in any discipline is in-person, face-to-face interviews (Patton, 2002; Herrington and Daubenmire, 2014). To accomplish this, researchers must have access to research participants and a space to conduct the interview, and researcher and participant schedules must align. This typically leads to access concerns, since researchers must physically meet participants; this can lead to smaller pools of potential interviewees and smaller sample sizes, thus minimizing the variability in studies and potential transferability of findings (Lincoln and Guba, 1985). To increase participation, gift cards to incentivize participation have become common in CER (*e.g.*, Szteinberg and Weaver, 2013; Bauer, 2014; Anzovino and Bretz, 2016); however, the concerns of minimal variability in the sample are still warranted when studies typically include only participants from one location/region. Therefore, while interviews in CER benefit from rich elicitation, access to participants is a primary concern. Means of increasing access to participants and diversifying samples have started to emerge in CER through the use of multimedia communication programs that facilitate remote interviews, such as Skype. However, CER publications that have discussed using these programs have provided little detail about the implementation of interviews mediated by the internet and how concerns of elicitation are addressed (Herrington and Daubenmire, 2014; Harshman and Yezierski, 2015).

Online interviews. Outside of CER, qualitative researchers have been investigating using online methods to conduct interviews and have argued over the quality of data obtained online *versus* in person. Such online interview methods include asynchronous techniques (non-immediate responses from participants) and synchronous techniques (immediate responses similar to face-to-face interviews) (Mann and Stewart, 2000; Fielding *et al.*, 2017). Various publications have focused on using different platforms to conduct these online interviews including over email (James, 2007), chat rooms (Chou, 2004), internet phone calls (Steeh and Piekarski, 2007), virtual reality systems/worlds (Dean *et al.*, 2013; Girvan and Savage, 2013), and multimedia-based programs such as Skype (Deakin and Wakefield, 2014). All of these method-focused publications have discussed the benefits of these techniques for researchers and participants. The primary benefits include increased access (since researchers and participants no longer need to be in the same location) and decreased costs associated with data collection. Asynchronous techniques also allow participants time to think, reflect, and craft responses, while synchronous techniques mimic in-person interviews allowing for immediate responses from participants and opportunities to ask follow-up questions. However, these various techniques are limited, and the strengths and limitations of both approaches (asynchronous and synchronous) must be weighed in light of research questions. Asynchronous techniques may be more beneficial for investigating sensitive topics (such as depression) since participants can take their time when responding; synchronous techniques may be more beneficial for investigations of a benign nature (such as chemistry conceptual understanding) (Mann and Stewart, 2000; Sullivan, 2012; Iacono *et al.*, 2016; Seitz, 2016; Fielding *et al.*, 2017). Proponents of multimedia-based environments such as Skype point out the added benefit of communicating with gestures and body language that is afforded by simultaneous audio and visual communication (Hanna, 2012; Sullivan, 2012; Hamilton, 2014; Janghorban *et al.*, 2014; Simeonsdotter Svensson *et al.*, 2014; Iacono *et al.*, 2016; Seitz, 2016). Such combined audio and visual communication is most similar to in-person interviews.

Multimedia-based interviews. One of the primary arguments against conducting interviews over multimedia-based programs is that rapport with participants may be hindered (*i.e.*, building trust and making the participant comfortable). Techniques used for in-person interviews are no longer available when the researcher and participant are not in the same location (such as having coffee or tea), and technology concerns (such as dropped calls due to poor internet connection) may also hurt rapport (Simeonsdotter Svensson *et al.*, 2014; Seitz, 2016; Weller, 2017). Multiple studies from a variety of disciplines (*e.g.*, business, child development, nursing and health sciences, psychology, sociology) have addressed these concerns and conclude that programs such as Skype actually can increase rapport because the participant chooses the most convenient location to attend the interview (*e.g.*, at home) (Bertrand and Bourdeau, 2010; Hanna, 2012; Hamilton, 2014; Janghorban *et al.*, 2014;

Simeonsdotter Svensson *et al.*, 2014; Nehls *et al.*, 2015; Iacono *et al.*, 2016; Weller, 2017). Additionally, participants can feel more comfortable when not physically in the presence of the interviewer (Bertrand and Bourdeau, 2010; Hanna, 2012; Weller, 2017), and participants actually see no difference between in-person interviews *versus* those conducted over Skype (Deakin and Wakefield, 2014; Hamilton, 2014; Iacono *et al.*, 2016; Weller, 2017). The ability of Skype to increase rapport has prompted multiple calls for using multimedia-based interview techniques. Such techniques can increase access to participants and add more diversity to samples, despite the technology concerns. Work in fields outside of CER has generated advice for mitigating technology concerns and building rapport prior to conducting the interview, including that steps are taken to ensure that researchers and participants have fluency in the technology, test technology prior to the interview, and have multiple contacts with the interviewee to establish the researcher as a real, trustworthy individual prior to meeting virtually (Bertrand and Bourdeau, 2010; Sullivan, 2012; Deakin and Wakefield, 2014; Nehls *et al.*, 2015; Iacono *et al.*, 2016; Weller, 2017). Additionally, advice on flexibility and participant choice has been discussed; allowing participants the choice of which programs to use may increase participation (Deakin and Wakefield, 2014; Simeonsdotter Svensson *et al.*, 2014; Nehls *et al.*, 2015; Seitz, 2016; Weller, 2017).

To minimize technology concerns, ensuring that both the researcher and participant have strong, reliable broadband internet has been suggested (Hay-Gibson, 2009; Sullivan, 2012; Hamilton, 2014; Janghorban *et al.*, 2014; Nehls *et al.*, 2015; Seitz, 2016), which may be less of a concern for current and future studies considering that 83% of households in Europe and 73% of Americans have a broadband connection (Eurostat, 2017; Pew Research Center, 2017). Additionally, 75% of K-12 students in America are connected to broadband internet (EducationSuperHighway, 2017). Participant fluency in the technology may be of lesser concern since 71% of Europeans and 88% of Americans are using the internet everyday (Eurostat, 2017; Pew Research Center, 2017). Despite the general population being familiar with and regularly using the internet, the population that may be more aligned with using multimedia-based techniques are teenagers and young adults, since 96% of Europeans ages 16–24 and 99% of Americans ages 18–29 use the internet everyday (Eurostat, 2017; Pew Research Center, 2017).

Research context

All of the issues and recommendations for conducting multimedia-based interviews became important considerations for a national chemistry outreach study. ACS and ΑΧΣ, which are primarily based in the U.S., specifically recruit undergraduate student members and support student chapters at individual universities; these student chapters are small, institution-based groups of students affiliated with the national organization that are supported/advised by a faculty or staff member. Every year, these student chapters report reaching almost 1 million members of the public through their outreach events (Connelly, 2015; Pratt, 2017). The ACS and ΑΧΣ national organizations support these student chapters through awards and funding opportunities illustrating the commitment the national organizations have to chemistry outreach, and thus outreach as part of the college student experience (American Chemical Society, 2017a, 2017c; Alpha Chi Sigma, 2017b). The types of outreach events that these student chapters typically engage in involve demonstration shows (where the audience watches the activity) or hands-on activities (where the audience actively participates in the activity) for elementary/primary school students (Connelly, 2015; Pratt, 2017; Pratt and Yezierski, 2018).

While the National Academies' report of U.S. chemists (National Academies of Sciences Engineering and Medicine, 2016) is useful in providing a broad view of informal chemistry education, it lacks the perspectives of these university students who have a large impact through chemistry outreach. Additionally, recent findings have suggested that this population of students involved with student chapters of these organizations are distinctly different from the U.S. chemists included in the National Academies' report, and that generalized goals for all informal chemistry education events do not capture the nuanced differences among various event locations, audiences, and event types (Pratt and Yezierski, 2018). As such, the overarching chemistry outreach study described in this paper stems from the results obtained from a national survey (Pratt and Yezierski, 2018) to understand why university students conduct chemistry outreach, the alignment between event evaluation methods and goals for events, and university students' conceptual understanding of the chemistry content embedded in outreach activities. The population investigated was university students conducting chemistry outreach in conjunction with ACS and/or ΑΧΣ student chapters. Considering that this population consists of regular, everyday internet users, multimedia-based interviews were a logical methodological choice. However, considering the lack of the literature describing using multimedia-based interview in CER, this paper analyzes the efficacy of the methods employed to collect data in this chemistry outreach focused study (see Fig. 1).

Research questions

This paper seeks to describe and demonstrate the efficacy of the novel data collection technique employed in the context of an Institutional Review Board (IRB) approved study about chemistry outreach, which was developed based on literature recommendations and adaptions of in-person interview techniques to the online environment. Given the limitations of survey methods and traditional in-person interviews, this novel method was investigated with the goal of addressing the following research questions:

In a national study of chemistry outreach,

(1) How effectively can technological solutions provide access to interview participants across an entire country to diversify samples and improve the transferability of findings?

(2) How can in-person interview tasks be adapted to function in an online multimedia platform to elicit rich description commensurate with traditional face-to-face interviews?

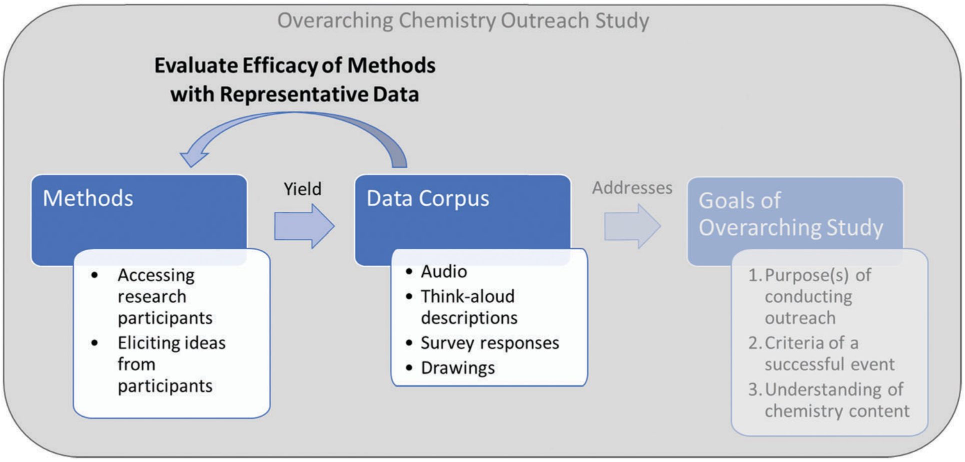

Fig. 1 Summary of the study about chemistry outreach. The focus of this paper is on the methods used to collect data related to the goals of the study.

Methods

Described below are the various methods related to recruiting and gaining access to participants, and eliciting their ideas, during an interview conducted virtually *via* a multimedia communication program (*i.e.*, programs which allow simultaneous audio, video, and instant messaging communication).

Research question 1: recruiting and gaining access to participants

Access to research participants, including geographic locations, time zone differences, and gatekeepers, limits all qualitative studies. For this study, location was not a barrier to accessing research participants as multimedia-based online interviews, *via* programs such as Skype, allowed researchers to sample participants from multiple institutions/student chapters. Therefore, gatekeepers primarily limited access to participants; these gatekeepers were faculty/staff advisors for individual student chapters and/or department chairs (Creswell, 2007; Maxwell, 2013). To reach a sample size leading to data saturation (reoccurring ideas with no new ideas emerging), multiple rounds of recruitment were necessary (Lincoln and Guba, 1985; Patton, 2002). These recruitment efforts included electronic recruitment *via* emails sent directly to gatekeepers, in-person recruitment at a national meeting, and snowball recruitment with previously interviewed participants. Snowball recruitment is when a participant already in the study recruits other participants that they identify as suitable for the study based on their own personal experiences (Patton, 2002). For example, in this study, snowball recruitment was employed by asking previously interviewed participants to recruit other students from their own student chapter to participate in the study. This technique relies on developing a relationship between the interviewer and the interviewee in order to tap into the network of relationships that the interview participant already has. While these recruitment efforts were fruitful in obtaining volunteers, sampling criteria limited the number of volunteers actually interviewed. Sampling criteria for this outreach-focused study included participants having prior experience facilitating at least one outreach event with an audience (rather than experience planning an event), and familiarity with activities involving making liquid nitrogen ice cream, the "elephant toothpaste" reaction, and/or making slime. These criteria were based on results from a previous study (Pratt and Yezierski, 2018) and the need for participants to have prior experience discussing chemistry content with their target audience(s) before being interviewed. Detailed below are the various recruitment efforts for both the pilot study (early spring 2016) and the full study (late spring 2016–spring 2017).

Pilot study. For the pilot study (early spring 2016), researchers targeted universities where members of student chapters had already participated in a national exploratory study, because a similar recruitment strategy was employed and proved successful in accessing this population of college students (Pratt and Yezierski, 2018). From these institutions, researchers randomly sampled 11 of the 74 universities for the pilot study and sent a recruitment email directly to student chapter gatekeepers (faculty/staff advisors of the student chapter and/or department chairs). The recruitment email informed gatekeepers of the goals of the study and requested that they forward a link to an electronic recruitment survey to the students in their chapter. The recruitment survey described the project to students (including details about a $15 Amazon.com gift card as compensation for participating in the interview), obtained informed consent, collected demographic information from the participants, and asked their ideas about the purpose(s) of conducting chemistry outreach.

Full study. For the full study (late spring 2016–spring 2017), a similar recruitment strategy employed during the pilot study was used (*i.e.*, using a recruitment survey emailed to gatekeepers to forward on to potential interview participants). However, multiple additional techniques were employed to access college student outreach practitioners for the full study. The first access technique was targeted, in-person recruitment at the spring 2016 ACS National Meeting. The research team distributed over 250 flyers to individual students involved with student chapters from institutions across the U.S. during a chapter-centric poster session; flyers had a QR code which linked students to the same recruitment survey described above.

In fall 2016, recruitment for the full study continued by directly contacting faculty/staff advisors (gatekeepers) of the student chapters that had participated in the national exploratory survey (Pratt and Yezierski, 2018); researchers contacted the 63 universities *not* recruited during the pilot study in two waves *via* the same procedure as the pilot study (contacting gatekeepers and requesting them to email a recruitment survey link to students). To increase the sample size and ensure variability of the sample, the research team also re-contacted the gatekeepers for the 11 chapters contacted for the pilot study (early spring 2016), while simultaneously conducting snowball recruitment with interviewed participants. To ensure trustworthiness of the data by evidencing data saturation (*i.e.*, no new ideas emerging during interviews) and negative cases (*i.e.*, data that did not support emergent patterns or trends) (Patton, 2002), the final recruitment technique involved contacting the 50 chapters that were awarded the highest organizational award for 2016: either the Exemplary Award from the ACS (American Chemical Society, 2017c) or the 3-star award from ΑΧΣ (Alpha Chi Sigma, 2017a). The assumption here was that award-winning chapters would have an involved advisor (gatekeeper), lots of outreach programs, and significant member participation. In late spring 2017, reoccurring ideas were captured during interviews and no new ideas emerged which confirmed data saturation and prompted the end of recruitment and data collection (Patton, 2002).

Research question 2: eliciting responses from participants

Since the target population for this study was geographically diverse, and in-person interviews were not feasible, researchers conducted synchronous, multimedia-based, semi-structured interviews. These interviews occurred using freely available programs (*e.g.*, Skype and Google Hangouts) with audio recording using a recorder placed next to the interviewer's computer. Using these programs allowed for simultaneous voice, video, and instant messaging communication. Skype was the primary program, as it is widely used (Microsoft, 2016, 2017a). Throughout this paper, multiple programs used to conduct the interviews will be cited but will collectively be referred to as the *interview platform* (*i.e.*, all of the technology used during the interviews).

Pilot study interviews were used primarily to build researcher expertise in using/troubleshooting the interview platform, as technology literacy of the interviewer has been presented as a concern in previous studies (*e.g.*, Nehls *et al.*, 2015). Additionally, in congruence with typical in-person interview practices in CER, the pilot study also helped test the interview guide for successful elicitation of meaningful data and give the interviewer practice probing student ideas using follow-up questions (*e.g.*, Novick and Nussbaum, 1978; Linenberger and Bretz, 2012b). Since these interviews primarily served as preparation for the full study, data elicited from these interviews are not presented in this paper. What follows are detailed descriptions of the full study interviews focused on the interview task(s) used to elicit student ideas during each phase of the interview and the technology harnessed to administer the task(s) and collect data.

Building rapport and member checking (interview phase 1). In our technique, we built rapport by multiple emails with participants prior to the interview, which has been suggested in the multimedia-interview literature (Nehls *et al.*, 2015; Iacono *et al.*, 2016; Weller, 2017). Additionally, we greeted the participant, discussed the consent information from the recruitment survey, and had participants expand on the demographic information they provided during recruitment during the early part of the interview.

While greeting the participant (common practice in in-person interviews) does differ when conducted online over the interview platform, similar questions are able to ease the participant and help them adjust to talking over the internet. Greetings including *"How are you?"* and technology-related questions like *"Can you see me? Am I loud enough?"* allowed the participants to communicate with the researcher and test out the technology, all while growing accustomed to the interview platform. Additionally, the interviewer discussed the consent information to emphasize the confidentiality of the interview, the use of pseudonyms in all presentations of findings, and to allow participants to ask questions. This step was very important since some participants completed the recruitment survey (and provided informed consent for the interview) weeks or months prior to the interview. This enabled the researcher to obtain verbal consent in addition to the written consent on the recruitment survey.

To build rapport and help participants become accustomed to the interview platform, demographic information collected in the recruitment survey was discussed, and participants were invited to elaborate upon their answers. This review technique elicited participants' ideas by allowing them to provide more details about their previous outreach experiences, how long they have been involved with their student chapter, and previous research experience (if applicable). These details enhanced their survey responses, added to the rich description of outreach practices obtained in the interviews, and built trust and rapport with the participant prior to asking interview questions specifically related to the research goals of the overarching chemistry outreach study.

One of the primary goals of the overarching study was to explore college students' perceived purpose(s) of conducting chemistry outreach. To elicit their ideas, two modes were employed. The first mode involved a question on the recruitment survey regarding participants' perceived purpose(s) of outreach. The question was built from raw responses received from an exploratory study (Pratt and Yezierski, 2018), and asked participants to select purpose(s) that they agreed with and then rank them into a hierarchy of importance (where one is the most important). Fig. 2 shows the first tier of this question in which participants selected items before ranking them.

Raw responses/hierarchies obtained from the recruitment survey were limited and did not provide any details about how participants interpreted items nor any rationale for item rankings. Therefore, the second mode of elicitation occurred during the interview where participants were asked to revisit/reflect on their responses and discuss with the interviewer their

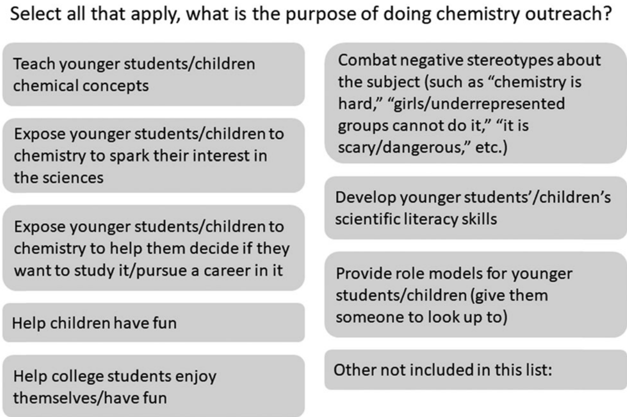

Fig. 2 Excerpt from the recruitment survey showing the first tier of the question and available options for purpose(s) of chemistry outreach; the second tier asked participants to rank only their selected items into a hierarchy of importance. Item choices were pulled directly from raw responses received from an exploratory study (Pratt and Yezierski, 2018).

selections and rankings. To do this, participants' hierarchies were instant-messaged *via* the messaging option of the interview platform, and participants were instructed to think aloud as they reviewed their responses to give insights into why they selected items and why they ranked items into their specific hierarchy (Bowen, 1994). Because this step focused on participants' prior experience in the study (*i.e.*, the survey completed prior to scheduling the interview), this step also continued building rapport between the interviewer and interviewee. Additionally, data obtained from revisiting the survey hierarchies became crucial to the overarching outreach study, since participants' verbal reflections on their survey inputs provided more details regarding item interpretations and their process in constructing hierarchies. This reflection was a form of member checking which added trustworthiness to the findings, as the think-aloud data ensured that researchers accurately interpreted participants' hierarchies (Lincoln and Guba, 1985). Data regarding the hierarchies, item interpretations, and varied processes for constructing the hierarchies are presented in the Results and discussion section. These data illustrate why accurate researcher interpretations of hierarchies would not have been possible without this specific revisiting/elicitation technique.

Adapting an interview task for the online platform (interview phase 2). To elicit student ideas regarding their chemistry outreach practices, multiple interview tasks had to be either adapted for, or created specifically for, the online environment. The first of these interview tasks was used to elicit ideas related to the evaluation of outreach events (interview phase 2) and resembled the member checking task discussed above. However, in this case, the task was conducted 'live' during the interview and resembled the common interview task of card sorting (*e.g.*, Krieter *et al.*, 2016). To adapt the card sorting task for the online environment, an electronic survey tool was used to provide options for participants to select and then sort into a hierarchy of importance. Like the purposes provided in the recruitment survey, responses from a national, open-ended survey became options for criteria of a successful outreach event (Pratt and Yezierski, 2018) used in this task. Using an electronic survey, participants selected success criteria that they agreed with before ranking their selected items into a hierarchy of importance (see Fig. 3).

Just like the hierarchies of purposes of outreach which were revisited early in the interview, the survey link for this task was instant-messaged to participants using the messaging capability of the interview platform. However, more similar to a card sorting task, participants completed the task 'live' during the interview. Additionally, participants were asked to think aloud as they completed the selection and hierarchy to give insight into why they selected items and the rationales for their rankings (Bowen, 1994). This think-aloud technique elicited the same type of descriptive, meaningful data obtained when participants reflected on their purpose(s) of outreach, but with

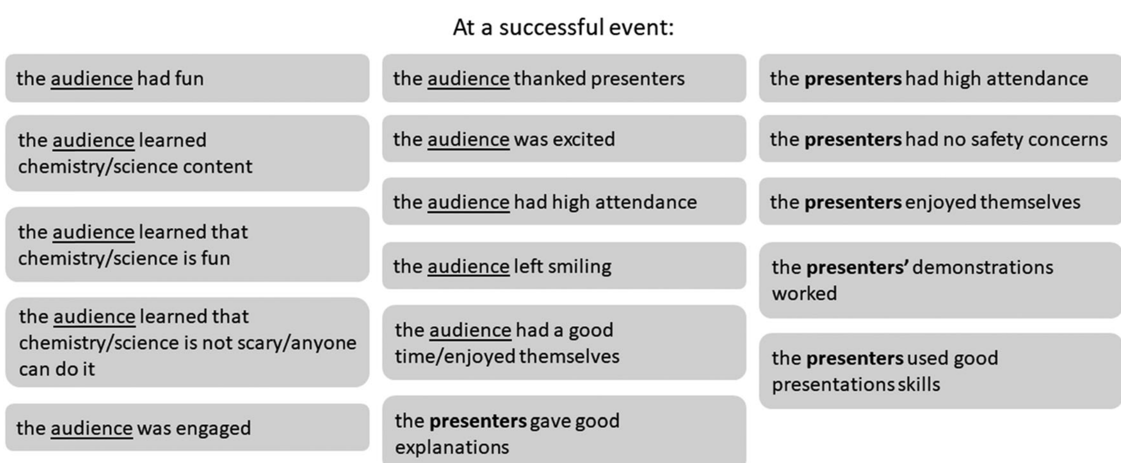

Fig. 3 Excerpt from the during-interview survey showing the first tier of the question and available options for success criteria of an outreach event; the second tier asked participants to rank their selected items into a hierarchy of importance. Item choices were pulled directly from raw responses received from an exploratory study (Pratt and Yezierski, 2018).

concurrent collection of survey responses and verbal rationales making it analogous to other interview tasks like card sorting; the survey technology was simply a means of translating the task into an electronic format.

Developing an interview task for the online platform (interview phase 3). The third interview task focused on eliciting participants' understanding of the chemistry content embedded in common chemistry outreach activities. The results obtained from an earlier investigation (Pratt and Yezierski, 2018) showed that activities involving making liquid nitrogen ice cream, the ''elephant toothpaste'' reaction (catalyzed decomposition of hydrogen peroxide), and making slime (gelation of polyvinyl alcohol with borax) are very common for this outreach-practitioner population. Therefore, sampling criteria for this study included having prior experience with one or more of these activities, since this part of the interview explored these activities in depth.

During the pilot study, this part of the interview guide was structured with only open-ended questions related to typical age groups (audiences) targeted with these activities, mode of implementation (demonstration shows *vs.* hands-on activities), and expected learning goals for the activities before probing students more deeply about the chemistry content. Surprisingly, many participants were unfamiliar with the chemistry embedded in the activities including not understanding the procedures for the activities. When prompted to explain the activities and the reactions involved, the majority of participants struggled and could not respond, despite having prior experience facilitating these activities (sampling criterion). This difficulty was noticed early during the pilot study and prompted the researchers to revise the interview protocol by developing a novel task specifically focused on eliciting meaningful data about student conceptual chemistry understanding.

This novel task took the form of written, partially inaccurate student explanations which incorporated some ideas discussed during the pilot study and published misconceptions about the chemistry content underlying the activities. The research team crafted these explanations for the three outreach activities studied (making liquid nitrogen ice cream, the ''elephant toothpaste'' reaction, and making slime) and for three different audience age levels (elementary/primary school, middle/early secondary school, and college general chemistry). During the full study interviews, the explanations were individually instant-messaged to participants *via* the messaging feature of the interview platform accompanied by verbal instructions from the interviewer. The interviewer told participants that the explanations were a mixture of accurate and inaccurate ideas, and that they should read the explanations and critique them in terms of (1) content accuracy and (2) appropriateness for the indicated age group. These instructions purposefully and clearly indicated that the explanations were a combination of accurate and inaccurate content, and that the responses were from other participants. Having students discuss inaccurate content has been used successfully in animation research providing precedence for this task (Kelly *et al.*, 2017), and the emphasis placed on the explanations obtained from other participants helped ensure that no power dynamics were introduced (*i.e.*, an interview participant critiquing the interviewer's words).

Ensuring trustworthiness

While quantitative studies rely on determinants of validity and reliability to support findings, qualitative studies rely on establishing trustworthiness which includes credibility, dependability, and confirmability (Lincoln and Guba, 1985; Shenton, 2004). Multiple techniques were employed during the development and analysis of the method described in this paper to ensure trustworthiness of the data. First and foremost, because the development of this study was informed by findings from a previous study (Pratt and Yezierski, 2018), credibility is added due to a data-driven study development. Additionally, the use of a pilot study to test the method and interview guide further adds credibility and dependability to the study. While these two techniques provide clear evidence of trustworthiness throughout the development of the full study, the two researchers also conducted weekly debriefing sessions throughout the study discussing data analysis, preliminary findings and limitations, and next steps, which further adds trustworthiness to the study in the form of credibility. As the method itself is entirely novel, peer scrutiny of the project was also conducted through multiple presentations at national and international conferences, and monthly, local presentations with chemistry education researchers not involved in the project. Such peer scrutiny ensured rigor in the design of the novel method and in the analysis of data, which further supports the trustworthiness of the study. Throughout the weekly debriefing sessions and various peer scrutiny sessions, detailed notes were also recorded to establish an audit trail and add confirmability to the study.

In addition to the techniques to ensure trustworthiness of the method design and analysis of data, trustworthiness techniques were also embedded in the application of the method itself (as described above) including member checking, iterative questioning, and overlapping data collection tasks to allow for triangulation which adds credibility, dependability, and confirmability to the study. As such, multiple provisions were included in the method itself, design of the method, and analysis of data to ensure trustworthiness of the data, results, and conclusions presented in this paper.

Results and discussion

The following section presents evidence of the efficacy of methods for access and elicitation to answer the research questions.

Research question 1: recruiting and gaining access to participants

For the pilot study, five students from the initial recruitment survey responses sent to gatekeepers met the sampling criteria and were interviewed. These participants recruited an additional two students through snowball sampling (Patton, 2002). In total, seven students ($N = 7$) were interviewed for the pilot study.

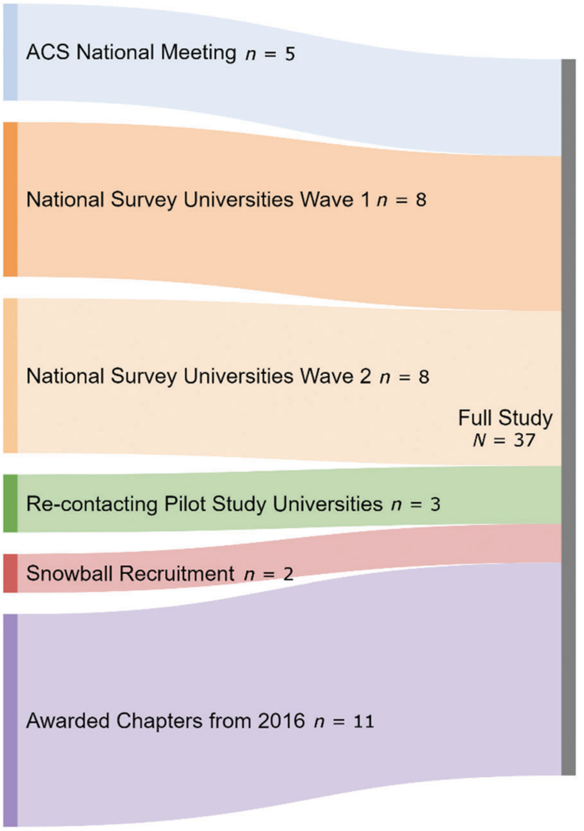

Fig. 4 Ribbon/Sankey diagram (Bogart, 2017) summarizing the recruitment efforts for the full study and the number of research participants resulting from each effort.

Fig. 4 summarizes the outcomes of recruitment for the full study. The full study began at the end of the spring 2016 semester with targeted, in-person recruitment at the spring 2016 ACS National Meeting. Because the recruitment occurred near the end of the semester and many of the volunteers were graduating seniors, only five interviews resulted from this recruitment effort despite distributing over 250 flyers.

From the combined two waves of electronic recruitment *via* emails sent to gatekeepers of student chapters that participated in the exploratory study, 32 students volunteered for the study who met the sampling criteria, and 16 interviews were conducted (8 participants from both waves of recruitment). As these responses did not evidence data saturation and had minimal sample variability, researchers re-contacted the universities recruited for the pilot study resulting in three interviews for the full study. Simultaneous snowball recruitment with previously interviewed participants resulted in two additional interviews. Saturation of data was suspected after these five recruitment strategies (n = 26 interviews), since participant answers from these two recruitment efforts discussed no novel features as compared to earlier data. However, to ensure trustworthiness of the data *via* data saturation and looking for negative cases (Patton, 2002), one last recruitment effort was made by targeting individual chapters which received awards in 2016. This route recruited 25 students who met the sampling criteria and resulted in 11 additional interviews; these interviews confirmed data saturation, as no new ideas emerged. In total, the full study included N = 37 students (17 males and 20 females). These students were from 22 unique student chapters/institutions (17 public institutions and 5 private institutions) of various sizes, as shown in Fig. 5.

Clearly, recruitment of a geographically diverse population requires flexibility and multiple strategies to ensure the same response rate as in-person recruitment. This is likely due to gatekeepers having direct contact with students and researchers being strangers to participants (and unable to introduce themselves as in in-person recruitment). Additionally, scheduling interview times with students over email proved challenging due to differing time zones and the busy schedules of students. These difficulties explain why only 37 of 92 total volunteers who met the sampling criteria were actually interviewed (40%). Despite these difficulties, survey and email technologies allowed the researchers to cast a wide net over the course of the study and contact over 100 chapters at individual universities through over 700 individual email interactions. This approach led to a very diverse sample which would not have been possible if recruitment only occurred at a single institution.

Fig. 5 summarizes the diversity of institution locations and sizes for the participants in the full study; Table 1 summarizes the demographic information for the interviewed participants. While sample sizes for qualitative studies are varied and are dictated by data saturation (Lincoln and Guba, 1985; Herrington and Daubenmire, 2014), the sample size of this study is in the range of typical sizes for in-depth qualitative studies in chemistry education research (*e.g.*, Henderleiter *et al.*, 2001; Luxford and Bretz, 2013; Benny and Blonder, 2018). However, no other studies have reported as diverse of a sample, in terms of

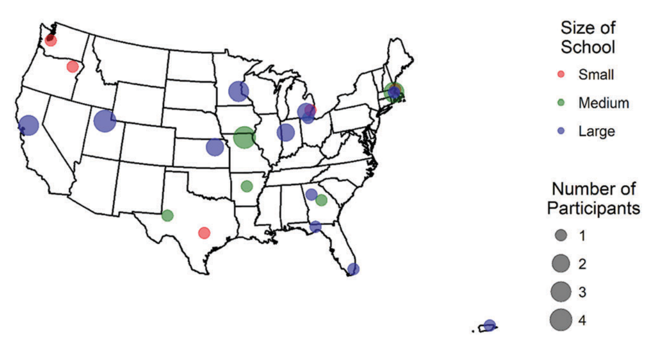

Fig. 5 Map detailing the locations and university sizes for the participants in the full study. Total student enrollment was used to classify sizes of schools (small <5000 students; medium 5000–15 000 students; and large > 15 000 students).

Table 1 Demographic information for the students interviewed in the full study (N = 37)

Year in school	n	Major	n
Sophomore (second year)	5	Chemistry or biochemistry	22
Junior (third year)	11	Science (non-chemistry)	11
Senior (≥fourth year)	19	Non-science	2
Graduate student	2	Chemistry graduate student	2

student demographics and locations, as this study. This lack of diversity in previous studies is likely due to limitations in accessing geographically diverse participants. Multimedia-based interviews greatly increased access to such participants in this study, which led to the large diversity in institutional and participant characteristics of this sample. Such diversity and inclusion of a wider range of perspectives increases the trustworthiness of the data and potential transferability of findings from this study to other teaching and learning contexts (Lincoln and Guba, 1985).

Research question 2: eliciting responses from participants

For every participant, a single interview took place on the interview platform. These interviews ranged from 47 minutes to 2 hours and 36 minutes and averaged 1 hour and 21 minutes in length. As discussed in the Methods section, every participant interviewed had completed the recruitment survey to volunteer for the interview, and had both prior experience facilitating an outreach event with an audience and experience with at least one of the three targeted outreach activities (making liquid nitrogen ice cream, elephant toothpaste, or slime) prior to volunteering/being interviewed. Described below are results related to the various elicitation tasks; representative data are included to provide evidence supporting the efficacy of the method. In-depth analysis of the interview data related to the goals of the overarching chemistry outreach study will be the subject of future submissions.

Building rapport and member checking (interview phase 1). As mentioned in the Methods section, the first elicitation task asked participants to revisit/reflect on their hierarchies of purpose(s) of outreach and provided evidence of varied processes for constructing hierarchies and differing item interpretations. One such example of varied processes for constructing the hierarchies comes from Veronica who discussed ranking *purpose* items both by importance and by order of occurrence during an event (despite the question prompt asking specifically to rank in terms of importance).

While reflecting on her hierarchy (Fig. 6), Veronica said that the purpose of *'Expose younger students/children to chemistry to spark their interest in the sciences'* was required for the purpose '*Expose younger students/children to chemistry to help them decide if they want to study it'* to occur. Additionally, this then led to the purpose *'Provide role models for younger students/children (give them someone to look up to)'* occurring. In her hierarchy, she placed these three purposes as first, second, and third, respectively. However, upon reflection Veronica said that this ranking was based on the order the items occurred in practice, not importance: *''[they] occur in a chain reaction.''* She actually thought of them as a single unit in her hierarchy, as together *''they [were] more important''* than others listed lower in the hierarchy. Therefore, her rankings of first, second, and third did not accurately represent her ideas of importance, and she would rather have all three ranked as equally important. This practice of grouping items and thinking about how they occur during an event, or as Veronica calls in order of *''lead[ing] to,''* was common in the data set (n = 16). Therefore, the technique of having students reflect and report on their survey responses produced meaningful and critical data as the hierarchies would be misinterpreted without this elicitation task.

In addition, some participants even chose to modify their rankings during reflection. One reason was that they interpreted items as equally important (like Veronica), but limitations of the survey software did not allow for equal item rankings. Lois is another participant who discussed this desire for equal rankings; her original hierarchy submitted during recruitment is shown in Fig. 7.

Upon reflection, Lois discussed the purposes she ranked as fourth and fifth as, *''I would probably say they're equal cause*

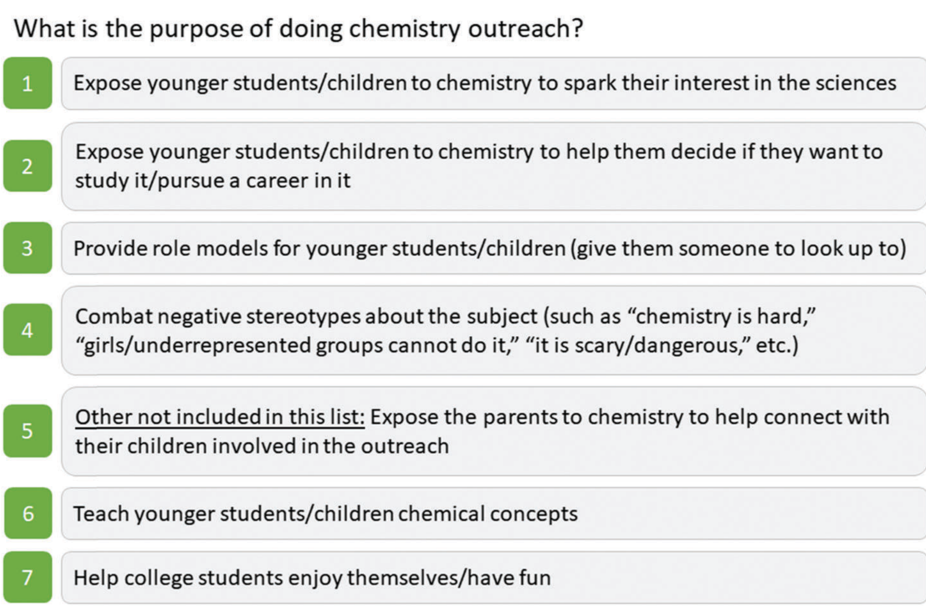

Fig. 6 Veronica's selected items for purpose(s) of chemistry outreach and the corresponding hierarchy.

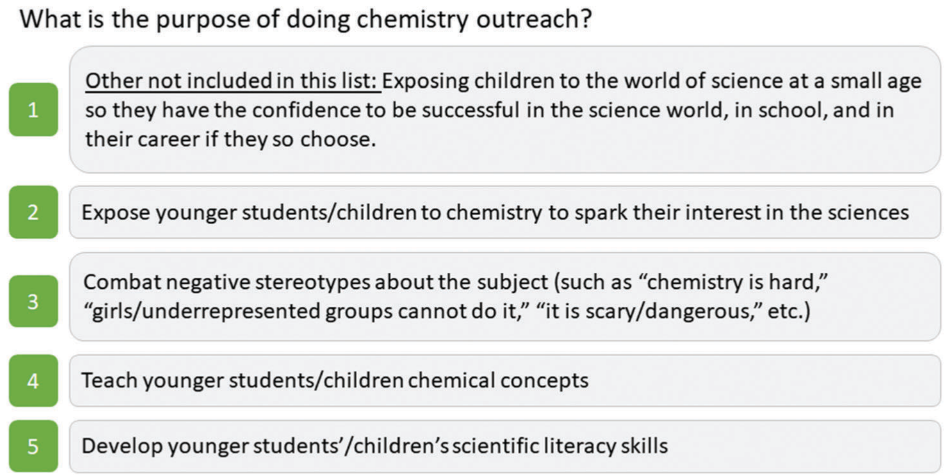

Fig. 7 Lois's selected items for purpose(s) of chemistry outreach and the corresponding hierarchy.

I think they're hand-in-hand with each other.'' This was common throughout the interviews, as some participants reported that some purposes were equally important (n = 10). Additionally, some participants, upon reflection, added additional purposes to their hierarchies which they did not originally include (n = 2). This reflection and revision to hierarchies adds trustworthiness to the data as a form of member checking (Lincoln and Guba, 1985). Furthermore, this illustrates how researchers would have misinterpreted many of the responses if this revisiting/reflection task was not included in the interview. This finding embodies one key limitation of survey-only research methods and adds support to the combined survey and interview methods employed in this study. Additionally, this member-checking task also helped participants become comfortable verbalizing their thoughts on familiar data/their prior experience, which was crucial in building rapport with the participants and ensuring that the remainder of the interview elicited meaningful data.

Overall, this interview phase successfully built rapport and trust with participants, while also eliciting the details needed to fully understand participants' ideas about the purpose(s) of outreach they communicated *via* their recruitment surveys. Evidence of rapport is best illustrated by Veronica and Lois's conversational interactions during the interview. With Veronica, she was very open about her lack of previous thought about the relationships between some of her selected items: *''I don't know... I just thought about that. I've never actually like sat down and figured it out.''* For Lois, her discussion about the purpose she ranked as third also illustrates this conversational nature: *''So then with number three, obviously I'm a girl, a female in science so [laughter] I totally get that one!''* While responses from only two participants are presented, their data are representative of the meaningful data obtained from, and conversational dialogue that occurred during, the interviews.

Additionally, no evidence throughout other phases of the interview suggested that participants were unwilling to share their ideas, or that the interview platform hindered discussion, as suggested by previous studies on multimedia-based interviews (*e.g.*, Seitz, 2016; Weller, 2017). Therefore, not only did this phase successfully build good rapport with participants, but it also elicited rich details about students' ideas regarding the purposes of conducting chemistry outreach. These details add trustworthiness to the data obtained *via* multimedia-based interviews. They also provide evidence that multimedia-based interviews have the ability to elicit meaningful, high-quality data commensurate with in-person interviews, and that rapport can be built over the internet.

Adapting an interview task for the online platform (interview phase 2). Results from the second interview task, the analogous card sorting task where participants constructed hierarchies of important success criteria, evidenced similar construction strategies as the purposes of outreach data/member-checking task. These strategies included participants ranking items by order of occurrence during events (n = 9) and revising hierarchies to equate items (n = 19). This is not surprising, since the two tasks had similar structures, and the discussion of purposes prior to this task may have primed participants to think in a similar fashion as they did when completing the success criteria task. One example of a participant discussing the order of occurrence of success criteria is Shayera, whose hierarchy of success criteria is shown in Fig. 8.

Shayera specifically discussed the necessity of criteria *'the presenters gave good explanations'* and *'the presenters used good presentation skills'* leading to *engagement* of and *excitement* in the audience: *''I put [those] lower because I feel like...without having [a] good presentation or good explanations you can't have an engaged and excited audience.''*

Although some participants interpreted all items as communicating unique ideas and continued through the task (such as Shayera above), others interpreted some of the success criteria items as having the same meaning. Participants either (1) ranked items as equally important in their hierarchy or (2) only selected one representative item to include in their hierarchy. Ten participants interpreted the items in one of these two ways (n = 10). Items which typically had similar interpretations included *'the audience had fun,' 'the audience left smiling,' 'the audience had a good time/enjoyed themselves,'*

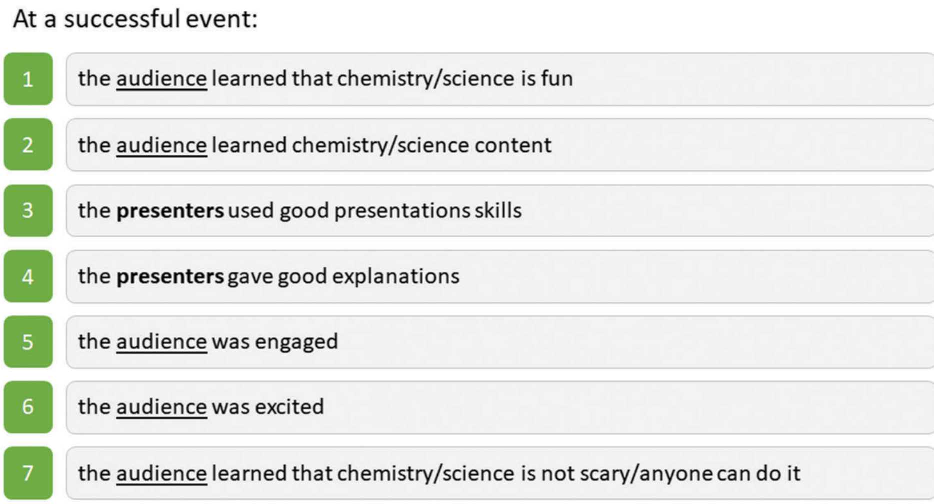

Fig. 8 Shayera's selected criteria for the success of an outreach event and the corresponding hierarchy.

and *'the audience was excited.'* Without the think-aloud descriptions accompanying the responses, these differences would be unidentifiable pointing towards the need for interviews rather than a survey-only investigation. Additionally, the thick description obtained from the participants (*i.e.*, item interpretations and processes of constructing hierarchies) illustrates that the electronic card sorting task elicited meaningful data, and the interview platform did not hinder discussion. Similar to Veronica and Lois, Kendra also had no reservations in discussing her feelings when completing the task, *"I think I misinterpreted [it]. It's been a long week! I think it's a Tuesday? [laughter]"*, and calling out discrepancies in her discussion of items, *"I think I may be contradicting myself!"* These student statements provide further evidence that rapport was built and sustained throughout the interview. Additional evidence of this sustained rapport comes from participant responses during the third interview task (related to chemistry content), detailed below.

Developing an interview task for the online platform (interview phase 3). While pilot study data prompted the development of the novel task involving partially inaccurate explanations, the interview protocol for the full study interviews retained open-ended questions to probe initial student ideas prior to completing the novel task. Similarly to the pilot study, students struggled to discuss the chemistry content during open-ended questioning during the full study. This is not surprising considering that the population of students sampled for the full study was the same as that of the pilot study, and no modifications were made to the open-ended questions in the interview protocol. Representative quotations from the full study which illustrate this difficulty in discussing the content during open-ended questioning include:

- *"It's been a long time since chem two!... it's not knowledge I deem important enough to keep in my brain on a daily basis."* – Sue
- *"I don't know what's goin' on"* – Shayera
- *"If we've learned anything today is that...[Max] doesn't remember chemical reactions"* – Max

While the willingness of the participants to share their uncertainty shows further evidence of the rapport built during the interview, these responses do not provide details about participants' chemistry content knowledge related to outreach activities, thus supporting the use of the novel elicitation/critiquing task.

While a total of nine explanations were crafted and used during the full study, only representative student responses from an excerpt from one explanation for the "elephant toothpaste" reaction will be presented, since the goal is to illustrate the efficacy of the task for successful elicitation; the appendices include all nine explanations for reference.

The "elephant toothpaste" reaction involves the catalytic decomposition of hydrogen peroxide into oxygen and water (Conklin and Kessinger, 1996; Cesa, 2004; Trujillo, 2005). An excerpt from the explanation written for the college general chemistry level is below (note: inaccurate ideas are boldfaced here for reference but were not boldfaced when sent to participants):

"...a catalyst is used because the decomposition is not spontaneous. The catalyst allows the reaction rate to increase because the mechanistic pathway changes. The catalyzed mechanism has two steps with **higher activation energies. Overall, the catalyst decreases the overall enthalpy change of the reaction**... Once all of the catalyst is converted to the intermediate, the reaction dramatically speeds up as noted by the increase in foam being produced..."

This excerpt specifically targets participants' conceptual understanding related to the role of the catalyst in the reaction and its connection to thermodynamics and kinetics. Sue, who initially could not discuss the reaction during open-ended questioning (above), responded to a portion of this passage (underlined) with:

"The line a couple of sentences from the end 'once all of the catalyst is converted to the intermediate' uhm...catalysts don't change so that's super wrong."

Shown here, despite being unable to discuss the content at the beginning of the phase, the explanation elicited her knowledge of catalysts, specifically regarding the known misconceptions that catalysts do not change during the course of a reaction (Cakmakci, 2010; Bain and Towns, 2016): *"catalysts don't change."* Similarly, Shayera who also struggled to discuss the content earlier in the phase responded to a portion of this explanation (underlined) with:

"Uhm...'overall the catalyst decreases the overall enthalpy change of the reaction'...yes? Yes, but only [as a] result...so...the catalyst decreases the activation energy which leads to a decrease in overall enthalpy, but a catalyst does not directly change enthalpy. The enthalpy changes as a result of the decreased activation energy."

Shayera's response indicates that she may understand the relationship between catalysts and activation energy during a reaction (*"the catalyst decreases the activation energy"*), but she does not understand how activation energy and enthalpy relate (or in this case do not relate) in a catalyzed reaction.

Both Sue and Shayera's responses are representative of the descriptive, meaningful data obtained through the novel, critiquing explanation interview task employed with all 37 participants; without this task, the interview would not have captured many participants' chemistry understanding, thus providing evidence that this task was successful as an elicitation technique. While the task clearly elicited new inaccurate ideas and misconceptions not specifically included in the written explanations, a detailed analysis of these ideas is out of the scope of this paper and will be the subject of future manuscript submissions.

Even though the critiquing task successfully elicited verbal descriptions from students of the chemistry content, it has been shown before in CER studies that participants' mental models may differ from their verbal and/or symbolic descriptions, thus calling for capturing drawings as well (Cooper *et al.*, 2015). As such, drawing was offered to participants as an option for them to express their ideas during the interview. For those that chose to draw ($n = 10$), participants provided and used their own materials from their interview location to communicate their ideas (*e.g.*, notebook paper). They would then display their drawings by holding them up to their webcam. Using screen capturing software, the interviewer then captured images of the drawings; representative drawings pertaining to the "elephant toothpaste" reaction are shown in Fig. 9.

In the case of drawings associated with elephant toothpaste, many participants only drew when discussing the age appropriateness of the explanations and the need to draw for kids to understand. For example, Bruce said that, *"If I was...telling this to a kid, I might draw on the board the activation energy barriers"* followed by drawing the left representation in Fig. 8. Bruce's drawings also evidence the published misconception that a catalyst does not change during a reaction (discussed by Sue above), since the formation of an intermediate including the catalyst is not shown on the diagram (Cakmakci, 2010; Bain and Towns, 2016).

The drawings from the participants offered an additional lens to interpret their chemistry content knowledge related to the activities used in chemistry outreach events. While not all participants chose to use drawings to convey their understanding, providing the choice ensured rich, meaningful data collection, as it offered another way for participants to represent and communicate their ideas.

Technology limitations and considerations

What has been described is a novel online interview technique that harnesses video conferencing software, electronic survey software, instant messaging, and screen capturing software to elicit interview participants' ideas. The examples provided illustrate the meaningful data and thick description obtained *via* this method. However, as discussed in previous discussions of online interviews, technology can be both a benefit and a limitation. While the various tasks implemented through the technology did provide meaningful data which mirror the quality of data obtained *via* in-person interviews, technical difficulties did occur and must be considered in the evaluation of the efficacy of the method.

As the population targeted was composed of students at university, the quality and reliability of internet access varied. Almost a third of the video calls ($n = 12$) froze and/or dropped during interviews, causing both the interviewer and the participant to work to reestablish the connection. Additionally, every

Fig. 9 Representative drawings of reaction coordinate diagrams drawn by Bruce (left) and Merina (right) when discussing the elephant toothpaste reaction.

interview had at least one instance of an internet-connection issue in which the audio and/or video skipped. While some have argued that these issues hurt rapport (*e.g.*, Seitz, 2016; Weller, 2017), we found no evidence of this. The participants seemed accustomed to troubleshooting connectivity issues and would continue the interview without any hindrance to rapport once the interviewer either repeated the question or asked the participant to repeat themselves. For example, internet connectivity was an issue for Lex; however, once reconnected, the interviewer simply repeated the question and continued the interview as normal, as shown in the following excerpt from the second elicitation task (analogous card sorting task):

Lex – *I wouldn't so much say the attendance has so much of uhm…part to play in successfulness because I could have a high attendance but have everyone distracted rather than having low attendance and…have anyone very…*

[Call Disconnected]

[Call Reconnected]

Interviewer – *You there?*

Lex – *Yes, I'm here*

Interviewer – *Ok and you were saying, you don't think you need high attendance to have a successful event?*

Lex – *Uhm I…attendance may play a part but I don't believe that it should uh…so much denote whether it was successful or not because…a high attendance may also lead to more people err…lead to it being a little harder to engage err…everyone in the audience rather than in a small crowd where you can interact with everyone watching the show.*

Being well versed in the interview guide and conducting a pilot study to develop literacy in the technology (Nehls *et al.*, 2015) was crucial to this study; this helped the interviewer be flexible, be able to quickly troubleshoot the technology, and rephrase/repeat questions to continue the interview without diminishing rapport. This population itself (college students) may also be more accustomed to using and troubleshooting technology due to daily internet use (Eurostat, 2017; Pew Research Center, 2017), which may also explain why disconnections did not seem to hinder rapport.

Flexibility was also important in terms of choosing the interview platform, and giving participants choices has also been suggested in previous studies as an access technique (*e.g.*, Deakin and Wakefield, 2014; Simeonsdotter Svensson *et al.*, 2014; Nehls *et al.*, 2015; Seitz, 2016; Weller, 2017). In this study, every participant had differing preferences about which video conferencing software to use. With the goal of access in mind, providing options for the participants was necessary and afforded technology needs to dictate the platform. Interview software used in this study included Skype, Google Hangouts, or Facebook, and participants used laptops, desktop computers, cellphones, or a combination thereof. An added limitation was that instant messaging capabilities of the multimedia programs would sometimes malfunction. As all of the interview tasks relied on sending information to the participant during the interview, email was used a backup to continue the interview and not disrupt the order of interview tasks prescribed in the interview guide.

Screen capturing suited the needs of this study to acquire the drawings some of the participants provided. However, the qualities of the images obtained *via* this method were wide ranging (illustrated in Fig. 8), and it is worth noting that the researchers may need to recreate some drawings for presentation and publication. The screen capturing software used in this study was the Snipping Tool included by default on Windows computers (Microsoft, 2017b); however, a similar free program exists for Apple computers called Snip (Tencent Technology (Shenzhen) Company Limited, 2012). In other qualitative CER studies, researchers have provided representations for the participant to interact with and encouraged participants to draw their own representations (*e.g.*, Linenberger and Bretz, 2012b). While this was not the goal of this study, the methods from this study can easily be adapted to stimulate and capture more drawings through the use of a freely available tool that allows researchers to provide representations with which participants can interact. The tool takes the form of a digital whiteboard where the interviewer can load representations, graphics, and even documents for the interviewee to interact with (including drawing on), and then capture the annotations/representations as an image using screen capturing software (Expat Software, 2017). A paid version allows for image capturing within the digital whiteboard tool without using additional software. However, while this tool is available, studies will need to investigate the ease of using this tool by research participants including drawing using a touchpad, computer mouse, and/or finger/stylus, and the learning that must occur for participants to use this tool easily. One study outside of CER has used this tool, but it does not discuss details about how the interviewees learned to use the program or how they performed their drawings (Hay-Gibson, 2009). As the participants in the study presented in this article demonstrated, various technologies may be used to attend the interview; additional technologies that give the participants choices for drawing likewise can increases access and are worthy of future investigation.

Summary of methods

In summary, the novel method described in this paper addresses two key considerations for research with human subjects: accessing research participants and eliciting responses from them. The techniques used in this novel method are summarized in Fig. 10. The novelty of the described method rests in the combined use of multimedia interviews with adapted in-person interview tasks, and the development of a novel interview task, to access research participants and elicit their ideas.

To access research participants and sample from a national population, three main recruitment techniques were used: (1) email, (2) in-person flyers, and (3) snowball recruitment. In all instances, electronic survey software was used to easily access students through gatekeepers. Additionally, interview scheduling also helped in accessing participants by providing participant choice in which multimedia interface was used.

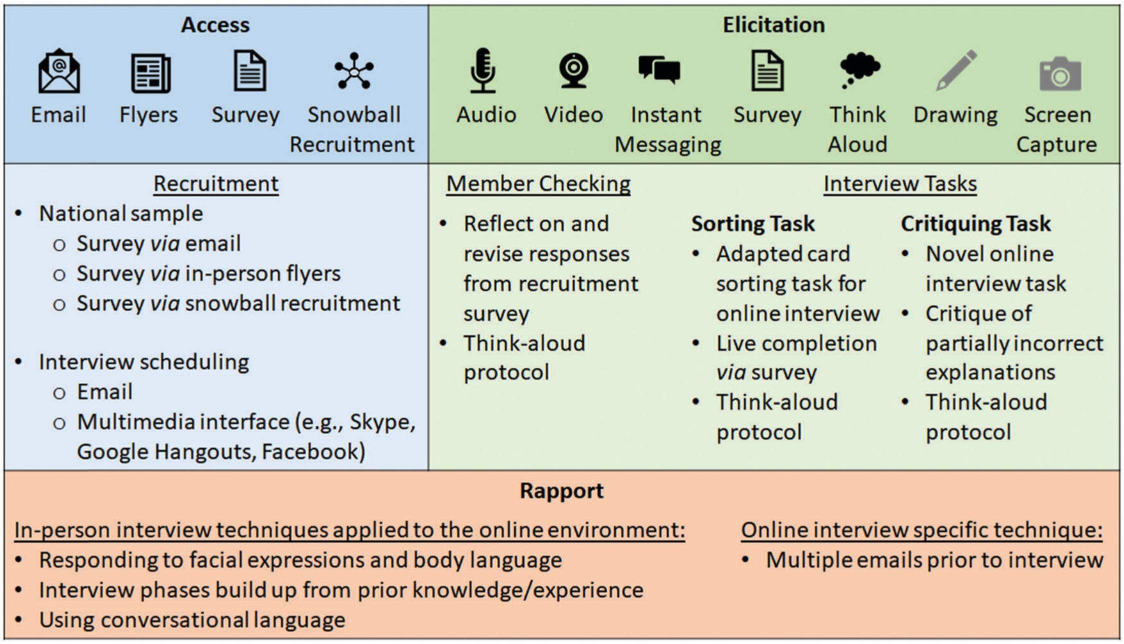

Fig. 10 Summary of the various techniques used to access research participants and elicit their ideas. The first row (dark hues of blue and green) uses icons to discuss the various techniques and technology employed when accessing participants and eliciting their ideas; the second row (light hues of blue and green) provides specific methodological details related to access and elicitation; the third row (orange) discusses the rapport building techniques employed throughout both stages.

To elicit student ideas, audio, video, and instant messaging communication was employed as they are embedded in freely-available multimedia programs. Additionally, survey software was used as a means to adapt in-person interview tasks for the online environment. Even though the interviews were conducted electronically, face-to-face elicitation tasks of think-aloud protocols, open-ended questions, and student drawing were easily implemented. The instant messaging capability of the multimedia programs helped administer the various elicitation tasks, minimizing the physical, location-based barrier of not meeting participants in person.

To establish and sustain rapport during the interviews, common face-to-face techniques were employed, such as responding to facial expressions and body language (afforded by the video communication). However, as suggested by previous studies on rapport building in multimedia-based interviews, the need to establish the interviewer as a 'real' person prior to the interview was required and achieved through multiple email communications leading up to the actual interview (*e.g.*, Deakin and Wakefield, 2014; Nehls *et al.*, 2015; Iacono *et al.*, 2016; Weller, 2017).

Conclusions and implications

This paper describes a novel method for qualitative data collection conducted electronically. One aim was to evaluate the effectiveness of these technological solutions in accessing participants across the entire U.S. The final sample included in this in-depth, qualitative study of chemistry outreach practitioners is more diverse than previously reported in CER (in terms of both institution and participant characteristics). The increased sample diversity includes more perspectives than typical single-institution studies, which improves and increases the transferability of findings (Lincoln and Guba, 1985). Additionally, the diverse sample enables findings to capture the diverse outreach practices among the ACS and ΑΧΣ organizations as a whole, rather than of only a few individual chapters.

The other goal of this study was to describe the adaptation of in-person interview tasks (and the creation of a novel interview task) for online multimedia-based interviews. Electronic surveys offer a means to adapt card sorting tasks for use in online interviews. Instant messaging allows for easy sharing of information (including written explanations to critique), and simultaneous audio and visual formats allow participants to think aloud and draw. The data presented accompanying the descriptions of the various tasks illustrate the rich, meaningful data elicited and obtained using these multimedia-based approaches, which are commensurate with data obtained through traditional face-to-face interviews.

Implications for research

The data presented provide evidence that the method described here has the potential to change how chemistry education researchers design and carry out qualitative studies. Harnessing freely available technologies minimizes location-based barriers, allowing qualitative studies to cross local and potentially national boundaries to enable the study of more diverse groups than previously reported. Additionally, this study has shown that common interview practices for eliciting participant ideas (*e.g.*, card sorting tasks) can be modified and implemented electronically (*e.g.*, electronic surveys with item ranking). Straightforward technologies (such as screen capture) enable an electronic way to implement a common interview practice, such as participants drawing, to be seamlessly integrated into an online electronic environment. With increased access yielding rich data commensurate with face-to-face interviews, multimedia-based interviews prove to be a worthwhile data collection tool that illustrates how qualitative research in the 21st century can increase the diversity of samples and improve the transferability of findings, without losing the rich description associated with in-person interviews.

More research needs to be conducted to further test this method, provide details on the differences between multimedia-based interviews and in-person interviews in CER, and optimize the method to identify when limitations of multimedia-based interviews preclude answering particular CER questions. As technology is continuously changing, investigations of using other tools in these electronic environments and developing new elicitation tasks tailored specifically to online interviews are needed to advance the field and increase understanding of best practices when conducting online, multimedia-based interviews.

Implications for practice

Although the aim of this study was not to investigate distance learning environments, the use of multimedia online tools in this study significantly overlaps with those used in online courses. Like online courses, this study required techniques to elicit, capture, and assess student understanding electronically. In the online course environment, while discussion forums and quizzes are common assessment tools administered through course management systems (*e.g.*, Blackboard, Moodle), the techniques presented in this paper provide *new* routes for eliciting rich, descriptive ideas from students. Providing students with prompts, tasks, and think-aloud protocols can capture their thought processes and yield more descriptive data about their understanding than a quiz or exam score. All of the aforementioned techniques can be conducted from a distance with data collected using technology, such as the survey tool used in this study. The use of online, multimedia tools coupled with research-based elicitation techniques demonstrates how distance learning environments could employ richer assessment tools to better evaluate student knowledge. However, future work would be required to test the research techniques used in this study as assessment approaches in online classroom environments.

For outreach practitioners, the data presented in this paper, although limited in scope, call for a closer examination of outreach practices. The data presented about student conceptual understanding of the chemistry content embedded in outreach activities suggest gaps in chemistry learning. While a great deal of research has investigated student understanding in the formal classroom, a gap in conceptual understanding is apparent in this sample. This gap is of significant concern for outreach education since these students are becoming informal chemistry educators who lack scientifically accurate foundational knowledge. Future publications will explore the gaps in student conceptual understanding and how that impacts chemistry outreach events.

The findings presented in this paper also illustrate the diversity of ideas related to why outreach is conducted and how to evaluate the success of events, evidenced by the varying ways participants responded to the tasks. These results call for outreach practitioners to closely examine their own outreach practices, particularly regarding the alignment between their goals and evaluation criteria. Additionally, examining the training of event facilitators (informal educators) is necessary to improve the teaching and learning taking place in these informal chemistry education environments.

Future work

The data presented in this paper evidence the rigor and success associated with using these novel data collection techniques, and are representative of the rich, meaningful data collected over the course of an in-depth qualitative study of chemistry outreach practices. Further analyses of the data presented in this paper are ongoing to address the goals of the overarching study about chemistry outreach practices.

Conflicts of interest

There are no conflicts to declare.

Appendix 1: explanations for the elephant toothpaste reaction†

College general chemistry level

This reaction involves the catalytic decomposition of hydrogen peroxide into water and **hydrogen gas**. This **acid–base reaction** is an exothermic reaction **because bonds are broken and heat is released**. A catalyst is used because the decomposition is not spontaneous. The catalyst allows the reaction rate to increase because the mechanistic pathway changes. The catalyzed mechanism has two steps with **higher activation energies**. **Overall, the catalyst decreases the overall enthalpy change of the reaction**. The reaction starts off slowly because the first step is the rate limiting step. **Soap is used to help break down the hydrogen peroxide**. Once all of the catalyst is converted to the intermediate, the reaction dramatically speeds up as noted by the increase in foam being produced. Since the products are gas, the foam expands as the gas molecules inside the foam spread out.

Early secondary/late middle school (8th grade) level

Hydrogen peroxide changes into water and **hydrogen** using a catalyst. A catalyst speeds up the rate of reaction. Think about water; it evaporates if we sit a cup of it on the counter but it does it very slowly. If we put it on the stove, it goes much faster. **The stove acts as a catalyst and speeds up the reaction. We use**

† Note: students received the explanations without boldfacing, but inaccuracies are boldfaced here for reference.

the soap to help break down the molecules of hydrogen peroxide. The water and **hydrogen** produced are gases **which want to be as far apart from each other as possible** so they expand, which is why the bubbles get bigger. **The heat is produced because when hydrogen peroxide is broken apart, energy that is stored in the molecules is released**.

Early primary/elementary school (2nd grade) level

In this reaction we change a liquid into multiple gases. When the particles become gas, **they grow and become larger, taking up more space** which is why gases spread out. However, most gases are invisible. In order to see this reaction occur, we need to capture the gas. Just like blowing bubbles or bubbles in the bathtub, we use soap here to capture the gas and give us evidence that the gas was produced. As the reaction progresses, you can see **the foam grow and expand as the particles grow and become gas**.

Appendix 2: explanations for making slime†

College general chemistry level

Polymers are long chains of repeating units. **White glue is primarily composed of the monomer vinyl acetate**. In solution, these monomers easily slide past one another with minimal attractions to each other. This is why glue flows out of the bottle. Borax, when dissolved in water, yields boric acid $B(OH)_3$ which **condenses the monomer to vinyl alcohol. The boric acid causes a polymerization reaction, creating the polyvinyl alcohol polymer (PVA) which is a solid. The more borax that is added to the glue, the more PVA that is produced. This is why the slime can behave like a liquid or solid. When a small amount of borax is added to the glue, a small amount of PVA is created (meaning that the majority is the liquid polymer). As the concentration of borax is increased, more PVA is made, causing the mixture to behave more like a solid**.

Early secondary/late middle school (8th grade) level

White glue is made up of a polymer. Polymers are long chains of molecules that are linked together. You use polymers every day; the rubber on your shoes, plastic drink cups, and Styrofoam containers are all different kinds of polymers. Some polymers are elastic and flexible (like rubber) and some are hard and firm (like hard plastics). The linked molecules in glue **do not slide past each other easily (that is why you have to squeeze the bottle to get the glue to come out)**. When we add borax, **we disrupt those connections. A small amount of borax causes some of the links to break, allowing the slime to flow more like a liquid**. As we increase the amount of borax, new links form, causing the slime to start behaving more like a solid.

Early primary/elementary school (2nd grade) level

Solids hold their shape. Liquids do not (they flow). In this experiment, we are going to create a slime that behaves both like a solid and like a liquid. We start with glue which is very thick. When we add a small amount of detergent, **the glue becomes less thick and more like a liquid** (it flows). When we add a lot of detergent, the slime hardens into a solid (it holds its shape). **Pushing or pulling on the slime causes the solid slime to loosen (and behave like a liquid). When we stop pushing or pulling on the slime, it returns to behaving more like a solid**.

Appendix 3: explanations for making liquid nitrogen ice cream†

College general chemistry level

The ice cream solution is a mixture of milk, sugar, and flavoring and milk is primarily composed of water. Dissolving the sugar in the milk **increases the freezing point of the milk, causing it to freeze at a higher temperature**. Nitrogen is a gas at room temperature because of **strong** intermolecular forces between the nitrogen molecules (London-dispersion interactions). Liquefying nitrogen requires low temperature and high pressure in order to decrease the kinetic energy/slow down the molecules enough to have the intermolecular forces take hold. As soon as the liquid nitrogen's container is opened, it boils because the vapor pressure of liquid nitrogen is so high. **During boiling, the temperature of the liquid nitrogen increases as it changes into a gas**. Heat from the ice cream solution is absorbed by the liquid nitrogen. Because the temperature difference between the ice cream solution and the liquid nitrogen is so great, the transfer of heat is very fast, allowing for the ice cream to freeze almost instantly. The water inside the ice cream mixture goes from a liquid state to a solid state because heat is lost and the molecules slow down, creating solid ice cream.

Early secondary/late middle school (8th grade) level

Ice cream is primarily made out of milk which is a mixture of fat and water. When we freeze the water, we get solid ice cream. We can use a freezer at your house to do this, but it takes a long time. If we use liquid nitrogen, we can do it in a few minutes. Your freezer at home is around 30 °F, liquid nitrogen is around −320 °F. Because liquid nitrogen is so cold, it freezes ice cream much faster. When we freeze the ice cream, the mixture goes from a liquid to a solid. In the liquid state, the molecules slide past each other and move around. In the solid state, the **molecules are so cold that they stop moving. When we add the liquid nitrogen, cold from the liquid nitrogen transfers to the water in the ice cream mixture, causing the water particles to slow down and freeze. The liquid nitrogen loses its cold and increases in temperature to become a gas**.

Early primary/elementary school (2nd grade) level

You use a freezer at home to keep your ice cream cold. Liquid nitrogen is about 12 times as cold as your freezer so it will let us make ice cream really fast. The liquid ice cream mixture is going to freeze to a solid because **the liquid nitrogen gives its cold to the ice cream. When something gets really cold, it stops moving and shivers in place. The liquid nitrogen, once it has given its cold to the ice cream, heats up to become** a gas and floats away.

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CHAPTER 4:

INVESTIGATION 2 – RESULTS FROM ANALYSES OF COLLEGE STUDENT CONCEPTUAL UNDERSTANDING OF CHEMISTRY CONTENT, BELIEFS ABOUT TEACHING AND LEARNING, AND TRAINING EXPERIENCES

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College Students Teaching Chemistry through Outreach: Conceptual Understanding of the Elephant Toothpaste Reaction and Making Liquid Nitrogen Ice Cream

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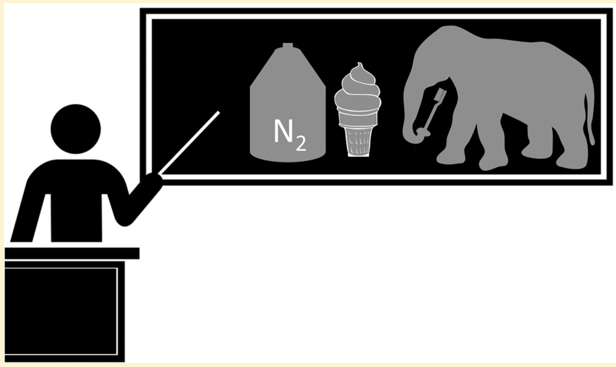
Supporting Information

ABSTRACT: Informal chemistry education/chemistry outreach is ubiquitous with the chemical enterprise. However, little research has focused on the planning, implementation, or evaluation of these events. Results from a previous study suggest that college students involved with collegiate chapters of the American Chemical Society and Alpha Chi Sigma are heavily involved with chemistry outreach, and their most frequently discussed purpose is to teach chemistry content to their audiences. Given this goal, it is timely to investigate how well these college students, who are acting as teachers in outreach environments, understand the chemistry content embedded in the activities they implement during their events. Presented in this paper are the results of a content analysis of semi-structured interviews (N = 37) focused specifically on student understanding of the elephant toothpaste reaction and making liquid nitrogen ice cream at a general chemistry level. Results show prevalent misunderstandings and misconceptions of the content despite the sample being composed primarily of junior and senior chemistry majors. Implications for teaching in both formal and informal environments are presented in light of these findings, as well as potential future investigations of the teaching and learning occurring during chemistry outreach.



KEYWORDS: *Chemical Education Research, Public Understanding/Outreach, Upper-Division Undergraduate, Second-Year Undergraduate, Misconceptions/Discrepant Events, Catalysis, Phases/Phase Transitions/Diagrams, General Public*

FEATURE: Chemical Education Research

INTRODUCTION

Informal Science Education

Over 80% of K−12 student learning occurs in informal learning environments (i.e., outside of the formal classroom); this number dramatically increases as students leave the K−12 environment.[1] Given that the majority of learning occurs outside of the classroom, informal learning environments are uniquely situated to provide learning opportunities that may address growing concerns about public understanding of science.[2] However, informal learning environments are much more complex and diverse as compared to formal learning environments.

Formal science learning environments are typically viewed as compulsory and in-the-classroom, with learning goals focused on content and state standards.[1,3,4] Informal science learning environments, on the other hand, are considered much more voluntary and occur in a variety of settings, including interactions with the media (e.g., television, radio, Internet, video games), cultural institutions (e.g., museums, zoos, aquariums), structured out-of-school-time programs (e.g., afterschool youth programs, clubs), and even just everyday experiences.[1,3−5] Additionally, the specific learning outcomes typically targeted in informal science environments are much more varied. While *understanding of scientific content and knowledge* is one area of focus for informal science learning, five other areas/learning goals are recognized by the informal science community: (1) sparking interest and excitement, (2) engaging in scientific reasoning/scientific practices, (3) reflecting on science and understanding of natural phenomena, (4) using the tools and language of science, and (5) identifying with the scientific enterprise.[1,6] On top of both environment and learning goal diversity, additional levels of complexity that make informal science learning environments unique include various audience levels/types (from young children to adults) and discipline-specific content differences (e.g., chemistry, biology, physics).

Informal science learning has been a national focus in the United States since 1957 when the National Science Foundation (NSF) first conducted studies on public understanding of science, before creating a program specifically

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focused on funding research on public understanding of science in 1958. Since then, informal science education has grown with NSF funding for broader informal science education investigations (beginning in 1983), special issues in research journals focused on informal science (*International Journal of Science Education* in 1991, *Science Education* in 1997, *Journal of Research on Science Teaching* in 2002), and multiple National Research Council reports in 2009 and 2010 focused on general informal science education practices.[1,6] While these are only highlights of the major events in informal science education, they illustrate an increased interest in informal science learning and research in the U.S. Despite such a focus on general informal science education, discipline-specific informal science education has only recently become a national focus, particularly in chemistry.

Informal Chemistry Education and Chemistry Outreach

In 2016, the National Academies published a report titled *Effective Chemistry Communication in Informal Environments*.[7] This report was the first scholarly investigation that tried to characterize national informal chemistry education practices. With focus placed specifically on practicing chemists, the report identified goals these chemists have for informal chemistry education events, including focusing on public appreciation of chemistry, developing scientifically informed consumers, and encouraging the public to pursue careers in the chemical sciences. The report also discussed the chemistry content typically targeted during chemists' informal events, including biochemistry and materials chemistry, the chemistry of everyday life, and environment-related topics like climate change.[7] While the report is limited and only represents the views of a sample of the population of chemists conducting informal chemistry education, it was the first in-depth investigation of informal chemistry education practices despite the ubiquity of informal chemistry education within the chemical enterprise.

Recently, a previous study by the authors[8] sought to characterize the practices of a population that was not included in the *Effective Chemistry Communication in Informal Environments* report: college students. College students affiliated with American Chemical Society (ACS) and Alpha Chi Sigma (AXΣ) student chapters reach almost 1 million people every year through their informal chemistry education events (typically termed *chemistry outreach*).[9,10] With such a large number of people affected by their outreach, it was prudent to characterize the chemistry outreach practices of these college students. Results from a survey on college students' and their faculty advisors' goals for outreach indicate that these collegiate chapters of ACS and AXΣ have goals distinguishable from the chemists included in the 2016 National Academies report;[7] the most prevalently discussed goal for college students and their faculty advisors is that their audiences *learn chemistry content* as a result of attending chemistry outreach events.[8] Other goals include that the audience learns that science is fun, develops curiosity, and has fun/enjoys themselves. The most prevalently facilitated activities during these college students' outreach events include the elephant toothpaste reaction (the catalytic decomposition of hydrogen peroxide into water and oxygen[11,12]) and making liquid nitrogen ice cream.[13,14]

These findings indicate that college students involved with chemistry outreach align their events with the general informal science learning goal of *understanding scientific content and knowledge*.[1,6] As such, given the cognitive learning goals these college students have for their teaching during chemistry outreach events (i.e., audience learning chemistry content),[8] it is timely to consider the role of content knowledge in the teaching and learning process for college students facilitating outreach. With little research in informal science education focused on the facilitator's content knowledge as it pertains to achieving content-centered learning goals, it is necessary to consider research from formal learning environments.

Content Knowledge and Teaching

Researchers have considered how teachers in formal learning environments develop teaching knowledge since 1986 when Shulman coined the term *pedagogical content knowledge* (PCK).[15] PCK refers to "*subject matter knowledge for teaching*", or the knowledge and skills needed to successfully teach a specific subject.[15,16] Since then, there have been multiple different interpretations of PCK, including refining it into discipline-specific (e.g., science), subject-specific (e.g., chemistry), and even topic-specific (e.g., equilibrium) levels.[17,18] No matter the interpretation, all models emphasize the role of the teacher's own content knowledge (CK) on the development of PCK; a teacher must understand the content in order to be able to teach it.[16] Multiple investigations (across a variety of disciplines, subjects, topics, and instructional levels) have supported that CK is a necessary component for developing PCK, and the CK of the teacher has an impact on their teaching and student learning.[19−24] Rollnick and colleagues[23] best summarized the importance of teacher CK as it relates to student learning: "*If teachers do not have in-depth knowledge of a topic themselves, it is clearly difficult for them to provide conceptual depth for their students.*"

Despite the known relationship between CK and PCK, the exact connection between a teacher's CK and how they develop PCK remains unclear; therefore, there is a need to explore teacher CK more in-depth to understand how CK leads to PCK.[25,26] Although all CK and PCK studies have investigated formal classroom teachers (both in K−12 and university settings), the influence of CK on teaching transfers to informal environments where events align with the learning goal of *understanding scientific content and knowledge*. This is particularly important for college students conducting outreach, since their goals for outreach include the *audience learning content*. Therefore, investigating the CK of college students acting as informal educators/teachers is warranted to further understand the teaching and learning occurring in chemistry outreach.

■ RESEARCH QUESTIONS

With the connections among teaching skills, content knowledge, and student/audience learning, investigating the CK of these college students is necessary (particularly considering their most prevalent goal of chemistry outreach is *audience learning*). Therefore, the study described in this paper seeks to address the following research questions (RQs): *For college students conducting chemistry outreach, what is the nature and extent of their content knowledge associated with (1) the elephant toothpaste reaction? and (2) making liquid nitrogen ice cream?*

■ METHODS

As part of an Institutional Review Board approved study on chemistry outreach practices, semi-structured interviews[27] were conducted with college student outreach practitioners

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associated with ACS and AXΣ student chapters throughout spring 2016 to spring 2017. As this population was dispersed across the United States, multimedia-based programs (e.g., Skype, Google Hangouts) were used to contact participants and to conduct the interviews. The interview protocol was structured in four phases: (1) demographics and purpose(s) of conducting chemistry outreach, (2) criteria for successful outreach events, (3) understanding of chemistry content embedded in outreach activities, and (4) training and skills development. Interviews conducted over this platform successfully elicited useful data that has been shown to yield trustworthy conclusions.[28] For the purpose of this paper, only data from phase 3 (chemistry content) will be presented, as it directly addresses the research questions above. Included in the Supporting Information are questions from the interview guide for phase 3.

Sample

Using a variety of recruitment efforts, including in-person recruitment and emails to gatekeepers, a total of 37 college student outreach practitioners were sampled and interviewed as part of this study.[28] The sampled students were from 22 geographically diverse institutions across the U.S.A., with small primarily undergraduate institutions to large research-intensive institutions represented. Participant demographics included a mixture of males ($n = 17$) and females ($n = 20$), chemistry/biochemistry majors ($n = 22$), other science majors ($n = 11$), nonscience majors ($n = 2$), and chemistry graduate students ($n = 2$). The undergraduate students in the sample included sophomores/second years ($n = 5$), juniors/third years ($n = 11$), and seniors/fourth or fifth years ($n = 19$). Since this study targeted the population of ACS and AXΣ student chapter members who had previous experience conducting chemistry outreach before, it is not surprising that the interviewed sample was composed primarily of upper-division chemistry/biochemistry majors. A table that disaggregates the sample demographics by participant is included in the Supporting Information. In addition, in congruence with findings from a national survey,[8] 31 of the 37 participants indicated that the purpose of chemistry outreach is to *teach chemical concepts*. In terms of evaluating the success of an event, many believed that a successful outreach event is when the *audience learned chemistry content* ($n = 31$), and when the college student presenters *gave good explanations of the chemistry* ($n = 35$). The prevalence of this sample's ideas focused on teaching and learning chemistry during an outreach event supports exploring how well these college students understand the chemistry embedded in common outreach activities.

Investigating and Analyzing Understanding of Chemistry Content

Results from a pilot study and open-ended questioning suggested that these college student outreach practitioners struggle to discuss the chemistry content underlying the common outreach activities of elephant toothpaste and liquid nitrogen ice cream, despite prior experience conducting these activities.[8,28] This prompted the development and testing of a novel elicitation task that took the form of inaccurate explanations written for second graders (7−8 years old), eighth graders (13−14 years old), and college general chemistry students. Inaccuracies embedded in the explanations included incorrect ideas that were expressed by the participants during a pilot study and published misconceptions. Because of the data-driven design, each explanation varies in the ratio of correct vs incorrect ideas. All of the inaccurate explanations, including the prompts and evidence for successful elicitation of chemistry understanding, have been discussed in detail in a previous study.[28]

During the interviews, students were asked to critique the explanations line-by-line and discuss if the content was accurate or inaccurate. After interviews were transcribed verbatim and pseudonyms randomly assigned (describing only the gender of the participant), a content analysis was performed on the student responses to the inaccurate explanations written at the general chemistry level.[27,29] Only student responses to the general chemistry level explanations were used for the purpose of assessing chemistry understanding, as these explanations were expected to be prior knowledge for the sampled students. The second grade and eighth grade explanations were written to elicit ideas about pedagogy and audience level, and a discussion of such ideas is outside of the scope of the research questions addressed herein.

Because the prompt asked students to critique individual statements/lines of the general chemistry level explanations, a content analysis was performed by analyzing student responses to these individual statements. The analysis coded student responses as (1) identified the content as correct, (2) identified the content as incorrect, or (3) made no comments about the accuracy of the content. The breakdown of the inaccurate explanations into individual statements are shown in Table 1 (elephant toothpaste) and Table 2 (making liquid nitrogen ice cream). Once student ideas about each statement were coded, patterns and trends were investigated by looking within and between students using the demographic data as grouping criteria. Responses were analyzed to see if major, gender, year in school, and/or school size had any relationship with student responses/understanding of the chemistry content.

Table 1. Statement Breakdown of General Chemistry Level Inaccurate[a] Explanation of Elephant Toothpaste

Number	Statement
1	This reaction involves the catalytic decomposition of hydrogen peroxide into water and **hydrogen gas**.
2	This **acid−base reaction** is...
3	...an exothermic reaction because **bonds are broken and heat is released**.
4	A catalyst is used because the decomposition is **not spontaneous**.
5	The catalyst allows the reaction rate to increase because the mechanistic pathway changes.
6	The catalyzed mechanism has two steps with **higher activation energies**.
7	**Overall, the catalyst decreases the overall enthalpy change of the reaction.**
8	The reaction starts off slow because the first step is the rate limiting step.
9	**Soap is used to help break down the hydrogen peroxide.**
10	Once all of the catalyst is converted to the intermediate, the reaction dramatically speeds up as noted by the increase in foam being produced.
11	Since the products are gas, the foam expands as the gas molecules inside the foam spread out.

[a]Inaccurate chemistry content is bold for clarity (adapted from Pratt and Yezierski, 2018).[28]

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Table 2. Statement Breakdown of General Chemistry Level Inaccurate[a] Explanation of Liquid Nitrogen Ice Cream

Number	Statement
1	The ice cream solution is a mixture of milk, sugar, and flavoring and milk is primarily composed of water.
2	Dissolving the sugar into the milk **increases the freezing point of the milk causing it to freeze at a higher temperature.**
3	Nitrogen is a gas at room temperature because of **strong** intermolecular forces between the nitrogen molecules (London dispersion interactions).
4	Liquefying nitrogen requires low temperature and high pressure in order to decrease the kinetic energy/slow down the molecules enough to have the intermolecular forces take hold.
5	As soon as the liquid nitrogen's container is opened, it boils because the vapor pressure of liquid nitrogen is so high.
6	**During boiling, the temperature of the liquid nitrogen increases as it changes to a gas.**
7	Heat from the ice cream solution is absorbed by the liquid nitrogen.
8	Because the temperature difference between the ice cream solution and the liquid nitrogen is so great, the transfer of heat is very fast allowing for the ice cream to freeze almost instantly.
9	The water inside the ice cream mixture goes from a liquid state to a solid state because heat is lost and the molecules slow down creating solid ice cream.

[a]Inaccurate chemistry content is bold for clarity (adapted from Pratt and Yezierski, 2018).[28]

Trustworthiness

As with all qualitative studies, it is necessary to provide evidence for the trustworthiness of conclusions by evaluating the data collection and analysis (similar to the validity and reliability of quantitative studies).[30,31] The data-driven design of this study, as well as a previously published case study analysis of the data collection techniques for successful elicitation of student ideas, provides evidence for the trustworthiness of the data obtained.[28] Additionally, the increased sample diversity, both in terms of institution type/size and student demographics, adds trustworthiness to the resulting conclusions from this study in the form of increased transferability.[30,31] While such holistic approaches support the rigor of the data collection, the content analysis performed was also subjected to steps that support the confirmability and dependability of the findings. These steps included initially treating each student as a case in order to categorize their initial responses to each statement, as well as any revisions to their responses that occurred later in the interview. Analysis within and between students also adds trustworthiness as it allowed for any patterns or trends to emerge due to demographics rather than individual chemistry understanding. Throughout the project, weekly debriefing sessions with the two researchers allowed for the team to come to consensus on unique cases/responses, and to collectively determine future analytic steps. Additionally, peer scrutiny with CER colleagues at the same institution (not involved with the project), and with those attending national research conferences, ensured that the research team's interpretations of data and presentation of findings were rigorous. All of the aforementioned techniques, as well as the inclusion of a copy of the interview guide questions in the Supporting Information, add transparency to the data collection and analyses, which augments the overall trustworthiness of the data presented and resulting conclusions.

RESULTS

RQ 1: Chemistry Understanding of the Elephant Toothpaste Reaction

Of the college students interviewed as part of this study (N = 37), only 26 had previous experience conducting the elephant toothpaste experiment and critiqued the inaccurate general chemistry explanation during the interview. To clarify the analysis, the explanation was subdivided into chemically correct statements (Table 3) and chemically incorrect statements (Table 4); representative student quotations for when a student said the chemistry was correct or incorrect for each statement are provided in both tables.

Of note are the differences in quotation lengths when a student believed the statement to be correct vs incorrect. When a participant said the statement was correct, they rarely expanded on their ideas as evidenced by the short, succinct quotations. However, when a student said the statement was incorrect, they tended to elaborate and explain why they believed the chemical idea was inaccurate, leading to longer excerpts.

To capture the frequency of students agreeing/disagreeing with the chemistry content and to understand which statements/chemical ideas students prevalently struggled with, the data were visualized. Separate graphs were constructed for the correct statements and incorrect statements (see Figure 1). In both graphs, green signifies students correctly identifying the content as accurate or inaccurate (i.e., evidence that the student understands the chemical concepts). Red is used when student responses about the accuracy/

Table 3. Representative Student Responses to Chemically Correct Statements in the General Chemistry Level Explanation for Elephant Toothpaste

Statement Number	Representative Quotation When Student Said Chemistry Was Correct	Representative Quotation When Student Said Chemistry Was Incorrect
5	"That's true and I... would say... I would tell that to a gen. chem. student" (Merina, senior chemistry major)	"No, no, no way, that's not what a catalyst is. That's horribly wrong! I have a horrible problem with that... [it's] not because the mechanistic pathway changes, but because it lowers the activation energy. A catalyst never changes what actually reacts with what, it only changes... the activation energy needed for the reaction." (Carrie, sophomore chemistry major)
8	"Well, that makes sense." (Betty, senior science major)	"I mean it's never really slow, it all sort of happens at once." (Oliver, senior science major)
10	"That makes sense. Um, the catalyst may be involved in reaction intermediate but it's produced again at the end of the reaction." (Gwen, senior chemistry major)	"Uhm... catalysts don't change so that's super wrong" (Sue, senior science major)
11	"Now the last sentence... yeah, that part makes sense." (Edwin, senior chemistry major)	"I think I know what they're trying to say but I think they're explaining it incorrectly... I don't think the size of the bubbles necessarily changes... Maybe I just don't understand bubbles... I think you just get more bubbles because... more of the gas is being captured... I think once the bubble forms, that's as big as it's gonna be." (Merina, senior chemistry major)

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Table 4. Representative Student Responses to Chemically Incorrect Statements in the General Chemistry Level Explanation for Elephant Toothpaste

Statement Number	Representative Quotation When Student Said Chemistry Was Correct	Representative Quotation When Student Said Chemistry Was Incorrect
1	"I have no problem with the first one. I think that is... that is an excellent explanation." (Steve, senior chemistry major)	"I'm pretty sure, yeah, [H_2O_2] decomposes into water and oxygen. Okay. So yeah, so I would change it from hydrogen to oxygen" (Vance, senior chemistry major)
2	"There's nothing really wrong with it" (Helena, sophomore chemistry major)	"I don't think it's an acid−base reaction... Um, because I've never said it was an acid−base reaction. I never read that." (Oliver, senior science major)
3	"Yep that sounds all good to me... It talks about how heat is stored inside the bonds and when those bonds are broken, heat is released" (Helena, sophomore chemistry major)	"Bonds breaking takes energy. Wait, bon... bonds breaking takes energy, so it should never be exothermic." (Carrie, sophomore chemistry major)
4	"It does a GREAT job of telling us why the catalyst is used 'because decomposition is not spontaneous'" (Lex, junior chemistry major)	"Uhm I don't mean to kind of like slash red pens through this, but that's also not true as well. Uhm... because... H-2-O-2 will decompose uhm spontaneously, it's just very slow." (Max, junior chemistry major)
6	"If they're like drawing the activation energy curve, I think that's good" (Kendra, senior nonscience major)	"What? What?! Hold on... the uncatalyzed mechanism should have the higher activation energy, and the catalyzed mechanism should have the lower activation energy." (Steve, senior chemistry major)
7	"Yea I could see that. It decreases the enthalpy change because the activation energy is lowered so less heat is released." (Johnny, junior chemistry major)	"This sentence is inaccurate... I don't think a catalyst should do that. It should just decrease the amount of energy you need... the energy released or absorbed is... the same." (Bruce, chemistry graduate student)
9	"Makes sense... So I don't know what else would be doing it... Perfect, yep." (Remy, senior science major)	"The foam is only there because there is soap, and soap is doing its soap thing... the soap isn't part of the reaction... it's just soap-ing." (Kendra, senior nonscience major)

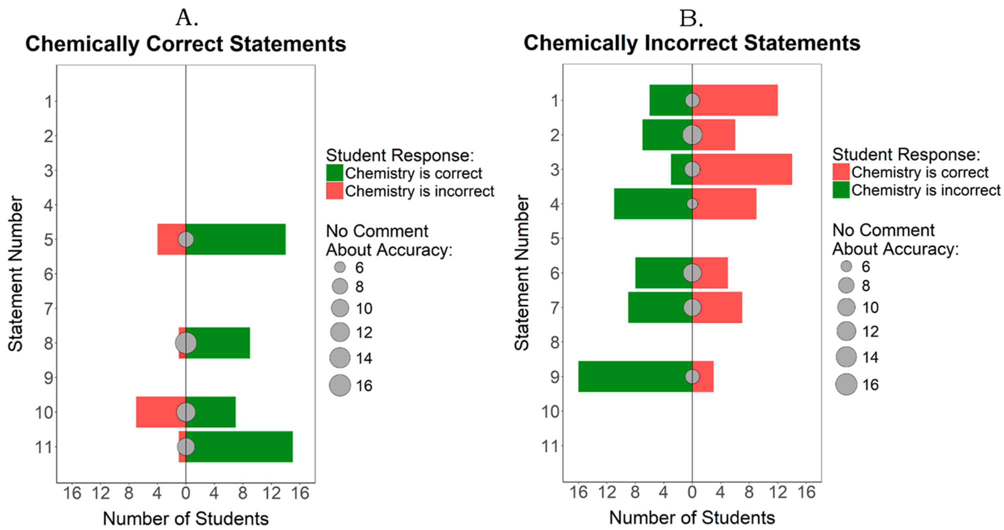

Figure 1. Line-by-line analysis of student responses to general chemistry level explanation of elephant toothpaste (n = 26). Green is evidence of students understanding the chemistry content; red is evidence of students misunderstanding the chemistry and/or having misconceptions.

Table 5. Other Inaccurate Chemical Ideas Elicited from Students When Responding to Elephant Toothpaste Statements

Statement Number	Inaccurate Idea(s)	
1	"I think... there's still oxygen, maybe not the water, but just oxygen and hydrogen [produced]." (Oliver, senior science major)	
3	"I'm pretty sure there are cases where bonds can be formed and things can also be exothermic." (Gwen, senior chemistry major)	
6	"It allows the reaction rate to increase which... in turn would lead to less energy being required, so essentially it is lowering the activation energy... it would be less activation energy needed once that catalyst is added [because] it raises the initial enthalpy, the enthalpy already in the system, before the reaction begins because a catalyst has increased the rate of reaction... the activation energy doesn't change... but because the enthalpy goes up, the activation energy overall is lower." (Lex, junior chemistry major)	"Activation energy only occurs... in... one step... I mean... I believe... I... mean... It would depend on the type of reaction I guess, but I don't think this is a reaction where you're gonna have two different... activation energies." (Harvey, senior chemistry major)

inaccuracy of the statements were incorrect (i.e., evidence of students misunderstanding the chemical concepts and/or having misconceptions). Despite the prompt asking students to discuss the accuracy of each line/statement, some students did not provide a response that critiqued the accuracy of the content in every statement (i.e., provided no evidence of their understanding of the chemistry content); these responses are represented by gray dots. Such responses in which students did not comment on the accuracy of the statements typically occurred when a student read two statements back-to-back, but only critiqued the second/final statement's accuracy. While the interviewer attempted to have students go back and critique these overlooked statements, there was a concern that overprompting the students would cause them to think statements were incorrect solely because the interviewer was asking the students to relook at them. In addition, while some students were critiquing individual statements, additional inaccurate chemical concepts were elicited; because these inaccurate ideas were separate from those included in the statements, these ideas were excluded from the graphs and

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Table 6. Representative Student Responses to Chemically Correct Statements in the General Chemistry Level Explanation for Liquid Nitrogen Ice Cream

Statement Number	Representative Quotation When Student Said Chemistry Was Correct	Representative Quotation When Student Said Chemistry Was Incorrect
1	"That's all true. I like that. We just add vanilla so I guess that's their flavoring." (Helena, sophomore chemistry major)	n/a
4	"Yep I agree with that sentence" (Neena, junior chemistry major)	n/a
5	"I think that sounds good. I would draw pictures... also. If they have like a board." (Ororo, chemistry graduate student)	n/a
7	"HEAT TRANSFER! Yes!!! [laughter] Good! Yes! This is how I would word it!" (Mary Jane, sophomore chemistry major)	"The temperature of the nitrogen is increasing because the cold is going to the ice cream, and nitrogen's increasing" (Lana, junior chemistry major)
8	"Yes, causing ice cream to freeze instantly, which I tried to hit [on] earlier" (Edwin, senior chemistry major)	n/a
9	"Sure. Sounds good." (Pamela, senior science major)	n/a

Table 7. Representative Student Responses to Chemically Incorrect Statements in the General Chemistry Level Explanation for Liquid Nitrogen Ice Cream

Statement Number	Representative Quotation When Student Said Chemistry Was Correct	Representative Quotation When Student Said Chemistry Was Incorrect
2	"Yaaas! Increases the freezing point! Yaaas! That's good cause that's a thing they learn!" (Mary Jane, sophomore chemistry major)	"Hold on. The part... I think that's wrong... I think it actually decreases the freezing point rather than increases it." (Reggie, junior chemistry major)
3	"I feel like that's missing the point of this specific demo... it's a good additive... [it's] perfectly fine." (Max, junior chemistry major)	"When molecules have strong intermolecular forces, doesn't it mean it's a solid?... Yea. I feel like strong intermolecular forces is a property of a solid because that means when the... when there's a strong force between molecules, there's limited... movement... makin' it a solid." (Beatriz, sophomore chemistry major)
6	"Which makes sense because it absorbs energy from the surroundings." (Johnny, junior chemistry major)	"Technically that's wrong... technically as you're changing from a liquid to a gas... the temperature does NOT change." (Steve, senior chemistry major)

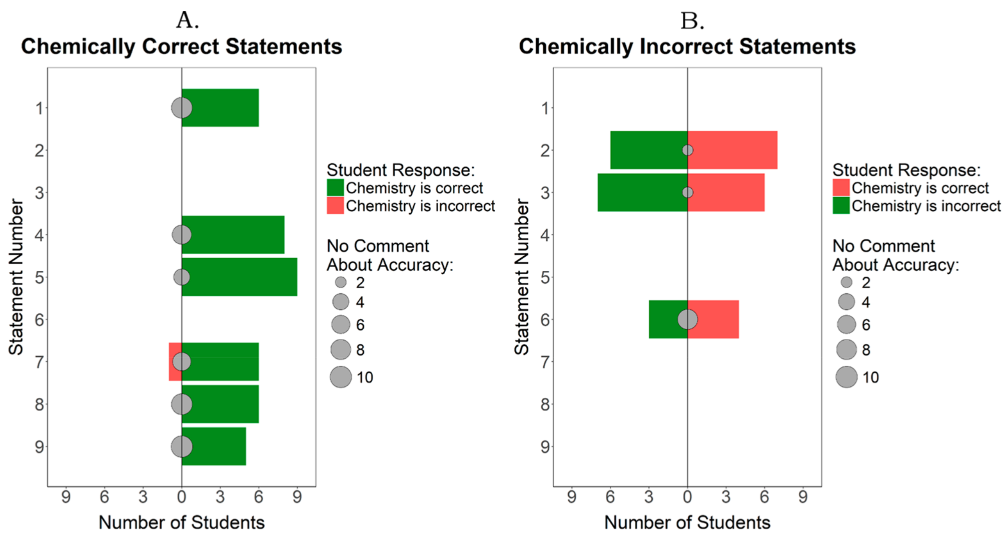

Figure 2. Line-by-line analysis of student responses to general chemistry level explanation of liquid nitrogen ice cream (n = 15). Green is evidence of students understanding the chemistry content; red is evidence of students misunderstanding the chemistry and/or having misconceptions.

included in Table 5. Despite the limitation in eliciting ideas (i.e., the gray dots where students provided no comments about the accuracy of statements), the majority of the participants provided critiques for every statement. Only one statement (statement 8) had a higher number of students who did not comment on the accuracy of the content than those who did critique the content accuracy. Additionally, since these statements elicited other inaccurate ideas not included in the statements, additional evidence for the trustworthiness of the data obtained is provided. These additional inaccurate ideas also add to the rich description of students' conceptual chemistry understanding as it relates to the elephant toothpaste reaction.

RQ 2: Chemistry Understanding of Making Liquid Nitrogen Ice Cream

Of the college students interviewed as part of this study (N = 37), only 15 had previous experience making liquid nitrogen ice cream and critiqued the inaccurate general chemistry explanation during the interview. Similar to the analysis of responses to elephant toothpaste, student responses to making liquid nitrogen ice cream were subdivided by the accuracy of the statements: chemically correct statements in Table 6 and chemically incorrect statements in Table 7. Included in both tables are representative student quotations for when a student said the chemistry was correct or incorrect.

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Table 8. Other Inaccurate Chemical Ideas Elicited from Students When Responding to Liquid Nitrogen Ice Cream Statements

Statement Number	Inaccurate ideas	
5	"I also think it would be... good to... cause people don't think of like... 'oh I'm going to open it and it's going to boil because of the vapor [pressure]'... like they might not know that vapor pressure can make it boil... you could say something like... 'vapor pressure or like temperature can like make it do that. Much like when you boil water on the stove, you increase the temperature" (Lana, junior chemistry major)	"It [N_2] just kind of steams off, right?... I think it just kind of like... like... not sublimating cause that's not... it's evaporating." [**Interviewer:** *"Instead of it boiling, it just evaporates?"* Pamela nods] (Pamela, senior science major)
7	"Technically the···liquid nitrogen is undergoing uhm···an endothermic reaction cause it's absorbing the heat. So···I would use endothermic and exothermic and stuff like that. They should know that at this level···[say] "the liquid nitrogen"s undergoing an endothermic reaction cause its absorbing heat.' It sounds more scientific and they should be able to understand it at that level." (Ororo, chemistry graduate student)	"You can also talk about that the... liquid nitrogen is... uh... getting warmer and that the ice cream is getting cold, and that's that the transfer... You can actually bring in the Second Law of Thermodynamics then, they should know that at that point. Energy can't be created nor can it be destroyed. As it's losing it's cold, the heat has to be transferred over as well to keep a balance... Second Law of Thermodynamics... everything has to be balanced on both sides." (Helena, sophomore chemistry major)

Just as with the responses to the statements about elephant toothpaste, student responses about liquid nitrogen ice cream were visualized to ascertain frequencies of responses (see Figure 2). The same color scheme was used: green for when students correctly identified the content as accurate or inaccurate, red for when student responses about the accuracy/inaccuracy of the statements were incorrect, and gray dots for when students did not provide a response that critiqued the accuracy of the content. Likewise, some statements from the liquid nitrogen ice cream explanation elicited additional inaccurate ideas from the students that were not included in the graphs; these ideas are included in Table 8.

■ DISCUSSION

RQ 1: Chemistry Understanding of the Elephant Toothpaste Reaction

As shown in Figure 1A, the majority of the students were able to successfully identify statements containing accurate chemistry content as correct (statements 5, 8, 10, and 11). However, there were instances for all four correct statements in which at least one student indicated that they believed the content was incorrect (despite it being chemically accurate). Of pressing concern are statements 5 and 10, which both discuss the role of the catalyst in the reaction. Statement 5 discusses general changes to the reaction mechanism when a catalyst is used, and statement 10 specifically discusses the catalyst reacting to form an intermediate. Four students said statement 5 was incorrect and that a catalyst only lowers the activation energy of a reaction; it does not change the mechanism. Carrie's quotation in Table 3 is representative of these responses. This idea is a published student misconception regarding kinetics and catalysis.[32] For statement 10, seven students said that the chemical idea was incorrect by stating that a catalyst does not change during a reaction. Sue's quotation in Table 3, as well as this quotation by Shayera, best illustrate these students' ideas: *"The catalyst is not being converted to anything. It stays the same. That's the whole point of a catalyst"* (Shayera, senior chemistry major). Once again, this is also a published misconception on student understandings of kinetics and catalysis.[33] While those familiar with the misconceptions literature may not be shocked by junior and senior chemistry/biochemistry majors having misconceptions related to kinetics and catalysis, the concern is that these students are acting as informal chemistry educators/teachers during chemistry outreach events without chemically accurate understanding of the chemistry they are teaching. This becomes even more alarming when the inaccurate statements related to elephant toothpaste are considered.

The graph in Figure 1B of student responses to chemically inaccurate statements about the elephant toothpaste reaction shows a much larger proportion of students coded as red, meaning that they believe the chemically inaccurate statements are actually scientifically accurate. For every inaccurate statement, at least three students indicated that the statements were correct. Statement 1, which targets students' understanding of the products of the elephant toothpaste reaction, had 12 students indicate that the products of the reaction are water and hydrogen, rather than the correct products of water and oxygen. Statement 2 focuses on how students classify the reaction, and six students supported, inaccurately, that the reaction was an acid−base reaction, while an almost equal number (n = 7) knew that the reaction was not an acid−base reaction. Oliver and Helena's quotations in Table 4 are representative of these student responses. Even though these seven students knew that it is not an acid−base reaction, only one student was able to correctly classify the reaction as an oxidation−reduction reaction. The remainder were only able to state that it was *not* an acid−base reaction. Both statements 1 and 2 are factual statements that primarily junior and senior chemistry/biochemistry majors should know. The tasks of predicting the products of a reaction and classifying the reaction type are very common in the general chemistry curriculum and should be easy for students nearing graduation with a chemistry degree. However, despite this, some students were unable to reason about the reaction type and felt unconfident doing so, as shown by a quotation from Merina (senior chemistry major), *"I've never fully been very confident in acid−base reactions in... my entire chemistry experience... I don't like classifying reactions as anything because I usually get them wrong."* While upper-division chemistry students struggling with general chemistry content is concerning, what is more pressing is that these college students are acting as informal educators and should understand these ideas before teaching them to children/younger students. This also raises a pressing safety concern. These college students/chemistry outreach practitioners may not know the reactants involved, products made, or type of reaction occurring, and yet they are performing the reactions with a vulnerable population where they must assume responsibility for the safety of all of those attending the event.

Statement 3 was by far the most frequently misunderstood statement that students discussed; it targets the prevalent misconception of exothermic bond breaking.[34,35] Fourteen students supported the idea that breaking bonds releases

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energy, such as the response by Helena in Table 4. Given the prevalence of this misconception in the literature, it is not surprising that students in this sample evidenced this inaccurate idea. However, it should concern chemistry educators that that this sample has a variety of experiences, comes from a variety of institutions/locations, and yet there were no trends based on the demographic information to suggest that certain schools/types, majors, etc. were the ones that had this misconception. This provides further support of the prevalence of this misconception across the country/different chemistry programs. Additionally, while an investigation of the type of formal instruction these college students had is out of the scope of this paper, this result may support the calls for active learning pedagogies[36] and curricular reforms that may promote conceptual understanding and minimize misconceptions (such as those by Cooper and Klymkowsky,[37] Sevian and Talanquer,[38] or the emphasis on three-dimensional learning from the National Academies[39]).

Statements 4, 6, and 7 all target student ideas of thermodynamic concepts related to catalyzed reactions (including spontaneity, activation energy, and enthalpy). For all three statements, 19−35% of students in the sample evidenced misconceptions of these thermodynamic concepts. With the numerous publications discussing students struggling to understand thermodynamics (including having misconceptions),[40] these results are not surprising. Additionally, other inaccurate ideas were elicited from a few students (see Table 5). While these ideas are idiosyncratic, they show misunderstandings and misconceptions not previously discussed in the literature. These add to the rich description of these college student outreach practitioners' chemistry understanding/misunderstanding that they are bringing to their teaching in outreach, particularly related to kinetics and thermodynamics.

One limitation of the data collection technique was that some students would not provide a critique of the accuracy of the content in every individual statement (i.e., the gray dots in Figure 1). While it may not be concerning when this occurs for chemically accurate statements, it is concerning that there were students not critiquing the accuracy of the chemically inaccurate statements. While we cannot comment on whether or not these students hold the inaccurate ideas embedded in these statements, Meaningful Learning theory[41,42] provides a lens that helps us draw some conclusions about these students' chemistry understanding. Meaningful Learning is a type of Constructivism[43,44] that differentiates rote learning (e.g., memorization of isolated ideas) from meaningful learning (e.g., meaningfully linked ideas).[41,42] Figure 3 provides a visual representation that differentiates rote learning from meaningful learning. One requirement of meaningful learning is that a student must actively choose to learn meaningfully and not memorize/rote learn.[41,42] If a student had meaningfully learned the chemistry content embedded in the inaccurate statements, reading the statements would prime the connections in their mind and they would recognize the inaccuracies. However, if a student rote learned the material, there are likely no connections (or nonmeaningful, incorrect connections) between ideas, and the student would likely not recognize the inaccuracies. Therefore, it is possible that the students who read the inaccurate statements and did not critique the accuracies of the content may have rote learned the material since no connections were primed to signal the students to the inaccuracies in the statements. Additionally, some students during the interview openly admitted to not knowing the chemistry or not choosing to learn it (n = 13). For example, while discussing the statements about elephant toothpaste, Oliver (senior science major) said, *"I don't know. I'm not an expert in any of these reactions"*, and Merina (senior chemistry major) said, *"I don't know·... Oh man! This is bad because I tutor so often too!"* Students who admitted to choosing not to learn the chemistry include Remy (senior science major) who said, *"It was never a priority of mine to, to know like exactly what's going on."* These quotations support that these students may not have chosen to meaningfully learn the chemistry content and, therefore, support rote learning as a lens that may explain why some students chose to make no comments about the accuracies of some of the statements.

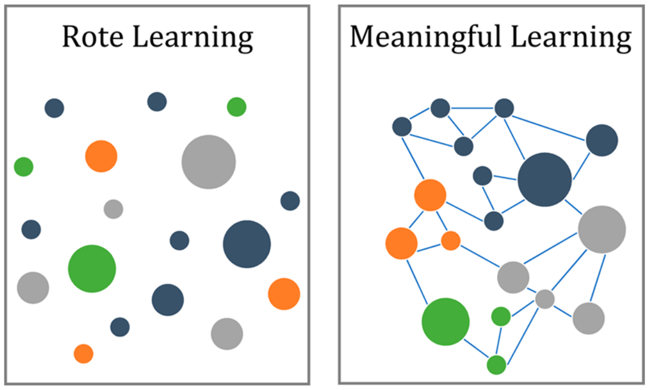

Figure 3. Representation of rote learning vs meaningful learning; individual circles represent unique chemical ideas, and lines represent meaningful connections between ideas.

Last, the data were analyzed for patterns and trends by comparing student responses to school characteristics and student demographics. No patterns or trends emerged from this analysis. The responses were varied, and no individual students were getting every statement right/wrong. Surprisingly, some students were inconsistent even in their own responses. For example, consider statements 5 and 10, which both target the role of a catalyst in the mechanism of the reaction. We would predict that if a student believed that the mechanism did not change upon the addition of a catalyst (i.e., saying statement 5 is incorrect), they would then also say that the catalyst does not convert to an intermediate (i.e., saying statement 10 is incorrect). However, we found that four students were inconsistent and saying statement 5 was correct while statement 10 was incorrect, or *vice versa*. This further supports the rote learning suggested for the no comment responses. If students are not learning meaningfully, then they may not have meaningful connections between related chemical ideas (like a catalyzed mechanism and an intermediate involving the catalyst). Therefore, it would not be surprising if a student did not see the connection between mechanism (statement 5) and forming an intermediate (statement 10), as we see in this study.

RQ 2: Chemistry Understanding of Making Liquid Nitrogen Ice Cream

Student responses to the statements about making liquid nitrogen ice cream are strikingly different than those for the elephant toothpaste reaction (see Figure 2). First and foremost, there was only one instance of a student saying that a chemically correct statement was actually inaccurate (statement 7). In this instance, the student discussed the flow of cold from liquid nitrogen to the ice cream mixture, rather

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than the flow of energy in the form of heat from the ice cream mixture to the liquid nitrogen (see Table 6). For all other chemically correct statements, students either recognized the accuracy of the content or made no comments about the accuracy. This is likely due to the differences in the content embedded in the elephant toothpaste reaction vs making liquid nitrogen ice cream. The elephant toothpaste reaction is a complex reaction involving thermodynamic, kinetic, and catalytic considerations, which are all included in the statements that the students critiqued. Additionally, there are many published misconceptions related to thermodynamics and kinetics illustrating the difficulty students have learning these ideas.[40,45] On the other hand, making liquid nitrogen ice cream does not involve a complex reaction; it is two concurrent phase changes (liquid-to-solid for the ice cream mixture and liquid-to-gas for the nitrogen) due to the transfer of energy between the ice cream and liquid nitrogen. Misconceptions related to phase changes are primarily due to misunderstanding the particulate nature of matter,[46,47] which was not explicitly evaluated in the statements written about making liquid nitrogen ice cream. These content differences, along with the smaller sample of students critiquing the statements regarding making liquid nitrogen ice cream, may explain these performance differences. However, when considering the inaccurate statements related to making liquid nitrogen ice cream, there are still concerns about student understanding that are worth discussing.

For all three chemically inaccurate statements, approximately equal numbers of students indicated that the content was correct and incorrect. For statement 2, which assesses the impact of a solute on a freezing point, seven students indicated that freezing point elevation was chemically correct, while six recognized that it should be freezing point depression. Statement 3 assesses student understanding of the structure−property relationship between intermolecular forces and state of matter; six students indicated that London dispersion interactions were strong interactions, while seven indicated that London dispersion forces between nitrogen molecules are relatively weak. Lastly, statement 6 assesses how temperature changes (or does not change) during a phase change. Three students indicated that temperature increases during a phase change, while only four students knew that temperature remains constant during a phase change. The remainder of the students made no comments about the accuracy of the statement.

The content embedded in all three chemically inaccurate statements is well-aligned with instruction in first-year general chemistry courses. Considering that almost half of the sample evidenced misunderstandings of statements 2 and 3, and over half did not comment on the accuracy of statement 6, instructors and those seeking out these college students to conduct chemistry outreach should be concerned. The assumption that passing a course indicates that students meaningfully learned the content, an assumption challenged by all of the misconceptions literature, is called into question. While an investigation of the type of instruction these college students had is out of the scope of this paper, the fact that these students have outreach goals aligned with teaching and learning, and they themselves evidence misunderstanding of core chemistry content, is alarming. Additionally, further evidence supporting the lens of rote learning/memorization, which may explain the inaccurate ideas and instances of no comments made about the accuracies of statements, is from Neena. As Neena critiqued statement 3 about London dispersion interactions, she said:

> *London dispersion is actually the weakest... I think. Right? It is pretty much the weakest intermo... intermolecular force. I do not even understand why London dispersion is a thing, honestly... I do not really know what it is! I do not know the theory behind it... it has something to do with like... I know that it... increases when the molecules are bigger and slower but I still do not know why it happens. (Neena, junior chemistry major)*

From her quotation, it is clear that Neena knows the fact that London dispersion forces are relatively weak in comparison to other intermolecular forces; however, she admits to not knowing what the interactions are, the theory behind how they occur, etc. This supports that Neena rote learned/memorized facts, but did not meaningfully learn (i.e., did not connect the fact that London dispersion interactions between nitrogen molecules are relatively weak to ideas like polarity, disruption of the electron cloud, or instantaneous and induced dipoles).

Just as with responses to the elephant toothpaste reaction, additional inaccurate ideas were elicited by some of the statements about making liquid nitrogen ice cream (Table 8). While these ideas are idiosyncratic, all additional inaccurate ideas were elicited by *chemically correct statements*; this adds to the rich description of student ideas related to making liquid nitrogen ice cream, supports the task as a successful elicitation tool, and helps to ensure the trustworthiness of the findings. In addition, these additional inaccurate ideas further provide evidence that these upper-division students struggle with thermodynamic concepts (shown by the quotations from Ororo and Helena in Table 8).

Patterns and trends were investigated by comparing student responses to making liquid nitrogen ice cream statements to school characteristics and student demographics. Once again, no patterns or trends emerged from this analysis. While this may be due to the small sample size (n = 15), this also supports the Constructivism/Meaningful Learning[41−44] lens applied to the data. If students are constructing their own knowledge, then it is not surprising that no patterns were found. All of the students had unique backgrounds, came from a variety of institutions, and therefore had varying prior knowledge. The likelihood that students would construct their knowledge in the same way is highly unlikely. Additionally, with the evidence that supports that students may be rote learning/memorizing, the lack of patterns or trends in responses is expected.

■ CONCLUSIONS

Presented in this study is evidence that college student outreach practitioners have misconceptions and misunderstandings related to the the elephant toothpaste reaction and making liquid nitrogen ice cream, despite having previous experience facilitating these activities with children/younger students and passing a college general chemistry course. Specifically for the elephant toothpaste reaction (RQ 1), the majority of the students did not know the products of the reaction, and evidenced published misconceptions related to catalysis and bonding/thermodynamics. For making liquid nitrogen ice cream (RQ 2), the students were more successful in their discussion of chemistry. However, approximately half of the students struggled with the general chemistry concepts

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of freezing point depression and ideas related to intermolecular forces.

Across both activities and investigations of the research questions, students provided evidence that suggests these students are memorizing/rote learning chemistry content during their undergraduate coursework. Considering that the content students discussed was written to align with the level of college general chemistry, and that a majority of the students in the sample were third- and fourth-year undergraduates, this is most concerning. Additionally, these students are in teaching roles during their outreach events and believe that teaching and learning are important goals/success criteria for their events. The fact that these students evidence misunderstandings and common misconceptions (i.e., inaccurate content knowledge) poses concerns about the quality of outreach instruction and what younger students/children may be actually learning during these events.

LIMITATIONS

While these findings suggest a need to look critically at outreach practices and formal instruction of undergraduate chemistry students, this study has several limitations. First and foremost, despite the total sample size (N = 37) being based on data saturation,[27] the subsample sizes for elephant toothpaste (n = 26) and making liquid nitrogen ice cream (n = 15) are small. While this may detract from potential transferability of the findings,[30,31] the increased sample diversity, which has not been seen before in previous in-depth qualitative studies in CER,[28] helps alleviate this concern. Additionally, it is possible that the demographics of the sample do not transfer to all outreach practitioners. Another limitation, as noted in the discussion, is that there were many instances where students chose not to provide comments about the accuracy of some of the statements. While this limits the conclusions that can be drawn about the overall sample, the lack of patterns or trends in responses (including no single students being the ones not providing comments) suggests that the task was mostly successful in eliciting student ideas. This, combined with the elicitation of other idiosyncratic incorrect chemical ideas, adds to the rich description of student ideas and supports the conclusions drawn about student understanding of the elephant toothpaste reaction and making liquid nitrogen ice cream. Lastly, it is important to note the differences in the explanations/prompts between the elephant toothpaste reaction and making liquid nitrogen ice cream. Approximately a third of the elephant toothpaste statements and two-thirds of the liquid nitrogen ice cream statements were chemically correct. This difference in the ratio between chemically correct vs incorrect statements embedded in the critiqued explanations poses limitations in the conclusions that can be drawn from comparing data from elephant toothpaste to that from liquid nitrogen ice cream. Combined with the subsample size differences mentioned above, it is important that readers not draw many conclusions that relate elephant toothpaste findings with liquid nitrogen ice cream findings. Rather, conclusions should be made about student understanding of content underlying elephant toothpaste and liquid nitrogen ice cream separately, aligned with the structure of this paper.

IMPLICATIONS

The findings presented have important implications for teaching and learning in chemistry. Because the sample includes a variety of institutions, and likely instruction types, the prevalence of misconceptions found in this study (including exothermic bond breaking) suggests a need for increased dissemination of the misconceptions literature and curricular reform efforts. Additionally, because of the goal these college student outreach practitioners have of *audience learning* during outreach, a close examination of what children/younger students are actually learning and taking away from their outreach experiences is needed. Outreach planners, including faculty soliciting college student organizations for outreach experiences, must carefully consider their desired goals for outreach events and how those are achieved by those facilitating the events. As teacher content knowledge is related to having the skills to successfully teach the content, the likelihood that younger students/children are actually learning during these events is low. Considering the number of misconceptions these college students may be bringing to their outreach teaching, it is further likely that if younger students/children are learning during these events, they are learning the misconceptions of the college students rather than accurate chemical concepts. Additionally, the assumption that "if a college student passed a course, they know the chemistry content" must be challenged. College students must carefully consider their goals for outreach events, the training they have in teaching and learning, and how well they understand the chemistry embedded in the activities they are facilitating. Becoming aware of the connection between CK and PCK is one step in improving college student training for teaching and learning in outreach, which may help to improve the impacts of their informal chemistry teaching.

For researchers, these findings support expanding qualitative studies to include multiple institutions for increased sample diversity. By increasing the diversity of samples included in investigations of student understanding of chemistry, qualitative studies can shed light on student understanding that crosscut institutional and instructional contexts. Additionally, on the basis of the findings presented in this study, targeted interventions focused on kinetics, thermodynamics, and catalysis implemented across multiple institutions are needed. Last, since these college students focus on their audiences learning chemistry, investigations of younger students/children attending outreach events and the resulting learning are needed. Such investigations are warranted because evidence from formal learning environments suggests that teachers with misconceptions pass them on to their students,[48−51] which likely transfers to instruction in informal settings.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.8b00688.

> Interview guide questions from phase 3 of the interviews focused on understanding of the chemistry content and a table disaggregating sample demographics by pseudonym (PDF, DOCX)

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Supporting Information

College Students Teaching Chemistry Through Outreach: Conceptual Understanding of the Elephant Toothpaste Reaction and Making Liquid Nitrogen Ice Cream

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Portion of semi-structured interview guide

Interview Phase 3: Chemistry Content

Part 1: Open-ended questions

Now I want to talk a little bit more about the specific activities you've done at these events. So according to the volunteer survey, you said you have experience with _________?

(say activity: elephant toothpaste or making liquid nitrogen ice cream)

1) What is the typical age group(s) that you do this activity with?

2) How do you normally perform/do _______ activity?
    a. Is it a demo? Hands-on? What materials do you use?

3) What learning do you expect the participants to gain from this activity?

4) Now I want you to pretend that I'm a *(insert typical audience member here from question 1)* attending your events and you are doing ________, how would you explain it to me?

5) What about for a fellow undergrad? Like a new member joining your organization…How would you explain the chemistry behind ______ to them?

(Repeat questions for all activities they have experience with)

Part 2: Inaccurate explanations

Directions: We've done a lot of these interviews and we've received a lot of different answers for the way different people explain these activities **(some accurate and some inaccurate**). What I want you to do is read some of these explanations and evaluate them for 2 things: **how age appropriate are they** and **how accurate the science is.** We really just want to understand what you think about these activities and get a sense of what is age appropriate so we can help write better explanations, **but it's definitely a mixture of accurate and inaccurate.**

So I'm going to send you a *(Grade Level)* explanation for *(Activity)*. I want you to read through and **go line-by-line** and talk with me about **how age appropriate is it** and **the accuracy of the science.**

Message participant explanations for activities they talked about for the age level they discussed (as well as for general chemistry level)

1) Overall Impression of it in terms of **scientific accuracy**?
   a. Something wrong? Why is it wrong? How would you re-word it?

2) Anything missing from the explanation?

3) Go line-by-line and talk me through each sentence for accuracy?

4) Overall impression of it for **age appropriateness?**
   a. Anything missing from it?
   b. Anything just too much/not age appropriate?

REPEAT FOR MULTIPLE ACTIVITIES AND MULTIPLE AGE LEVELS

Table of demographic information

ET = in elephant toothpaste subsample | **LN_2** = in liquid nitrogen ice cream subsample

Pseudonym	Sex	Year in School	School Size*	School Type	Major	ET	LN_2
Barbara	Female	Senior	Small	Private	Chemistry/Biochemistry	Yes	No
Barry	Male	Junior	Large	Public	Science (non-chemistry)	No	No
Beatriz	Female	Sophomore	Small	Private	Chemistry/Biochemistry	No	Yes
Betty	Female	Senior	Small	Private	Science (non-chemistry)	Yes	No
Bobby	Male	Junior	Large	Public	Chemistry/Biochemistry	Yes	No
Bruce	Male	Grad Student	Medium	Private	Chemistry/Biochemistry	Yes	No
Carrie	Female	Sophomore	Medium	Private	Chemistry/Biochemistry	Yes	No
Charles	Male	Junior	Large	Public	Science (non-chemistry)	No	Yes
Edwin	Male	Senior	Large	Public	Chemistry/Biochemistry	Yes	Yes
Frank	Male	Sophomore	Medium	Public	Non-science	Yes	Yes
Gordon	Male	Senior	Large	Public	Chemistry/Biochemistry	Yes	No
Gwen	Female	Senior	Large	Public	Chemistry/Biochemistry	Yes	No
Harley Quinn	Female	Senior	Medium	Public	Chemistry/Biochemistry	No	No
Harvey	Male	Senior	Medium	Public	Chemistry/Biochemistry	Yes	No
Helena	Female	Sophomore	Small	Public	Chemistry/Biochemistry	Yes	Yes
Jenny	Female	Junior	Large	Public	Science (non-chemistry)	No	No
Jesse	Female	Junior	Large	Public	Science (non-chemistry)	No	No
Johnny	Male	Junior	Large	Public	Chemistry/Biochemistry	Yes	Yes
Kendra	Female	Senior	Large	Public	Non-science	Yes	No
Kitty	Female	Senior	Large	Public	Science (non-chemistry)	Yes	No
Lana	Female	Junior	Large	Private	Chemistry/Biochemistry	No	Yes
Lex	Male	Junior	Medium	Public	Chemistry/Biochemistry	Yes	No
Mary Jane	Female	Sophomore	Large	Public	Chemistry/Biochemistry	No	Yes
Max	Male	Junior	Large	Public	Chemistry/Biochemistry	Yes	Yes
Merina	Female	Senior	Medium	Public	Chemistry/Biochemistry	Yes	No
Neena	Female	Junior	Large	Public	Chemistry/Biochemistry	No	Yes
Oliver	Male	Senior	Large	Public	Science (non-chemistry)	Yes	No
Ororo	Female	Grad Student	Large	Public	Chemistry/Biochemistry	No	Yes
Pamela	Female	Senior	Large	Public	Science (non-chemistry)	No	Yes
Pepper	Female	Senior	Small	Public	Chemistry/Biochemistry	Yes	Yes
Reggie	Male	Junior	Medium	Public	Chemistry/Biochemistry	Yes	Yes
Remy	Male	Senior	Large	Public	Science (non-chemistry)	Yes	No
Shayera	Female	Senior	Large	Public	Chemistry/Biochemistry	Yes	No
Steve	Male	Senior	Medium	Public	Chemistry/Biochemistry	Yes	Yes
Sue	Female	Senior	Large	Public	Science (non-chemistry)	Yes	No
Thor	Male	Senior	Large	Public	Science (non-chemistry)	Yes	No
Vance	Male	Senior	Medium	Private	Chemistry/Biochemistry	Yes	No

*School size classification: **small** < 5,000 students; **medium** 5,000–15,000 students; and **large** > 15,000 students

“You Lose Some Accuracy When You're Dumbing It Down”: Teaching and Learning Ideas of College Students Teaching Chemistry Through Outreach

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ABSTRACT

College students associated with American Chemical Society and Alpha Chi Sigma student/collegiate chapters reach almost 1 million people every year through their informal chemistry education events (chemistry outreach). Previous work has characterized their goals for chemistry outreach, with the most prevalent goal being audience learning. With such large audiences being impacted every year and the goal of audience learning, investigating how these college students approach teaching in informal environments is needed to further understand chemistry outreach practices. Presented in this paper are the results of inductive coding focused on teaching beliefs expressed by these college students as they discussed elephant toothpaste and making liquid nitrogen ice cream for 2nd graders, 8th graders, and general chemistry students. Results indicate three broad categories of beliefs: 1) beliefs about the audience, 2) beliefs about the teaching process/pedagogy, and 3) beliefs about the scope and sequence of the content. While some beliefs are supported by literature on teaching and learning, some of the expressed beliefs are contrary to learning theories and these outreach practitioners' goal of audience learning. Implications for outreach education are presented in light of these findings, as well as potential future investigations of the teaching and learning in chemistry outreach.

GRAPHICAL ABSTRACT

KEYWORDS

Chemical Education Research, Outreach, General Public

INTRODUCTION

Informal Chemistry Education and Chemistry Outreach

Teaching and learning can be parsed into two instructional-context categories: formal environments (*i.e.,* classrooms) and informal environments (*i.e.,* outside of a classroom). Chemistry education research (CER) has primarily focused on teaching and learning in formal environments. However, over 80% of K-12 learning occurs in informal environments, and greatly increases once a student progresses beyond K-12.[1] Informal science education environments encompass a variety of contexts, including everyday experiences, interactions with the media, and museums/zoos/aquariums.[1,2] Added complexity to informal education is the variety of strands of learning/learning goals that informal environments target. These include, sparking interest and excitement, understanding scientific content and knowledge, engaging in scientific reasoning/scientific practices, reflecting on science and understanding of natural phenomena, using the tools and language of science, and identifying with the scientific enterprise.[1,3] The diversity of learning goals and duration makes informal teaching and learning a ripe area for CER.[4,5]

While interest in investigating general science informal education has been growing since 2009,[1,3] chemistry-specific informal science education research only recently became a national focus in the U.S. through a 2016 National Academies report.[6] This 2016 report, titled *Effective Chemistry Communication in Informal Environments,* studied the informal chemistry education (ICE) practices of professional chemists, including their goals for their events and chemistry content typically addressed. Despite this investigation, the National Academies' 2016 report excluded the viewpoints of a group responsible for frequently providing ICE – college students. College students affiliated with the professional chemistry organizations American Chemical Society (ACS) and Alpha Chi Sigma (ΑΧΣ) reach almost 1 million people every year through their ICE events (termed *chemistry outreach*).[7,8] With such a large number of people being impacted by collegiate chapters of ACS and ΑΧΣ, targeted investigations of their chemistry outreach practices were necessary. This prompted the development and analysis of a survey to characterize outreach practices of this college student population.[9] Results indicated that college students have a variety of goals for their chemistry outreach, but most prevalently discuss audience *learning chemistry content* during outreach events (*i.e.*, aligned with the informal science learning goal of *understanding scientific content and knowledge*). Other goals include audience *learning that science is fun*, *developing curiosity*, and *having fun/enjoying themselves*.[9] Additionally, results indicated that two activities are prevalently facilitated by members of these organizations: *the elephant toothpaste reaction* (catalyzed decomposition of hydrogen peroxide)[10,11] and *making liquid nitrogen ice cream*.[12,13]

It is useful to examine teaching and learning in outreach, since college students most frequently discussed *audience learning* as part of their chemistry outreach. While the chemistry education literature contains many publications discussing outreach, such works emphasize sharing ideas and procedures (*e.g.*, procedures for demonstrations, models for camps) rather than investigations of outreach outcomes or efficacy measures.[14–21] However, Fusion Science Theater (FST) is an exception. FST has investigated audience learning during demonstration shows implemented using a specific format incorporating storytelling, modeling, and assessment.[22–25] Their investigations illustrate that scholarly investigations of chemistry outreach are possible, and that audience learning is achievable and measurable. Recently, publications have started to incorporate evaluations of outreach including event attendees' perceptions of event implementation, the facilitators, and perceived gains.[26–28] Despite such reports, there are few investigations that focus on college students associated with ACS and ΑΧΣ. Since these college students assume teaching roles during their outreach (and express cognitive learning goals for event attendees), examining how college students perceive themselves in teaching roles can give insights into the teaching process (and hopefully the learning) that can occur during chemistry outreach. With little literature in informal science education focused specifically on teachers and facilitators, it is necessary to use findings from formal learning environments to shed light upon college student outreach practitioners' perceptions. One lens that has been shown to be useful in the examination of teaching and learning in formal education environments is teacher beliefs. Adopting this construct to study outreach practitioners is productive, since college students assume teaching roles when they facilitate outreach events, and most frequently discuss *audience learning* as their goal for events.

Teacher Beliefs

Since the mid-1980s, education researchers have discussed the importance of investigating the beliefs educators have when studying classroom practice.[29] Many studies about practice describe the beliefs construct, including attitudes, values, opinions, and judgments.[30] Despite these various ways beliefs have been discussed in the literature, it is well accepted that science teachers' beliefs impact their instruction and student learning.[29-43] Based on nearly three decades of research, the scholarly community has adopted a set of assumptions about teacher beliefs,[37] including:

1. Beliefs are more influential than content knowledge in making teaching decisions.
2. Teachers may have competing beliefs about the same idea.
3. Beliefs are structured into a framework and are not independent from each other.
4. A change in one belief likely affects the entire belief system.
5. Some beliefs are more strongly held and may be resistant to change.

One goal of teacher education is to help future teachers develop beliefs aligned with research and best practices (*e.g.,* adopting student-centered beliefs). However, previous experiences as students in the classroom (both in K-12 and college) heavily influence beliefs that future teachers develop.[34,44–47] In fact, students develop beliefs about effective teaching prior to entering college.[30,47–50] The issue comes with the static, unchanging nature of beliefs (*i.e.,* assumption #5 above).[37] Once a student develops a teaching/learning belief, it is difficult to change. Future teachers may then experience dissonance as they try to implement practices from their education courses that are not aligned with their beliefs.[51] Dissonance resolved in favor of old beliefs can lead to teachers' believed practices differing from their implemented ones (*i.e.,* saying they use student-centered approaches when they actually use teacher-centered approaches).[51] Since many studies conclude that educators' beliefs greatly influence their teaching and student learning, investigating teaching beliefs of informal educators is warranted. However, for college students assuming teaching roles in outreach, no studies have investigated the teaching/learning beliefs these outreach educators bring to their events. This is of particular concern since college students most frequently indicate that *audience learning* is their goal for outreach.[9] Since college student outreach practitioners develop teaching and learning ideas from their previous experiences as students, characterizing and understanding their various beliefs about teaching/learning that may impact the outcomes of their outreach is necessary and motivated the study herein.

RESEARCH QUESTION

This study seeks to address the following research questions as they pertain to ACS and AXΣ college student outreach educators:

1. What beliefs about teaching and learning were expressed by college student outreach practitioners?
2. How do college students' teaching and learning beliefs about outreach vary (if at all) depending on audience age level?

METHODS

This study was part of an Institutional Review Board approved investigation of college students' chemistry outreach practices. Semi-structured interviews[52] were conducted throughout spring 2016 to spring 2017 with college students associated with ACS and AXΣ student chapters in the U.S. Because this population was geographically diverse, multimedia-based programs (*e.g.*, Skype, Google Hangouts) were used for interviews and collecting audio data. The interview protocol had four phases: 1) demographics and purpose(s) of outreach, 2) criteria for successful events, 3) understanding of chemistry content and ideas about teaching aligned with outreach activities, and 4) training and skills development. The method was shown to be effective and generate trustworthy data and conclusions.[53,54] To address the research questions herein, only data pertaining to phase 3 will be presented. A previous study by the authors also analyzed phase 3 data by focusing on college students' understanding of chemistry content. Findings showed that these college student outreach practitioners express previously published and novel misconceptions related to the thermodynamics and kinetics underlying elephant toothpaste (ET) and making liquid nitrogen ice cream (LN_2).[54]

Sample

Students from ACS and AXΣ chapters were recruited using multiple methods, including in-person recruitment with flyers and emails to gatekeepers (*e.g.,* faculty advisors, department chairs, chapter presidents). These efforts resulted in 37 college student outreach practitioners from 22 geographically diverse institutions across the U.S. being sampled and interviewed. These institutions ranged from small, primarily undergraduate institutions to large, research-intensive institutions, including both public (n = 17) and private (n = 5) institutions. The efficacy of the sampling and interview procedures were established by previous analyses.[53]

Shown in Table 1 are detailed student demographics for the sample. Since the study purposefully targeted ACS and ΑΧΣ chapter members with previous experience conducting chemistry outreach, the sample was primarily composed of upper-division chemistry/biochemistry majors. However, the added diversity of non-chemistry/biochemistry majors is representative of the goals of the national ACS and ΑΧΣ organizations who target those *interested* in pure and applied chemistry. Additionally, students' outreach goals align with previous findings[9] including *teaching chemical concepts* (n = 31), *audience learning chemical concepts* (n = 31), and *presenters giving good explanations of the chemical concepts* (n = 35). Obviously, this sample's emphasis on teaching and learning during chemistry outreach aligns with previous findings from a national survey[9] of the same population, and supports college student outreach practitioners as a distinct population from those studied by the National Academies in 2016.[6] It further supports investigating this sample's teaching beliefs, since they heavily emphasize teaching and learning during their outreach.

Table 1. Student demographic information (N = 37)

Sex	Students, n	Major	Students, n	Year in school	Students, n
Female	20	Chemistry or biochemistry	22	Sophomore (second year)	5
Male	17	Science (non-chemistry)	11	Junior (third year)	11
		Non-science	2	Senior (≥ fourth year)	19
		Chemistry graduate student	2	Graduate student	2

Investigating and Analyzing Ideas about Teaching and Learning

Students were asked to describe the ways they facilitate and teach ET and/or LN_2 (*i.e.,* open-ended discussion). Additionally, students critiqued explanations written for 2nd graders (7-8 years old), 8th graders (13-14 years old), and college general chemistry students for the accuracy of the content and the age appropriateness of the descriptions. To address the research questions herein, student responses from the open-ended discussion and to the critique of explanations related to age appropriateness were analyzed. An analysis of their understanding of the chemistry content has been previously reported.[54]

Of the 37 students interviewed, 34 discussed ET and/or LN_2. To characterize these 34 students' teaching and learning ideas, interviews were transcribed verbatim, pseudonyms were randomly assigned (describing only the gender of the participant), and a content analysis was performed.[52,55] Given the lack of literature focused on the teaching and learning beliefs of college students assuming teaching roles, inductive/open coding was conducted[52,56] using constant comparative analysis.[57] The qualitative data analysis software Dedoose was used to manage data and conduct the analysis.[58]

To develop the codebook, data were subdivided by activity (LN_2 or ET) and by audience level (2nd grade, 8th grade, or general chemistry) to capture differences in teaching/learning beliefs aligned with content and/or audience level. The preliminary analysis was first conducted independently by the first author solely on the LN_2 data. Through weekly debriefing sessions with both authors, these initial codes were revised, and unique cases were discussed. Additionally, the authors collaboratively grouped codes into categories that crosscut audience level. These revised teaching/learning codes and categories were then tested on the ET data. While the majority of the codes/categories functioned well, unique content-specific ideas about LN_2 and/or ET emerged. To ensure consistency in code interpretation and application, the second author independently applied the full codebook to a representative student who discussed both LN_2 and ET. The two authors then compared code applications and negotiated disagreements. The revised codes/categories were then reapplied to the full data corpus. Counts were calculated to determine the prevalence of codes (teaching/learning beliefs) in the data. The full codebook and a discussion regarding trustworthiness of conclusions are in the Supporting Information.

RESULTS AND DISCUSSION

Two categories transcended all three audience levels: Beliefs about the Teaching Process/Pedagogy and Beliefs about the Scope and Sequence of Content. A third category surfaced only for 2nd grade and 8th grade: Beliefs about the Audience (*i.e.,* Beliefs about 2nd Graders and Beliefs about 8th Graders). Given these differences, the teaching/learning ideas are presented disaggregated by audience level.

2nd Grade

For teaching and learning beliefs associated with 2nd graders, three categories of ideas emerged: 1) Beliefs about 2nd Graders, 2) Beliefs about the Teaching Process/Pedagogy and 3) Beliefs about the

Scope and Sequence of Content (Table 2). The most prevalent belief about 2nd graders was that they *will not care about the accuracy of the content.* Since the explanations students critiqued included inaccurate chemical ideas, this belief stemmed from students recognizing an inaccuracy but not correcting it, because 2nd graders would not know. This belief is best embodied by Mary Jane when discussing an inaccurate idea related to heat, *"I don't really think a 2nd grader's going to care"* (Mary Jane, sophomore chemistry/biochemistry major). Max also expressed this idea when referring to an inaccuracy about the particulate nature of matter: *"Most likely they're not gonna really care too much about the science behind it"* (Max, junior chemistry/biochemistry major). Another belief about 2nd graders was that they have *short attention spans*. This belief was expressed as students considered the depth of content presented. One example is Barbera who said, *"If I was a 2nd grader, I would not pay attention to any of this"* (Barbera, senior chemistry/biochemistry major). The remaining beliefs about 2nd graders were idiosyncratic. However, they illustrate that college students assuming teaching roles bring varying ideas about 2nd graders to their events, including that they will *only retain a few vocabulary words* and that *complex chemical ideas* are appropriate.

Table 2. Beliefs about teaching and learning aligned with a 2nd grade audience

Category	Code/Teaching and Learning Belief	Students (*n*)
Beliefs about 2nd Graders	2nd graders will not care about accuracy of content	9
	Kids have short attention spans	7
	Kids can understand complex chemical ideas	3
	Kids only retain a few vocab words	1
Beliefs about the Teaching Process/Pedagogy	Context is a valuable teaching tool	25
	Use of fake, implausible context	11
	Need to use representations/drawings	7
	Need to talk about atomic particles	6
	Need to use numbers/quantitative ideas	4
Beliefs about the Scope and Sequence of Content	OK to teach wrong content	15
	Anthropomorphism is a useful teaching tool	14
	Assumption about prior knowledge	11
	Need to use scientific terms	11
	NOT OK to teach wrong content	9
	Do not discuss chemistry content	8
	Do not use scientific terms	6
	Should be fun/attention grabbing	4
	Content must be dumbed down enough	3

Content ideas tied to specific demonstrations	6
Need to teach catalysis (ET)	4
Need more advanced chemistry to understand (LN_2)	1
Teach green chemistry ideas (ET)	1
Liquid nitrogen ice cream is a reward (LN_2)	1

The second category of beliefs focused specifically on the teaching process. The most prevalent belief about 2nd graders was *context is a valuable teaching tool* (*n* = 25). This belief focused on incorporating examples from everyday life or *"something that they can relate [to]"* (Helena, sophomore chemistry/biochemistry major). The college students also emphasized 2nd graders connecting content to prior experience. For example, Betty focused on helping 2nd graders understand the gas production of ET by relating it to their experience: *"Gases are invisible, that's a good concept...you can apply that too...saying like, we're breathing gases all the time [but] we can't see them"* (Betty, senior science/non-chemistry major). The prevalence of the *context is a valuable teaching tool* belief is positive, given the emphasis on context in the Next Generation Science Standards (NGSS) and the literature that encourages using context to help students apply concepts to their everyday lives.[59,60] Contrary to literature recommendations, however, eleven students discussed a *fake, implausible context* when referring to ET. All eleven students discussed a context where a pet elephant needs toothpaste. An excerpt from Sue shows this: *"We usually name him Jeffery the Elephant, and he's been eating a lot of nasty onions lately, so he really needs to brush his teeth. But the thing is...toothpaste is really expensive, so we decided to make some of our own"* (Sue, senior science/non-chemistry major). The use of fake context likely lies with the name of the demonstration (Elephant Toothpaste), as well as the ACS's electronic resource that discusses an elephant named Bruno needing toothpaste.[61] No matter the cause, while it is positive that these students support using context to foster learning, choosing an implausible context is contrary to such a goal. All of the remaining beliefs about the teaching process are idiosyncratic, but they illustrate how the college students focus on incorporating *representations/drawings*, *atomic particles*, and *numbers* as teaching tools to help students learn. This is supported by the teacher beliefs literature: Experiences as chemistry students (where representations, particles, and numbers are typically used) influence beliefs about teaching and learning.[34,44–47]

The remaining category of beliefs aligned with 2nd graders is Beliefs about the Scope and Sequence of Content. These focus specifically on the chemistry content that should be taught. The most prevalent belief is *OK to teach wrong content*. This belief, similar to *2nd graders will not care about the accuracy of the content*, was elicited by the inaccurate ideas embedded in the critiqued explanations. In these instances, students recognized inaccurate content, but then said it was "ok" for 2nd graders. An exchange between Remy (senior science/non-chemistry major) and the interviewer, discussing the inaccuracy of particles growing during a liquid-to-gas phase transition, shows this belief:

> Remy: *The part where they said, 'when the particles become gas they grow and become larger taking up more space.' I- I can see what they're doing there, they're trying to phrase it in a way that kids understand, right...although I don't think that's scientifically true...I, I think if I had to explain it to a second grader I probably would say something like that...because in a lot of ways the demonstration looks like you're making a lot of something from a - very little nothing.*
>
> Interviewer: *So it's not necessarily scientifically accurate, but because it's a second grader it's the best way to get them to understand?*
>
> Remy: *Yeah, and I think sometimes that trumps. Um, as long as the science isn't like blatantly incorrect, um, I think sometimes it's better to get them to understand rather than really hammer the details.*

Through this exchange, Remy understands that the chemical idea is incorrect, but he makes the judgement that it is *OK to teach the inaccuracy* to help 2nd graders understand, because it does not *"hammer the details."* Shayera justified her choice in teaching inaccurate chemistry because of the nature of simplifying concepts for the age level: "*See the problem is...you lose some accuracy when you're dumbing it down"* (Shayera, senior chemistry/biochemistry major). This *OK to teach wrong content* belief is concerning considering that it is the most prevalent Belief about the Scope and Sequence of Content for 2nd graders (n = 15), and these college student practitioners report one of their outreach goals is *audience learning*.

Another prevalent content belief is *anthropomorphism is a useful teaching tool* (n = 14). This was detected when students gave examples that incorporated anthropomorphism, and specifically stated that using anthropomorphism helps make explanations age appropriate. For example, Edwin discussed a statement from the explanation using anthropomorphism to explain the freezing process of LN_2 (statement underlined in quote for reference): *"<u>When something gets really cold it stops moving and shivers in place.</u> That is an appropriate second grade level...explaining why it goes from a liquid to a solid"* (Edwin, senior chemistry/biochemistry major). Merina used anthropomorphism to explain why gas molecules expand in ET, *"They have more energy and they're err…all over the place and they're just…running around like crazy people…because of that they kind of…just go all over the place"* (Merina, senior chemistry/biochemistry major). The prevalence of this idea is concerning because college students support *audience learning* as a goal for outreach, and yet literature suggests that anthropomorphism actually promotes misconceptions and misunderstandings.[62]

College students also made *assumptions about the prior knowledge* of the 2nd graders (n = 11) when discussing content. This was detected when college students assumed what 2nd graders are able to understand based on what they *think* is taught in school. A quote from Charles related to phase changes and LN_2 illustrates this: "*I never normally use like…phase change, like with the kids that I'm usually dealing with cause I feel like that's like too…advanced for them...they really haven't covered that kind of in like...elementary schools"* (Charles, junior science/non-chemistry major). A similarly prevalent idea (n = 11) was an emphasis on *using scientific terms* (reactants, products, reaction, and actual chemical names). Frank's quote best summarizes this, *"We want to use science-y terms"* (Frank, sophomore non-science major).

Other less prevalent beliefs include those who think it is *NOT OK to teach wrong content* (n = 9), those who think you should *not discuss chemistry content* at all with 2nd graders (n = 8), and those who think you should *not use scientific terms* (n = 6). Additionally, a less common (yet alarming) belief is that the *content must be dumbed down enough* (n = 3). Frank saying *"I do feel that that's very age appropriate. That's [a] very dumbed-down explanation"* (Frank, sophomore non-science major) is an example of students indicating that making chemistry age appropriate means 'dumbing' the content down. Alternatively, both Helena and Lana indicated that 'dumbing it down' means being *"not so* *scientific"* (Lana, junior chemistry/biochemistry major) or *"not hardcore chemistry"* (Helena, sophomore chemistry/biochemistry major). Given goals aligned with cognitive learning, college student outreach practitioners approaching teaching 2nd graders as dumbing down content or making content not scientific suggests that audiences may not be learning chemistry content at all. Combined with prevalent ideas of *OK to teach wrong content* and *anthropomorphism,* teachers requesting outreach events (and event attendees) should question what impact these events are having.

The remaining beliefs are unique ideas associated with content embedded in ET and LN_2. While these ideas are idiosyncratic, they help illustrate the variety of beliefs these students have about content appropriate for 2nd graders. Of particular concern is the belief that it is important to *teach catalysis* to 2nd graders, even though NGSS does not even mention atoms/molecules until middle school level disciplinary core ideas are presented.[59]

8th Grade

Like the 2nd grade audience findings, beliefs about teaching and learning associated with an 8th grade audience fell into three categories: 1) Beliefs about 8th Graders, 2) Beliefs about the Teaching Process/Pedagogy, and 3) Beliefs about the Scope and Sequence of Content. A table of the individual beliefs is in Table 3. Overall, the number of students who expressed teaching/learning beliefs related to 8th graders was lower than the number for 2nd graders. However, despite the lower frequencies, the individual codes/teaching and learning beliefs are similar to those found for 2nd graders.

For Beliefs about 8th Graders, a similar idea was found that *8th graders will not care about the accuracy of the content,* thus justifying not correcting chemical inaccuracies. However, ideas about 8th graders that differ from ideas about 2nd graders include *8th graders do not like science* and *particles are too hard for 8th graders to understand.* While these ideas are idiosyncratic, they show how college students assuming teaching roles bring audience-focused beliefs that can impact teaching choices. For example, Barbara discussed 8th graders not liking science based on her own experience: *"In 8th grade…I still didn't even want to…I liked science, but I didn't know I wanted to do science. I feel like a lot of people didn't even like science"* (Barbara, senior chemistry/biochemistry major). Barbara's use of her previous experience as a student supports findings from the teacher beliefs literature that experiences as a student impact the teaching ideas developed.[34,44–47]

More differences were identified when examining Beliefs about the Teaching Process/Pedagogy. Not surprisingly, beliefs crosscutting both 2nd and 8th grade audiences include *using representations*, *talking about atomic particles*, and *using numbers/quantitative ideas*. This further supports that experiences as college students in chemistry courses shape how they approach teaching in outreach. Additionally, believing that *context is a valuable teaching tool* also surfaced when discussing 8th graders. However, the frequency of discussing *fake, implausible contexts* diminished (n = 1). Such results suggest that college students view 2nd graders and 8th graders differently (*e.g.*, using a 'context' of an elephant needing toothpaste was more prevalent with 2nd graders than 8th graders).

Table 3. Beliefs about teaching and learning aligned with an 8th grade audience

Category	Code/Teaching and Learning Belief	Students (n)
Beliefs about 8th Graders	8th graders will not care about accuracy of content	3
	8th graders do not like science	1
	Particles are hard for 8th graders to understand	1
Beliefs about the Teaching Process/Pedagogy	Context is a valuable teaching tool	12
	Use of fake, implausible context	1
	Need to use representations/drawings	8
	Need to talk about atomic particles	6
	Need to use numbers/quantitative ideas	4
	Value understanding audience prior knowledge	3
	If you tell them, they learn it	1
	Analogies do NOT explain concepts	1
Beliefs about the Scope and Sequence of Content	OK to teach wrong content	16
	Assumption about prior knowledge	11
	NOT OK to teach wrong content	10
	Anthropomorphism is a useful teaching tool	9
	Need to use scientific terms	9
	Content ideas tied to specific demonstrations	4
	Need more advanced chemistry to understand (LN_2)	3
	Need to teach catalysis (ET)	2
	Catalyst are NOT age appropriate for 8th graders (ET)	1
	Teach green chemistry ideas (ET)	1

Interestingly, three unique teaching process/pedagogy beliefs were detected when practitioners discussed 8th graders as compared to 2nd graders. These include *valuing understanding audience prior* *knowledge*, expressing the idea that *if you tell them they learn it*, and saying that *analogies do NOT explain concepts*. Once again, these ideas were expressed in lower frequency (three or fewer participants). However, they shed light on the unique teaching ideas these college students have. While the discussion of 2nd graders included different *assumptions about their prior knowledge*, the discussion of 8th graders involved how valuable it is to assess/*understand prior knowledge*. Pamela expressed this idea when considering how in-depth to explain the chemistry: *"So I think like an effective science outreach...it's critical that it really like assesses like...what...they know [and] what they're able to learn*" (Pamela, senior science/non-chemistry major). This belief is a positive finding considering the literature on teaching and learning emphasizes the impact of prior knowledge on learning.[63–65] However, this is contrasted against the *if you tell them, they learn it* belief: *"If you teach that to 8th graders, they'll...remember it"* (Carrie, sophomore chemistry/biochemistry major). This belief is completely contrary to constructivist learning theories emphasizing prior knowledge as a key factor for learning.[63–65] These two opposing beliefs articulated by college student outreach educators further illustrates the diversity of teaching beliefs being brought to outreach. Additionally, it suggests that meeting outreach goals of *audience learning* may have sparse success if college students' ideas about learning are not aligned with how students actually learn.

The last category of beliefs is Beliefs about the Scope and Sequence of Content. Surprisingly, all ideas about content expressed for an 8th grade audience match ideas expressed for 2nd graders. This includes those not aligned with *audience learning* goals and literature on teaching and learning, like *OK to teach wrong content* and *anthropomorphism is a useful teaching tool*. Even more striking is that the most prevalent content belief, once again, is *OK to teach wrong content* (n = 16). While some students countered this popular belief with *NOT OK to teach wrong content* (n = 10), more students indicated that it was acceptable to teach inaccurate content. Once again, this calls into question whether or not audiences are learning during outreach events and how accurate the content they are actually learning is. Additionally, more unique ideas were expressed that aligned with content underlying the specific demonstrations (LN_2 or ET). Although idiosyncratic, the contradicting ideas of *need to teach catalysis* to 8th graders (n = 2) and *catalysts are NOT age appropriate for 8th graders* (n =

1) are noteworthy. These contrasting ideas further illustrate the striking lack of consensus these college students have about outreach teaching and learning.

General Chemistry

Beliefs about teaching and learning aligned with general chemistry students are in Table 4. The most obvious difference for beliefs at this level, as compared to 2nd and 8th grade, is that there were no beliefs about the audience. All of the beliefs expressed by participants when discussing general chemistry students were focused on the Teaching Process/Pedagogy and the Scope and Sequence of the Content. This may suggest that as the level of the audience approaches that of the outreach educator, beliefs about the audience as students/learners go away. Instead, the emphasis is placed on teaching methods and content. In addition, there were fewer beliefs expressed overall, as compared to 2nd and 8th grade audiences. This may be due to evidenced misunderstanding of the chemistry content impeding discussion about teaching and learning,[54] or lower confidence in discussing teaching an audience very similar to themselves (only a one to three year difference).

When examining Beliefs about the Teaching Process/Pedagogy in Table 4, it is not surprising that *need to use representations/drawings, need to use numbers/quantitative ideas,* and *need to talk about atomic particles* were expressed. These three teaching process/pedagogy beliefs surfaced no matter the audience level discussed. Additionally, since representations, numbers, and particles are prevalent in the college general chemistry curriculum, it is not surprising that these outreach educators support using these to teach a general chemistry audience. However, there were two unique teaching process/pedagogy beliefs that were uncovered for general chemistry students, including *explanations need to be short* and *need to teach to learning style*. Bobby discussed the need for short explanations by comparing demonstrations to lectures: *"I feel like that's... more of a lecture kind of explanation...not an...explanation if you're trying to do it in front of an audience who's here just to see the demo"* (Bobby, junior chemistry/biochemistry major). Kitty further expanded on the idea by specifically referring to length: *"The whole point is keep your audience engaged...you want this [explanation] to be at least half the size"* (Kitty, senior science/non-chemistry major). This focus on length may be due to two competing outreach purposes – *audience learning* and *audience having fun/enjoying themselves* – both of which were prevalent ideas discussed in a survey of the same population.[9] The other unique belief about the teaching process/pedagogy was *need to teach to learning style*. Merina specifically discussed wanting to *"cover all your bases as far as learning styles go"* (Merina, senior chemistry/biochemistry major). Steve, on the other hand, used himself to justify this belief, *"I'm a very visual learner myself. I think just about nearly everyone is. It's a lot easier to learn and remember things, if you can see them. That's why a lot of our demos use pretty colors because it's…easier to remember"* (Steve, senior chemistry/biochemistry major). These quotes suggest that personal or private empiricism[66,67] may be the cause of these teaching beliefs (*i.e.,* beliefs derived from personal experience not literature or theory). In fact, literature suggests that learning styles are a myth, and that instruction tailored to learning styles lacks experimental evidence for improved learning.[68–71] This once again calls into question the impact of outreach if teaching beliefs/practices are not aligned with well-accepted learning theories.

Table 4. Beliefs about teaching and learning aligned with a general chemistry audience

Category	Code/Teaching and Learning Belief	Students (*n*)
Beliefs about the Teaching Process/Pedagogy	Need to use representations/drawings	9
	Need to use numbers/quantitative ideas	5
	Need to talk about atomic particles	3
	Context is a valuable teaching tool	2
	Explanations need to be short	2
	Need to teach to learning style	2
Beliefs about the Scope and Sequence of Content	Assumption about prior knowledge	24
	Do not use/use less scientific terms	2
	Need to use/use more scientific terms	2
	Content ideas tied to specific demonstrations	12
	Liquid nitrogen ice cream should just be fun/social (LN_2)	11
	Need more advanced chemistry to understand (ET and LN_2)	8
	Not important, superfluous, extraneous (LN_2)	6
	Need to focus on ice cream NOT nitrogen (LN_2)	4

The final category of beliefs aligned with a general chemistry audience is Beliefs about the Scope and Sequence of Content. Once again, there is a strikingly lower number of beliefs expressed by participants for this audience level (only four beliefs). However, the most prevalent idea was *assumption about prior knowledge*. Much like responses for 2nd and 8th graders, participants made claims about what general chemistry students should already know and/or be able to learn. For example, Ororo discussed whether or not she should explain the difference between exothermic and endothermic reactions when discussing ET: *"I guess you could probably…I mean they have a better...understanding of what an exothermic or endothermic reaction is…I guess. So I feel like you wouldn't even have to explain something like that."* (Ororo, chemistry graduate student). Bruce further illustrates this belief, *"We don't do very much of…uhm…the background because...we're trying to put on…good shows...[and] they…will…understand [it] already"* (Bruce, chemistry graduate student). Clearly, these outreach practitioners make many assumptions about what a general chemistry audience already knows to justify what/how they teach.

Other unique content-related beliefs were those that are *tied to specific demonstrations*. Of note is the idea that *liquid nitrogen ice cream should just be fun/social.* Neena best exemplifies this idea, *"I think our primary purpose is just like social. It's…I don't think any college student's going to change their major because of a liquid nitrogen event. So like...it's mostly just...fun…it's not educational in nature; [we] never use it educationally"* (Neena, junior chemistry major). While expressed only by eleven participants, the finding suggests that overarching outreach beliefs (like *audience learning* and *having fun*) may be tied to specific demonstration/activities. Another belief worth noting is *need more advanced chemistry to understand*, expressed for both ET and LN_2. While the explanations students critiqued were written using age-appropriate content/depth,[53] students in this sample believed that more in-depth chemical ideas (*i.e.,* organic or physical chemistry) were needed to help students understand. One example stated that ideas related to catalysts changing mechanisms were organic chemistry ideas, and not appropriate for general chemistry students: *"But 'mechanistic pathway' is like...something you learn in like...cause you don't learn how a catalyst helps a reaction move in gen. chem....as far as I remember. But like...I remember learning that in like o-chem...that I don't think is really at the right level"* (Kendra, senior non-science major). Additionally, this included phase transitions and boiling were physical chemistry ideas, not general chemistry: *"I don't actually remember what the explanation for boiling was before physical chemistry"* (Reggie, junior chemistry/biochemistry major). The boundaries college students place between general chemistry topics and more advanced topics are unclear and may be due to lack of training on what content is appropriate for general chemistry students, as well as resulting from evidenced misunderstandings of the chemistry concepts themselves.[54] Additionally, what was *not* found for a general chemistry audience, including beliefs contrary to *audience learning* goals such as *OK to teach wrong content* and *anthropomorphism*, is of interest. The more advanced/older the audience, the less applicable these teaching strategies/beliefs may become.

CONCLUSIONS

Presented in this study is evidence that college students assuming teaching roles in chemistry outreach have a variety of beliefs. Specifically, for research question 1, we see three broad categories of teaching/learning beliefs: 1) beliefs about the audience, 2) beliefs about the teaching process/pedagogy, and 3) beliefs about the scope and sequence of the content. Some beliefs are aligned with learning theories and literature recommendations (*context is a valuable teaching tool* and *valuing understanding audience prior knowledge*), while many beliefs are contrary to *audience learning* goals (*OK to teach wrong content*, *2nd & 8th graders will not care about the accuracy of content*, and *anthropomorphism is a useful teaching tool*).

Research question 2 focuses on differences in beliefs based on audience. While there are some beliefs that crosscut all three audience levels (*e.g.*, *need to use representations/drawings, numbers/quantitative ideas,* and *atomic particles)*, there are some noteworthy differences. The greatest difference is the number of unique teaching/learning ideas; many ideas are expressed for 2nd graders, and this number gradually decreases moving from 8th graders to general chemistry students. Additionally, beliefs aligned specifically with the audience members were only expressed for the lower levels, not for general chemistry students (*i.e.*, *beliefs about 2nd graders/8th graders*). Lastly, some ideas became less prevalent moving from talking about 2nd graders to general chemistry students, including *use of fake, implausible context* and believing that it is *OK to teach wrong content.* Despite these differences, it is clear than many beliefs stem from either personal or private empiricism[66,67] or from experiences as a chemistry student. No instances in which participants specifically state the use of theory or literature to support their beliefs were in the data corpus. Overall, the diversity of ideas expressed shed light on the lack of uniformity in outreach notions, and likely implementation. In fact, some beliefs pose concerns about the quality of outreach education and what younger students/children may actually be learning at events.

LIMITATIONS

While these findings shed light on outreach practices and suggest a critical examination of potential outreach impacts, there are some key limitations. First and foremost, while the total sample size (N = 37) was based on data saturation,[52] only 35 participants were included in this analysis. This is because of the necessity for participants to have previous experience teaching ET and/or LN_2. Despite this smaller sample, the diversity of the participants minimizes this concern. Additionally, the prompt asked students to consider how age appropriate previously written explanations were for 2nd graders, 8th graders, or general chemistry students.[53] It did not specifically probe teaching beliefs or the underlying rationales of such beliefs. All student discussions were by-products of their considerations of the content's appropriateness for the audience. This explains the lower sample sizes for individual beliefs. However, the fact that these ideas emerged from the data and were robust when subjected to multiple trustworthiness considerations (*e.g.*, interrater coding, peer scrutiny, testing on different data sets) support these findings as novel and useful for future outreach investigations.

IMPLICATIONS AND FUTURE WORK

The findings presented have important implications for outreach education and research. The diversity of teaching/learning beliefs, particularly those contrary to learning theories, suggest the need for training targeting the mechanisms of learning and best practices for teaching. Additionally, it suggests the need to investigate attendees' learning outcomes and college students' teaching efficacy.

As this investigation was a by-product of discussing content, there is also a need for more targeted study of the prevalence of these teaching/learning beliefs with different samples. Additionally, identifying sources that influence the beliefs development is needed. As this study used findings from formal learning environments to understand teaching/learning in informal environments, further examinations of the alignment between teaching chemistry in formal and informal environments and in what instances the two deviate are needed

ASSOCIATED CONTENT

Supporting Information

Included in the supporting information is a description of the trustworthiness of the conclusions and the full codebook (including categories, codes/teaching beliefs, and descriptions).

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Supporting Information

"You Lose Some Accuracy When You're Dumbing It Down": Teaching and Learning Ideas of College Students Teaching Chemistry Through Outreach

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Discussion of the Trustworthiness of Conclusions

All qualitative studies require a discussion of evidence that supports the trustworthiness of drawn conclusions.[1,2] For this study, considerations both in data collection and analysis add to the trustworthiness of the conclusions presented. Evidence that supports the trustworthiness of the data collection techniques and tools to elicit meaningful data through multimedia-based interviews (including students critiquing written explanations) have been previously reported.[3,4] Additionally, this study reports a more diverse sample, both in terms of student and institutional characteristics, than previously discussed in the CER literature. This adds trustworthiness through increased transferability.[1,2] For the data analysis, the content analysis was subjected to multiple steps that support the confirmability and dependability of the conclusions. These steps include independent development of the codebook based on LN_2 data, and testing the codes on ET data. Additionally, weekly debriefing sessions between the two authors ensured that code descriptions included multiple perspectives, and consensus was reached for unique cases. Lastly, the interrater coding helped ensure the functionality of codes, and allowed for adjustments to be made prior to final coding of the data corpus. In addition to these steps, this work was also subjected to peer scrutiny with CER colleagues at the same institution (not involved with the project), and with those consuming early results from presentations at national research conferences. Such scrutiny helped ensure that the research team's interpretations of data were rigorous and consistent.[1,2] Included below is the full codebook. Interview guide questions and disaggregated demographic information have been report as well.[4] All of these aforementioned techniques add transparency to the data collection and analysis, thus adding trustworthiness to the data presented and resulting conclusions.

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Codebook – Teaching/Learning beliefs for 2nd Graders

ET = Elephant toothpaste reaction
LN_2 = Making liquid nitrogen ice cream

Key

Color	Type
(blue)	Category
(gray)	Code
(yellow)	Subcode

Beliefs about 2nd Graders	
2nd Graders will not care about accuracy of content	Discussion of 2nd graders not caring about the accuracy of the content
Kids have short attention spans	Assertion that kids have short attention spans
Kids can understand complex chemistry ideas	Assertion that kids can understand more complex chemistry
Kids only retain a few vocab words	Assertion that kids will only retain a few vocabulary words
Beliefs about Teaching Process/Pedagogy	
Context is a valuable teaching tool	Discussing the importance of giving context and applying to everyday life/prior experience
Use of fake, implausible context	Discussing a not real context (needing toothpaste to brush an elephant's teeth)
Need to use representations/drawings	Discussing needing to use representations/drawings when teaching
Need to talk about atomic particles	Discussing needing to include ideas about atomic particles when teaching
Need to use numbers/quantitative ideas	Discussing needing to use numbers/quantitative ideas when teaching 2nd graders
Beliefs about the Scope and Sequence of Content	
OK to teach wrong content	Recognizes chemical concepts as incorrect, but discusses teaching incorrect chemical ideas because it is age appropriate
Anthropomorphism is a useful teaching tool	Discussing using anthropomorphism to make explanations of content age/grade-level appropriate OR provides examples using anthropomorphism
Assumption about prior knowledge	Makes an assumption about the prior knowledge of the audience
Need to use scientific terms	Emphasizing using scientific terms/vocabulary (reactants and products, reaction, chemical names, etc.)
NOT OK to teach wrong content	Recognizes chemical concepts as incorrect, but discusses NOT teaching incorrect chemical ideas
Do not discuss chemistry content	Says that they do not (or should not) discuss the chemistry for this age level. Includes only describing what is observable to the audience
Do not use scientific terms	Emphasizing using basic/simple language or terms (not scientific terms)
Should be fun/attention grabbing	Discusses focusing more on having fun/grabbing audience attention
Content must be dumbed down enough	Makes a judgement about the depth of content related to audience age level (it is dumbed down enough, not hardcore chemistry, not too scientific)

Content ideas tied to specific demonstrations	Unique content-related ideas that are tied specifically to elephant toothpaste or liquid nitrogen ice cream
Need to teach catalysis (ET)	Emphasizing teaching catalysis ideas
Need more advanced chemistry to understand (LN_2)	Talking about needing more in-depth chemistry (beyond general chemistry) to understand liquid nitrogen ice cream
Teach green chemistry ideas (ET)	Emphasizing teaching ideas related to green chemistry
Liquid nitrogen ice cream is a reward (LN_2)	Discussing using liquid nitrogen ice cream demo as a reward for attending an outreach event

Codebook – Teaching/Learning beliefs for 8th Graders

Beliefs about 8th graders	
8th Graders will not care about accuracy of content	Discussing that 8th graders do not care about the accuracy of the content
8th Graders do not like science	Saying 8th grades do not like science
Particles are hard for 8th graders to understand	Discussing that particles are hard to understand/not appropriate for 8th graders
Beliefs about Teaching Process/Pedagogy	
Context is a valuable teaching tool	Discussing the importance of giving context and applying to everyday life/prior experience
Use of fake, implausible context	Discussing a not real context (needing toothpaste to brush an elephant's teeth)
Need to use representations/drawings	Discussing needing to use representations/drawings when teaching
Need to talk about atomic particles	Discussing needing to include ideas about atomic particles when teaching
Need to use numbers/quantitative ideas	Discussing needing to use numbers/quantitative ideas when teaching
Value understanding audience prior knowledge	Expresses the need or importance of eliciting prior knowledge to tailor explanation
If you tell them, they learn it	Expressing the idea that simply telling the audience something means they learn it (non-constructivist idea)
Analogies do NOT explain concepts	Discussing that analogies do not explain chemical ideas
Beliefs about the Scope and Sequence of Content	
OK to teach wrong content	Recognizes chemical concepts as incorrect, but discusses teaching incorrect chemical ideas because it is age appropriate
Assumption about prior knowledge	Makes an assumption about the prior knowledge of the audience
NOT OK to teach wrong content	Recognizes chemical concepts as incorrect, but discusses NOT teaching incorrect chemical ideas

Anthropomorphism is a useful teaching tool	Discussing using anthropomorphism to make explanations of content age/grade-level appropriate OR provides examples using anthropomorphism
Need to use scientific terms	Emphasizing using scientific terms/vocabulary (reactants and products, reaction, chemical names, etc.)
Content ideas tied to specific demonstrations	Unique content-related ideas that are tied specifically to elephant toothpaste or liquid nitrogen ice cream
Need more advanced chemistry to understand (LN_2)	Talking about needing more in-depth chemistry (beyond general chemistry) to understand liquid nitrogen ice cream.
Need to teach catalysis (ET)	Emphasizing teaching catalysis ideas
Catalysts are NOT age appropriate for 8th graders (ET)	Emphasizing that catalysis ideas are not age appropriate for 8th graders
Teach green chemistry ideas (ET)	Emphasizing teaching ideas related to green chemistry

Codebook – Teaching/Learning beliefs for General Chemistry Student

Beliefs about Teaching Process/Pedagogy	
Need to use representations/drawings	Discussing needing to use representations/drawings when teaching
Need to use numbers/quantitative ideas	Discussing needing to use numbers/quantitative ideas when teaching
Need to talk about atomic particles	Discussing needing to include ideas about atomic particles when teaching
Context is a valuable teaching tool	Discussing the importance of giving context and applying to everyday life/prior experience
Explanations need to be short	Emphasizing needing the explanation to be short (less like a lecture)
Need to teach to learning style	Discusses teaching to different learning styles/tailored to audience learning style
Beliefs about the Scope and Sequence of Content	
Assumption about prior knowledge	Makes an assumption about the prior knowledge of the audience
Do not use/use less scientific terms	Emphasizing using basic/simple language or terms (not scientific terms) OR less jargon overall
Need to use/use more scientific terms	Emphasizing using scientific terms/vocabulary (reactants and products, reaction, chemical names, etc.)
Content ideas tied to specific demonstrations	Unique content-related ideas that are tied specifically to elephant toothpaste or liquid nitrogen ice cream
Liquid nitrogen ice cream should just be fun/social (LN_2)	LN_2 ice cream should only be a fun/social event (not content focused)

Need more advanced chemistry to understand (ET and LN_2)	Talking about needing more in-depth chemistry (beyond general chemistry) to understand (including mechanisms are an organic chemistry idea, not gen chem)
Not important, superfluous, extraneous (LN_2)	Content is not important, superfluous, extraneous. Do not need to explain
Need to focus on ice cream NOT nitrogen (LN_2)	Frame of reference needs to be on the ice cream being made not the LN_2 used to make it

Goodwill Without Guidance: College Student Outreach Practitioner Training

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ABSTRACT

Chemistry-specific informal science education (chemistry outreach) is widely practiced across all levels of the chemistry community. College students associated with American Chemical Society and Alpha Chi Sigma collegiate chapters are one population of chemistry outreach practitioners who reach upwards of 1 million people every year. Previous studies of this population have characterized their goals/purposes for conducting outreach, their understanding of the chemistry content underlying common demonstrations/activities, as well as their teaching and learning beliefs that they bring to their outreach teaching. The study reported herein provides another characterization of this population's chemistry outreach practices by focusing on the training experiences they receive prior to facilitating events. Using a combination of inductive and deductive approaches, training experiences and perceived gaps in training are characterized and compared to stages of the Cognitive Apprenticeship Theory. Results indicate little involvement from chapter advisors, widespread practice of 'winging it' or using trial and error when teaching children, and little training overall. Comparisons to Cognitive Apprenticeship Theory show a primary emphasis on modeling and coaching, with little metacognitive considerations. Implications for outreach teaching and training (for both practitioners and national chemistry organizations) are presented in light of these findings.

GRAPHICAL ABSTRACT

KEYWORDS
Chemical Education Research, Outreach, General Public

INTRODUCTION

Informal Science Education and Chemistry Outreach

Informal science education occurs in a collection of complex environments where over 82% of K-12 science learning occurs (and 93% or more of post-secondary science learning occurs).[1] These learning environments include *science-specific institutions* (museums, zoos, aquariums), *media* (games, TV, internet), *out-of-school programs* (after-school programs, clubs, outreach), and *everyday experiences.*[1,2] Formal science learning environments (*i.e.,* classrooms) are typically characterized by cognitive learning goals, such as understanding content. Informal science learning environments, on the other hand, encompass understanding content learning goals, as well as sparking interest, engaging in science practices, reflecting on the role of science, learning the tools and language of science, and even scientific identity formation.[1,3]

In chemistry, informal science learning is typically termed *chemistry outreach* and consists of both university students and practicing chemists sharing chemistry with the public through public lectures, informal conversations, demonstration 'magic' shows, camps, etc. In fact, chemistry outreach is so common in the chemical community that a cursory keyword search conducted on October 20, 2018 across all American Chemical Society (ACS) Publications results in 47 journal articles and 63 *Chemical & Engineering News* (C&EN) articles which include "chemistry outreach." When the search is expanded to include "informal science," 75 peer reviewed articles and 24 articles from C&EN are found. The earliest publication included in these searches dates back to 1989. While this search only focused on ACS Publications, it helps to illustrate the widespread focus on informal chemistry education and chemistry outreach within the chemical enterprise (particularly within the United States). Unfortunately, the majority of these publications focus on ideas and procedures for conducting chemistry outreach, rather than scholarly investigations of the efficacy and impacts of outreach on practitioners and their audiences.[4–11] In 2010, Fusion Science Theater started to change the nature of peer-reviewed publications on informal chemistry education by using scholarly approaches to investigate the development and implementation of a novel demonstration show format that results in measurable audience learning outcomes.[12–15]

College students associated with professional chemistry organizations who conduct chemistry outreach, namely ACS and Alpha Chi Sigma (ΑΧΣ) student chapters, devote a great deal of time and resources to outreach efforts. Statements from the national organizations encourage collegiate outreach as a way to "promote chemistry in your community" (ACS),[16] further the goals/objects of the organizations (ΑΧΣ),[17] and clarify the benevolent aims embedded in their missions. In fact, college students affiliated with ACS and ΑΧΣ report impacting approximately 1 million people every year through their chemistry outreach[18,19]; however, little scholarly investigations of their outreach practices have been conducted. To shed light on this understudied phenomenon and population, a large, national survey explored these college students' ideas about the purpose of chemistry outreach and the prevalent activities/demonstrations used.[20] Findings showed that the most frequently discussed purpose of outreach for college students was that their *audiences learn chemistry content.* Additional purposes which target affective dimensions include *generating interest/curiosity in the audience*, *audience enjoyment*, and addressing concerns of *accessibility* (who can do science) and scientist identity (what scientists look like). Prevalent activities/demonstrations practiced across the country include the elephant toothpaste reaction[21–23] and making liquid nitrogen ice cream.[24,25] Evidently, students part of ACS and ΑΧΣ have a variety of goals for outreach, and a diverse set of activities/chemistry content embedded in their events.

Subsequent investigations have closely examined college student outreach practitioners' understandings of the chemistry content underlying elephant toothpaste and making liquid nitrogen ice cream, as well as the beliefs about teaching and learning they bring to their outreach teaching. Findings evidenced prevalent misunderstandings and misconceptions about the chemistry content,[26] as well as beliefs about teaching and learning that may undermine audiences learning chemistry.[27] With an understanding of *what* college students are doing in their chemistry outreach, and subsequent concerns about the outcomes of their outreach, there is a need to investigate the experiences that lead up to these college students conducting outreach. Understanding how students develop skills and expertise to conduct outreach can shed light on the sources of these misunderstandings, misconceptions, and teaching and learning ideas misaligned with best practices for instruction and audience learning. These findings can then be used by the organizations to improve outreach training, and therefore the likely impacts of outreach on audiences and the community.

Cognitive Apprenticeship Theory

One lens that may be useful in understanding how college student outreach practitioners develop the skills necessary to conduct chemistry outreach is Cognitive Apprenticeship Theory.[28,29] In this theory, the focus is on a novice developing skills and understanding with support and guidance from an expert. In the end, the novice successfully transitions into an expert themselves. This theory adapts traditional apprenticeship models (*e.g.,* blacksmithing) by combining it with considerations of socio-cultural theories of learning,[30,31] Vygotsky's zone of proximal development (ZPD),[32] and situated learning/cognition.[33–35] Cognitive apprenticeship relies heavily on the notion that humans develop and learn out of social and cultural interactions (*e.g.,* the interactions between a novice and an expert). Additionally, the role of the expert is to guide and scaffold novice learning by keying into the novice's ZPD, or area of learning/potential development that can only occur through assistance and guidance. Lastly, the expert must help enculturate the novice, or help them understand the norms, behaviors, skills, beliefs, etc. of the expert's community (*i.e.,* situate the novice's learning within the physical and social contexts of the expert community). To this end, cognitive apprenticeship differs from traditional apprenticeship as it relies on meaningful social contexts, focuses on novices building both skills and understanding, and only works if the thought process of the expert/teacher is visible for the novice/student.[36]

Table 1. Overview of Cognitive Apprenticeship Theory and methods to promote developing expert skills and understanding

Category	Stage	Description
Core components – Acquiring skills and understanding through observation and guided practice	Modeling	Novice observes expert completing a task (*i.e.*, expert demonstrating skills)
	Coaching	Novice attempts simple tasks with expert assistance and support
	Scaffolding and fading	Novice attempts complex tasks with expert guidance that slowly diminishes as novice builds expertise
Monitoring components – Becoming conscious of own skills and understanding	Articulation	Novice verbalizes their thinking/knowledge/understanding
	Reflection	Novice compares thinking/knowledge/understanding with expert
Autonomy – Focusing on carrying out expert processes and transferring skills to new situation	Exploration	Novice is now an expert and is able to pose and solve their own problems

Six teaching methods/stages are proposed to help structure the cognitive apprenticeship learning environment and to promote the novice developing expert skills and understanding.[28,29,36–39] The six stages are described in Table 1. These six stages are further simplified and grouped into three categories: core components, monitoring components, and autonomy. Core components specifically focus on developing skills and understanding, and consist of experts *modeling* behavior, *coaching* the novice, and building *scaffolds* which gradually fade (*i.e.,* keying into the novice ZPD). The second category, monitoring components, is comprised of metacognitive stages in which the novice actively *articulates* their understanding, and *reflects* on the similarities and differences between their understanding and that of an expert. The final category, autonomy, is when the novice transitions into an expert such that they are able to *explore* or pose and solve their own problems. This final stage ends when the novice/new expert gains confidence in their ability to learn on their own and perform at the level of an expert. The stages of Cognitive Apprenticeship Theory will be used to interpret outreach training experiences of college students; the stages will provide a deductive coding framework that will help classify students' experiences in light of the social, contextual, and metacognitive aspects of learning.

RESEARCH QUESTIONS

To shed light on college student outreach practitioners' training experiences, this study seeks to address the following research questions (RQs):

1. What are the training experiences and perceptions of gaps in training expressed by college student outreach practitioners?
2. What alignment (if any) is there between training experiences expressed by college students and Cognitive Apprenticeship Theory?

METHODS

This study was conducted as part of an Institution Review Board approved investigation of college student chemistry outreach practices for students associated with ACS and/or AΧΣ student chapters. Data were collected through audio recorded, semi-structured interviews conducted over multimedia-based programs (*e.g.*, Skype, Google Hangouts) to sample students from across the United States.[40] Interviews were conducted during spring 2016 and spring 2017, and were structured into four phases: 1) the purpose of conducting outreach, 2) criteria for a successful event, 3) understanding of chemistry content in elephant toothpaste and/or liquid nitrogen ice cream, and 4) training experiences to conduct outreach. Previous reports include findings from the first three interview phases showing that these college students emphasize audience learning as both a purpose of outreach and a success criterion. Additionally, these students evidenced significant misconceptions and misunderstandings of the chemistry content underlying elephant toothpaste and making liquid nitrogen ice cream, particularly for ideas related to thermodynamics, kinetics, and catalysis.[26] Students also discussed teaching and learning ideas that were contrary to an *audience learning* goal/success criterion.[27] For the purpose of addressing the research questions here, and potentially shedding light on the sources of these misunderstandings and non-productive teaching ideas, data from the fourth phase (training experiences) will be presented. Phase 4 interview guide questions are included in the Supporting Information.

Sample

The sample is comprised of 37 college student outreach practitioners associated with ACS and/or AΧΣ student chapters who had previous experience conducting chemistry outreach with either elephant toothpaste or making liquid nitrogen ice cream, prior to completing the interview. These students were from 22 geographically diverse institutions across the United States, ranging from primarily undergraduate institutions to research-intensive universities.[40] Participants were diverse in terms of *gender* (17 males, 20 females), *major* (22 chemistry/biochemistry majors, 11 other science majors, 2 non-science majors, and 2 chemistry graduate students), and *year in school* (5 sophomore/second-year students, 11 juniors/third-year students, 19 seniors/fourth-or-fifth year students, and 2 graduate students). Because the sampling criteria included previous experience facilitating outreach with elephant toothpaste and/or liquid nitrogen ice cream, the predominance of upper-division students in the sample was expected. Additionally, because the population consisted of students involved with ACS or AXΣ student chapters, the majority of sampled students being chemistry/biochemistry majors was likewise expected by the investigators.

When the sampled students' ideas about outreach are compared to previous findings from a large, national survey of the same population,[20] consistent ideas about the purpose of outreach and criteria for success were found: 31 of the 37 participants indicated that the purpose of chemistry outreach is to *teach chemical concepts*, 31 indicated than an outreach event is successful if the *audience learned chemistry content*, and 35 supported presenters *giving good explanations of the chemistry* as a success criterion.[26,27] Because of the emphasis on teaching and learning that this sample places on chemistry outreach, it is important to consider the training experiences these college student outreach practitioners are receiving that may influence their ability to achieve *audience learning* during their events.

Investigating and Analyzing Training Experiences

During the interview, a semi-structured protocol was used to probe students' training experiences by keying into 1) the role of the advisor in their outreach, 2) specific training experiences they had, 3) how they prepare for an event, and 4) any perceived gaps in their training. To answer the two research questions herein, a two-stage analysis was conducted using the qualitative data analysis software Dedoose.[41] The first stage was open/inductive coding[42,43] to characterize student experiences and ideas. This took the form of independent coding by the first author using constant comparative analysis[44] to generate code names and descriptions that conveniently fit into four categories matching the four foci of the training phase interview questions. The second stage involved a deductive approach[42,43] where the stages of Cognitive Apprenticeship Theory[28,29] were compared to emergent codes from the first analysis to classify student experiences based on the theory. To ensure the trustworthiness[45,46] of both stages of the analysis, weekly meetings with the two authors allowed for the team to debrief and reflect on student ideas, as well as to revise code names and descriptions. These debriefing sessions were particularly important for stage two analysis (deductive comparison of Cognitive Apprenticeship Theory with emergent codes), whereby the team sought out disconfirming evidence in the data corpus to justify the deductive categorization of training experiences. Additionally, the team subjected coding decisions and interpretations to peer scrutiny with another CER colleague at the same institution (not involved with the project) to ensure the fidelity and rigor of code application. All of the aforementioned techniques add transparency to the data analysis and supports the trustworthiness of the resulting conclusions.

RESULTS AND DISCUSSION

RQ 1: Training Experiences and Perceptions of Gaps

Included in Table 2 are all of the categories and codes of training experiences and perceptions of gaps in training. The four focus areas in the questions posed during training phase of the interview defined the categories: 1) the role of the advisor in outreach, 2) ways students learn to facilitate outreach events, 3) how students prepare for events, and 4) perceived gaps in training where ACS and AXΣ could help.

Role of advisor in outreach. The most prevalent advisor-related idea discussed by college students was that the *advisor is not involved with outreach.* Despite ACS and AXΣ requiring a university faculty or staff member designated as the advisor for the collegiate chapters,[47,48] students expressed that the advisor typically is not actually involved with their outreach. Jenny (junior science major) described her chapter advisor's lack of involvement in outreach as, *""We definitely don't…we've been doing it long enough by ourselves that we don't need [help]…right now [advisor]'s not involved at all, honestly."* Harley Quinn (senior chemistry/biochemistry major) even described the lack of advisor involvement as, *"It's not necessarily their job to supervise us."* Some students further described the lack of involvement as a monetary relationship. Steve (senior chemistry/biochemistry major) described the relationship as, *"[Advisor] gives us money...they had no interaction outside of the general meetings...for outreach, they didn't really have any kind of interaction."* Kendra (senior non-science major) described her chapter's advisor as, *"[Advisor] was actually the person who funded our like chemicals... he was pretty much just our sugar daddy."*

ACS indicates that "faculty advisors play an important role in guiding, supporting and motivating students" in student chapters.[49] Similarly, ΑΧΣ states that "A Chapter Advisor has the opportunity to guide, counsel and encourage the growth and development of the chapter."[50] However, the majority of the students perceive that such guidance and support is not applied to their outreach. When students do discuss the chapter advisor having a role in outreach, most only describe the advisor as a resource to *answer questions if students have them* (n = 14) and/or as a gatekeeper or *community contact person for event planning* (n = 12). Only eight students (less than a quarter of the sample) actually discussed their advisor attending their outreach events. More striking is the lack of involvement from the advisor in terms of training. Only four students specifically discussed the advisor *helping college students understand chemistry content* as part of their outreach training experiences. Collectively, this means that the majority of outreach being conducted by these college students is completely student run, with little input or supervision from a faculty or staff member/expert.

Table 2. Categories of outreach training experiences and perceptions of gaps (N = 37)

Category	Code/Training Experience or Gap	Students (n)
Role of advisor in outreach	Advisor is not involved with outreach	16
	Advisor answers college students' questions, if they have them	14
	Advisor is community contact person for event planning	12
	Advisor is in charge of money	8
	Advisor attends outreach events	8
	Advisor helps college students understand chemistry content	4
Learning to facilitate outreach events	Trial and error for learning to give age appropriate explanations	21
	No training (figure it out on own)	19
	No training on explaining activities to kids	18
	Dedicated training day	16
	Training is observations of other people	15
	Training is being paired with older students	12
	Training is older students telling what to do/tips	6
	Training is practicing explanations	6
	Training is safety training	6

	Training is being told procedure	5
Preparing for events	No practice, just show up and do it	23
	Practice only if first time doing activity/demo	10
	Practice demos	8
Gaps in training/areas for help from ACS/AΧΣ	Want procedures with age-appropriate explanations	28
	Want tips and tricks for successfully conducting outreach	18
	Want detailed safety considerations/procedures to improve training	11
	Want information for about how to successfully conduct training for outreach	4
	Want data about the impacts of outreach on audiences	1

Learning to facilitate outreach events. When students discussed the specific training experiences they had to learn how to facilitate outreach, a variety of ideas were uncovered. The variety suggests a lack of uniformity in training across ACS/AΧΣ chapters. The most prevalent training experience discussed was that it is *trial and error for learning to give age appropriate explanations* (*n* = 21). This took the form of 'winging it,' *"I just kind of...taught myself I guess. I didn't...I don't think I've really ever had someone sit me down and be like 'this is what I want you to say.'... I just kind of winged it"* (Ororo, chemistry graduate student). Others specifically discussed learning through experience, *"[It's] trial and error. If uh...we say something and the students look really confused uhm...then we know that we went too far and that we should back off a bit. Or...uhm...yea...just trial and error based on their reactions"* (Frank, sophomore non-science major). Remy (senior science major) further described that learning how to explain chemistry to different age levels must be learned through experience, not training:

> *"I mean I think you watch anybody do one thing, and you kind of, you maybe learn 60% of what's going on. Um, and then the rest ... Then you get up and you try and imitate what that person was talking about, and you realize that like it's a little tougher than that, you know, or like you don't say things or think about things in the way that they did, so then you kinda have to tweak it, change it."*

The prevalence of this *trial and error* practice for explaining chemistry to outreach audiences is quite concerning given that ACS and AΧΣ students specifically discuss *audience learning* content as a goal for their outreach events. If college students are using trial and error approaches, that means that the learning outcomes for a practitioner's first few events are likely not met until they 'learn' the appropriate ways to explain the chemistry/build their expertise. This, coupled with the turnover of students doing outreach (such as by graduating and moving), means that every year the trial and error process may be starting over as new members join and start learning how to do outreach.

In addition to stating that trial and error are common parts of learning how to explain chemistry, 19 students specifically said that they have *no training* for outreach and have to *figure it out on their own.* Merina's (senior chemistry/biochemistry major) experience is representative of these 19 students, *"The first time I ever did elephant toothpaste was for the demo show...I had to look it up...I just looked up elephant toothpaste and found the recipe and I just...prepared the stuff."* Pamela's (senior science major) response further emphasizes the *figure it out on their own*, *"You're like setting up while you're like figuring out what to do. It's like a MacGyver experiment."* Not only are students lacking training on how to explain chemistry to youngsters, training seems to be lacking on conducting outreach, including procedures, safety considerations, etc.

For students who did discuss having training, 16 said they have a *dedicated training day* every semester where their chapter meets to discuss outreach. Despite this 'training day,' the experiences that students described were quite varied. Vance (senior chemistry/biochemistry major) described focusing specifically on procedures for the demonstrations where older/more experienced students led the training, *"We get new volunteers every year, and we have a magician show training kinda thing. So they spend like a couple hours in the undergrad teaching labs. And we have experienced magicians, like, tell them uh, show them how to do the demos, and then they can do them themselves."* Remy (senior science major) specifically discussed focusing on both the procedure and the explanations he would give to kids during his training day:

> *"They would teach you to like do the demo, which is always the easiest part, and then you kind of had to work through the talking method. Um, and that's when she would, um, kinda be like okay, that's a good talking point, but, but leave it out because it's not gonna, um, it's not gonna affect how people understand this, you know, or, um, that's too much information*

> *for these kids, or that didn't, that didn't make sense, you know, so change the way you talked about that."*

Despite the variety of foci for training days (focusing on procedures and/or explanations), the commonality in all responses was that more experienced students were mentoring and training the newer students. This practice is further emphasized by students who did not discuss any dedicated training day, but still had some sort of informal training experiences.

These informal training experiences include *observing* more experienced students doing outreach (*n* = 15), being *paired* with an older student to learn how to do the demos (*n* = 12), being given *tips* from more experienced students (*n* = 6), *practicing explanations* (*n* = 6), being trained on *safety* (*n* = 6) and just *being told the procedure* (*n* = 5). As evidenced by the variety of codes, these informal training experiences are diverse. Pepper (senior chemistry/biochemistry major) discussed her informal training experiences as observing more experienced students, *"I guess just kind of by listening to how other people do it. You know, kind of like uhm...observing kind of things they say and how they like...you know...handle themselves or whatever. You know, just kind of watching how they do different things."* Lana (junior chemistry/biochemistry major) reflected on her training experience of just being given tips from more experienced students as:

> *"Yea I don't know...cause a lot of times, at least for our outreach, it's all student run. There's no real like adult running it or preparing for it. Uhm...so honestly even when you were asking me these questions...like I'm having trouble answering them probably cause I...never had...no one ever sat down with me and went over it, you know? It's...word of mouth. Someone told me a little bit...someone else told me a little bit."*

Lana's quote illustrates a lack of involvement from a chapter advisor (an 'adult'), while also showing the practice of more experienced students sharing information with less experienced students (*"It's word of mouth. Someone told me a little bit...someone else told me a little bit."*). However, in this case, Lana recognizes that the word-of-mouth method may not be the best practice ("W*hen you were asking me these questions...I'm having trouble answering them."*). Despite the variety of informal training experiences, the most prevalently discussed experiences include mentoring through observations and partnerships between novice outreach practitioners and more experienced, expert practitioners.

Preparing for events. Students were also asked to describe how they prepare for an upcoming outreach event. The most common response was that they *do not practice, just show up and do it* (*n* = 23). While this may not be concerning for the students who have dedicated training days, the fact that the majority discuss having no training on either procedures or giving explanations is alarming. It seems that the 'wing it' mentality is quite prevalent as students *"just show up and do it"* (Harvey, senior chemistry/biochemistry major). However, this calls into question how these outreach practitioners can achieve goals of *audience learning* without appropriate preparation and training. Even more concerning is the safety considerations; few students discuss having dedicated safety training, and yet when they conduct outreach they must ensure the safety of all attendees and presenters.

Despite the majority of students discussing no preparation for events, some did describe that they *practice only if it's their first time doing the activity/demo* (*n* = 10) or that they *practice every time* (*n* = 8). These training experiences are promising, as it suggests a consideration of expertise and experience in the preparation process; an outreach practitioner with significant experience facilitating a specific demonstration may not need to practice for every event. Harley Quinn (senior chemistry/biochemistry major) supported this by describing it as *"I just show up and do it [laughs] it's all...its old hat by now."* It is possible that this experience-related decision on whether to practice is much more common, however only 10 students specifically discussed it.

Gaps in training/areas for help from ACS/AXΣ. Students were also asked about their perceived gaps in their training experiences, and how ACS or AXΣ could help support their outreach efforts. The question took the form of asking what type of information would students want in an outreach handbook made by ACS or AXΣ. The majority of the students discussed the difficulty of finding *procedures* and coming up with *age-appropriate explanations* (*n* = 28). Ororo (chemistry graduate student) described wanting these procedures and explanations, *"if [ACS or AXΣ] have specific experiments...the steps to [do] them. Maybe like a little blurb on the concepts or some keywords that you should mention during this kind of thing...for each specific experiment."* Reggie (junior science major) expanded on wanting procedures and explanations by talking through an example with elephant toothpaste:

> *"Like…when you do elephant toothpaste for second-graders, like say this. Or [ACS/AXΣ] recommends covering these topics. Um, but if you were going to do it for like eighth-graders or high schoolers, like you would cover these topics rather than these topics. Or um, maybe expand a little more on these topics, kind of thing. So definitely…[we want] what it is, how to do it, and what to cover. Maybe not like a script, but like have what to cover for each grade group"*

Other areas that students discussed wanting more information include *detailed safety considerations/procedures to improve training* (n = 11), *information for about how to successfully conduct training for outreach* (n = 4), and *wanting data about the impacts of outreach on audiences* (n = 1). While these are less frequently discussed, they show an emphasis on wanting to improve their training and recognizing a need to include safety considerations in outreach training. Overall, all of these responses show that these college student outreach practitioners perceive gaps in their training (procedures, age-appropriate explanations, safety considerations, training pedagogies, and data to show that outreach has an impact), and believe that the national organizations ACS and AXΣ may be able to help by providing more resources to support outreach.

Patterns and trends across demographics and codes. The data were subjected to multiple analyses to investigate patterns and trends by comparing training experiences (codes) with demographics, as well as for co-occurrence of codes (*i.e.,* discussing multiple training experiences). Surprisingly, no patterns or trends emerged for either analysis (demographics or code co-occurrence). While some of the training experiences discussed above were prevalent across the sample, individual student responses were highly varied and idiosyncratic. This resulted in a lack of uniformity in training experiences for college student outreach practitioners, and the null result associated with demographics and co-occurrence of training ideas. The most surprising null result was for students from the same chapter. While only 8 of the 22 chapters included in the study had multiple students represented in the sample, no patterns or trends were found within these student responses. This suggests that even within individual ACS and AXΣ chapters, training experiences differ. An investigation of the reasons for why experiences within chapters vary is out of the scope of this study, but is a fruitful area for future investigations of chemistry outreach practices.

RQ 2: Alignment Between Training Experiences and Cognitive Apprenticeship Theory

When comparing training experiences expressed by college student outreach practitioners with the categories/stages of Cognitive Apprenticeship Theory,[28,29] there are similarities worth discussing. First and foremost, while it may be assumed that the chapter advisor is an expert who could help facilitate novice outreach practitioners (students) becoming experts, the students overall expressed a lack of chapter advisor involvement in outreach. However, all other discussion from the students (particularly within the *learning to facilitate outreach events* category) emphasized more experienced students (experts) helping less experienced students (novices) learn how to facilitate outreach.

Table 3. Outreach training experiences aligned with stages of Cognitive Apprenticeship Theory

Stage of Cognitive Apprenticeship Theory	Training Experience Expressed by Students
Modeling	Training is observations of other people Training is older students telling what to do/tips Training is being told procedure
Coaching	Training is being paired with older students Dedicated training day
Scaffolding and fading	Training is practicing explanations
Articulation	n/a
Reflection	n/a
Exploration	No training (figure it out on own)

The ways that these expert students helped facilitate the learning/training of the novice students were diverse. However, there is clear alignment between some of the training experiences uncovered and the stages of Cognitive Apprenticeship Theory. Shown in Table 3 are training experiences expressed by the students that align with some of the stages of Cognitive Apprenticeship Theory. While the majority of the training experience do not explicitly align with a stage of the theory, there are three that directly align with *modeling* (*e.g.,* learning through observation). These include specifically observing other people, as well as being told information/procedures. Two training experiences align with the *coaching* stage (*e.g.,* novice performing tasks with expert assistance/support). These include an experienced student being paired with a novice student, as well as those who had dedicated training days.

For the remaining four stages of Cognitive Apprenticeship Theory, few training experiences have direct alignment. *Training is practicing explanations* aligns well with the *scaffolding and fading* stage as it focuses on the novice attempting the complex task (*i.e.,* explaining the chemistry) with support from an expert. However, no training experiences align with the *articulation* or *reflection* stages of the theory. These two stages are metacognitive and focus on the novice verbalizing their understanding and reflecting on how well it aligns with expert understanding. It is possible that *practicing only if it is their first time doing the activity/demo* may align with either *articulation* or *reflection,* as the student decides that they have enough expertise to do the demo and only need to practice if it is new. However, students did not discuss these practicing ideas in a way which suggested they were being metacognitive or reflecting on their experiences/expertise, thus supporting not aligning these practicing ideas with either stage of the theory.

For the final stage of Cognitive Apprenticeship Theory (exploration), one training experience directly aligns, *no training (figure it out on own).* However, the majority of the students discussed no formal training experiences. Furthermore, the fact that no patterns were found through a co-occurrence analysis (expressing multiple training experiences) suggests that students view their informal training experiences as adequate. The theory would suggest that this may not actually be the case. Because students typically indicated that one informal training experience occurred prior to facilitating outreach, students seem to be progressing directly to the *exploration* stage where the theory considers them an expert who is able to conduct outreach on their own. Therefore, this supports the interpretation that these students view their informal training experiences as a way to help facilitate their progression directly to the *exploration* phase; once a student has 'some' informal training (safety training, told procedure, observed a more experienced student) they are now 'fully trained' and able to conduct outreach on their own. No student discussed any sort of gradual progression where they spent a significant amount of time observing, practicing, and reflecting prior to leading an event on their own. This, combined with the lack of experiences aligned with articulation and reflection, suggests that training experiences for college student outreach practitioners primarily focus on modeling and coaching before considered themselves ready to conduct outreach (the exploration stage).

Since the stages of Cognitive Apprenticeship Theory are only considered methods which help support developing expertise, it is not a requirement that every student progresses through every stage; the stages are simply suggested as ways to promote successful development into an expert. Therefore, the fact that these college student outreach practitioners skip stages is not inherently a problem. However, it is important to consider these finding in light of previous investigations. Since these college students specifically state that *audience learning* is a primary goal of their outreach,[20] previous work has investigated their understanding of the chemistry content as well as their beliefs about teaching and learning. Findings show that these college students evidence significant misconceptions and misunderstandings of thermodynamics, kinetics, and catalysis.[26] Additionally, they express ideas about teaching and learning that are contrary to *audience learning* as a goal for outreach.[27] Therefore, it calls into question the kinds of impacts outreach has on audiences, and what attendees are actually learning at events. However, the lack of alignment between training experiences and Cognitive Apprenticeship Theory may explain these content issues and beliefs about teaching/learning that do not support *audience learning*.

These college students primarily discussed focusing on procedures of demonstrations as their training experiences. Whether this took the form of modeling or coaching, the emphasis is more on the mechanics of conducting experiments. Little emphasis is placed on understanding the chemistry content (only four students discussed making sure they understood the chemistry content with their faculty advisor). Additionally, little emphasis is placed on learning how to explain the chemistry to their audiences (21 students said it is *trial and error* and not part of training). Therefore, with little training focused on understanding chemistry or ability to explain the chemistry, it is not surprising that students evidence misunderstandings and misconceptions. Nor is it surprising that they articulate teaching and learning beliefs that are contrary to *audience learning* goals. Nowhere do the students discuss any training experiences related to how to teach in outreach, best practices for teaching and learning, etc. Such a lack of discussion by students helps explain why Cognitive Apprenticeship Theory emphasizes metacognition (the *articulation* and *reflection* stages). If these college students were encouraged to verbalize their chemistry understanding as it relates to their outreach events, verbalize their beliefs about teaching/learning, and then compare their understanding and beliefs with experts, these gaps in understanding could be minimized, and the likelihood of achieving *audience learning* during events would have the potential to improve.

CONCLUSIONS

Evidenced in this paper are many different training experiences expressed by college student outreach practitioners; some are formal (such has a dedicated training day) while the majority are informal (observations, sharing tips). The commonality across all ideas was that older, more experienced students act as experts in the training of new students (novices). Chapter advisors have very little involvement in outreach training or implementation. When compared to the Cognitive Apprenticeship Theory, there is only clear alignment between training experiences and the early stages of the theory (modeling and coaching). In fact, almost all of the training experiences may be a way to help facilitate a student progress directly to the final phase of Cognitive Apprenticeship Theory (exploration), and bypass the rest of the phases. No matter the interpretation, there is little evidence to suggest that metacognitive aspects of Cognitive Apprenticeship Theory are considered in current training practices of college student outreach practitioners. When the training experiences expressed by the students are viewed in light of previous findings that indicate a lack of understanding of the chemistry content[26] and teaching/learning beliefs[27] not aligned with audience learning, the results seem quite expected. There is little emphasis in current training practices on understanding chemistry or being able to explain it to kids. In addition, students expressed a number of training gaps that ACS and/or ΑΧΣ could address, including providing procedures for demonstration with accompanying age-appropriate explanations, providing information on safety, and providing information on how to successfully conduct outreach training.

LIMITATIONS

As with all studies, there are limitations that must be discussed to help critically analyze findings. The primary limitation in this study was that students lacked consensus on their definitions of training. Some students would indicate that they had no training, but then proceed to talk about observing older students. While this is an implication that students may not be viewing observations (*i.e.,* modeling) as a training technique, it posed issues during coding. In the end, this led to students being double coded to include their perspective (*i.e.,* thinking they had no training experiences), while also accurately characterizing current training practices (*i.e.,* observing older students). Additionally, some students would discuss training from two different temporal perspectives: 1) when they, themselves were trained and 2) the current training practices now that they are more experienced. This once again posed issues during coding and resulted in students being coded into multiple codes/categories to accurately reflect all of the training experiences they discussed. All of these limitations led to codes/categories not being mutually exclusive; the number of students expressing each training idea (Table 2) are characteristic of all ideas students expressed during the interviews. The limits the interpretation of training experiences as no conclusions can be drawn about individual students, and the frequencies presented in Table 2 must be interpreted individually. However, by characterizing all of the student ideas, this allow us to comment on overall training practices and experiences for ACS and ΑΧΣ chapter members.

IMPLICATIONS

Cognitive Apprenticeship Theory seems to be a useful lens for viewing current outreach training practices. It helps categorizes different training experiences while also explaining some of the training deficiencies that may manifest in misconceptions and teaching/learning beliefs that are contrary to audience learning. However, there are clear gaps in training that challenge assumptions of the chapters and the national organizations. First of all, there is little evidence to suggest that chapter advisors are involved in outreach (both in training students and in implementation). Secondly, it is clear that there is a lack of emphasis on metacognitive practices (*articulation* and *reflection*) for outreach training. Both of these findings regarding training help explain previous discoveries of deficient content knowledge and non-productive teaching and learning beliefs held by collegiate outreach practitioners. Combined, these findings suggest that current outreach practices may be "goodwill without guidance." These students have positive goals for outreach (such as audience learning chemistry and audience enjoyment), which are supported by the national organizations through funding opportunities, award programs, and significant emphasis on National Chemistry Week and Chemists Celebrate Earth Week events.[16,51–53] However, these students discuss having little guidance from experts (faculty advisors or resources from the national organizations) on how to best conduct their events to successfully meet their goals. Furthermore, these students have little experience verbalize their chemistry understanding as it relates to their outreach events, verbalizing their beliefs about teaching/learning, or comparing their understanding and beliefs with experts. In fact, evidence suggests that current practices are likely unsuccessful in achieving *audience learning* goals, and such unsuccessful practices may be perpetuated through a never-ending-cycle of passing down information from graduating students to newer students, with little intervention from experts (faculty advisors or the national organizations). As such, these findings have clear implications for outreach improvement in the areas of implementation and training.

Without a doubt, there are clear implications for improving outreach training. Not only do the students express a need for help from ACS and AXΣ (*gaps in training/areas for help from ACS/AXΣ* category), but training deficits are likely leading to teaching misconceptions during outreach events.[26] Interventions from actual experts (faculty advisors and the national organizations) which target conceptual understanding and beliefs about teaching/learning are necessary. Additionally, outreach training can incorporate the Cognitive Apprenticeship Theory as one way to address these concerns, particularly by emphasizing metacognition and students reflecting on their understanding. Lastly, the data presented in this paper provide research to support the national organizations ACS and AXΣ in examining current resources and support practices for these college students/chapters. By taking a data-driven approach to outreach practices (and training), ACS and AXΣ have the opportunity to improve chemistry outreach practices to successfully meet their goals (including audience learning), which can have lasting impacts on attendees. Finally, there is clearly a need for more research on outreach by targeting different populations than college students; this includes looking at other practitioners (like those in industry), as well as investigating the impacts of outreach on children/younger students attending events.

ASSOCIATED CONTENT

Supporting Information

Included in the supporting information are Phase 4 interview guide questions and the full codebook used to code training experiences/perceptions of gaps.

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Supporting Information

Goodwill Without Guidance: College Student Outreach Practitioner Training

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Portion of semi-structured interview guide

Interview Phase 4: Training Experiences and Perceptions of Gaps

Now I want to talk a little bit about how you kind of trained or learned to facilitate these activities

1) So how did you learn how to facilitate____ activity?
    a. What is your role in facilitating them?

2) How did you learn the chemistry behind _____ activity?

3) How did you learn how to explain ______ activity to different audiences?

4) Is it the same for ________ activity(s)? Does something different happen?

5) How do you prepare for an event?
    a. Do you practice? Do you just show up and do it?

6) What is the role of your faculty advisor in planning/doing outreach events?

7) How does your group get new members up-to-speed so they can lead and explain the activities to kids?

8) If *(insert organization name here)* was to make a handbook for chapters about outreach, what do you think should be included?

Codebook of training experiences & perceived gaps

Code/Training Experience/Gap	Description
Advisor attends outreach events	Says advisor or other faculty member attends outreach events
Advisor helps college students learn content	Advisor is involved with training to help students understand chemistry behind demos/procedures.
Advisor is contact person for planning community events	Advisor acts as gatekeeper for community; community members contact advisor to get access to group for scheduling demo shows/activities.
Advisor is not involved with outreach	Advisor is not involved with outreach
Advisor answers questions if have them	Advisor's role in outreach is primarily as a resource person that will answer student questions, if they have them.
Advisor in charge of money	Advisor is in charge of group funds/bank account.
No practice, just show up and do it	Student does not practice, they just show up for events.
Practice if first time	Student only practices demos if they are new demos/never done them before.
Practice demos	Student practices demo before events.
No training (figure it out on own)	Student says they learned through observations of other students doing demos.
No training on explaining activities to kids	Student is only told the procedure (verbally or in writing).
Dedicated training day	Students says they had no formal training and had to just 'figure it out' on their own.
Training is observations of other people	Older students provide advice/tips for doing outreach.
Training is being pair with older students	Student says they have some formal training day each semester.
Training is older students tell what to do/tips	Student says they never were told how to explain demos to kids.
Training is practicing explanations	New students get paired with older students to learn demos and have a support person.
Training is safety training	Student is explicitly trained on safety.
Training is told procedure	Students practice explaining demonstrations with more experienced person.
Trial and error for age appropriate explanations	Student expresses that learning to explain chemistry for various levels comes from experiences/trial-and-error.
Want handbook with procedures and explanations	Discussing wanting written procedures and age-appropriate explanations.

Want handbook with tips and tricks for outreach	Discussing want tips and tricks for how best to do outreach (from other chapters, from national organizations, etc.) Includes discussing event planning/management, as well as specific tips for activities.
Want handbook with safety considerations	Discussing wanting information about safety to include in their training (specific to chemistry outreach).
Want handbook with training ideas	Describing wanting ideas for how to do their outreach training, including structuring a training day and what to include.
Want handbook with data about impacts of outreach	Wanting data about how outreach has an impact on audiences (to be shared with college students and to justify to community members why they should let them do outreach).

CHAPTER 5:
CONCLUSIONS AND IMPLICATIONS

The purpose of this chapter is to summarize the conclusions and implications presented in the previous chapters. Additionally, this chapter will discuss the limitations of the conclusions drawn from these two investigations as well as future areas for research following this study. The research questions of this study were:

Investigation 1:

1. What are collegiate students' and faculty/staff's ideas about the purpose(s) of chemistry outreach?
2. What activities are most commonly practiced in chemistry outreach?
3. What evaluation methods do collegiate chemistry organizations use during outreach?

Investigation 2:

1. How effectively can technological solutions provide access to interview participants across an entire country to diversify samples and improve the transferability of findings?
2. How can in-person interview tasks be adapted to function in an online multimedia platform to elicit rich description commensurate with traditional face-to-face interviews?
3. For college students conducting chemistry outreach, what is the nature and extent of their content knowledge associated with
    a. the elephant toothpaste reaction?
    b. making liquid nitrogen ice cream?
4. What beliefs about teaching and learning were expressed by college student outreach practitioners?
5. How do college students' teaching and learning beliefs about outreach vary (if at all) depending on audience age level?
6. What are the training experiences and perceptions of gaps in training expressed by college student outreach practitioners?
7. What alignment (if any) is there between training experiences expressed by college students and Cognitive Apprenticeship Theory?

Answers to Research Questions

Investigation 1:

Results from the open-ended survey administered to both student and faculty/staff members of ACS and ΑΧΣ collegiate chapters indicate that both populations have a variety of ideas about why outreach is conducted and what the audience (and college students) is supposed to gain as a result of participation. Most frequently discussed across both samples was *audience learning* as a result of attending outreach events. Additionally, people in both groups also discussed multiple purposes for outreach, suggesting that events are not designed to have a single, measurable goal. Faculty/staff members added an additional category of purposes that focused on learning outcomes for the college students, with the most common being *college students developing into scientists* (including communicating with non-scientific audiences). Furthermore, little similarities were found between the purposes discussed by those affiliated with ACS or ΑΧΣ, and the practicing chemists studied as part of the National Academies report on *Effective Chemistry Communication in Informal Environments* (National Academies of Sciences Engineering and Medicine, 2016). This suggests that members of the collegiate chapters of these professional chemistry organizations are a distinct population from other outreach practitioners, and that further investigation of this sample is needed.

Both students and faculty/staff members discussed specific activities used during their outreach events, with the most common being making liquid nitrogen ice cream, the elephant toothpaste reaction, and making slime. The two samples differed in their discussion of the method of implication/facilitation; both groups heavily emphasized using demonstration shows, while faculty/staff members also prevalently discussed hands-on activities.

Meaningful data about the ways college students and faculty/staff members evaluate the success of an outreach event were minimal. This suggests a lack of specific, measurable criteria, as well as a lack of fluency in discussing evaluation techniques. Furthermore, it indicates that these chemistry organizations may subscribe to the broader Informal Science Education community's philosophy that de-emphasizes evaluation (National Research Council, 2009, 2010). Data that were meaningful indicate *some* alignment between the cognitive and affective purposes for events, that are evaluated through observations. However, such evaluation criteria were highly subjective (*e.g.*, "Did it appear that they learning something?"), and lacked specifics on how these outreach practitioners collect and evaluate data to inform their outreach practices.

Investigation 2:

The development and implementation of the novel qualitative method was subjected to a rigorous case-study analysis to evaluate the effectiveness of accessing diverse research participants, and the functionality of interview tasks over a multimedia platform to elicit rich description of student ideas. Evidence indicates that a variety of techniques are needed to access geographically diverse research participants; a single recruitment effort is not sufficient, particularly when you only have direct access to gatekeepers rather than potential research participants. However, by combining in-person recruitment with emails to gatekeepers and snowball recruitment, we were able to successfully access ACS and ΑΧΣ student members. This resulted in a more diverse sample than previously reported in many qualitative studies of the same size in Chemistry Education Research. Such increased diversity (both in institution and participant demographics) supports the trustworthiness of the conclusions through increased transferability, as more perspectives than typical single-institution studies are included (Lincoln & Guba, 1985).

In terms of elicitation, we were able to show that electronic survey software (such as Qualtrics) offers a means to adapt card sorting tasks (a common in-person interview elicitation technique) for use in online interviews. Additionally, instant messaging capabilities minimizes barriers to online interviews by allowing for the easy sharing of information. By comparing pilot study results (only open-ended questioning) to results from the full study (open-ended questioning combined with the critiquing of written explanations), we were able to show successful elicitation of student conceptual understanding and teaching/learning beliefs. Additionally, we were able to evidence rich, meaningful data obtained through multimedia-based approaches that are commensurate with data obtained through traditional face-to-face interviews.

The analysis of college students' content knowledge associated with the elephant toothpaste reaction and making liquid nitrogen ice cream revealed that these college student outreach practitioners have misconceptions and misunderstandings of the content underlying these two activities. This is particularly concerning considering that students had previous experience facilitating these activities with children/younger students, and passed a college general chemistry course. For the elephant toothpaste reaction, the majority of the students did not know the products of the reaction, and evidenced published misconceptions related to catalysis and bonding/thermodynamics. For making liquid nitrogen ice cream, students were more successful in their discussion of the chemistry; however, approximately half of the students struggled with the general chemistry concepts of freezing point depression and ideas related to intermolecular forces. Across both activities, students provided evidence that suggests these students are memorizing/rote learning chemistry content during their university coursework. Considering that the content students discussed was written to align with the level of college general chemistry, and that the majority of the students in the sample were third- and fourth-year chemistry/biochemistry majors, this is most concerning.

By analyzing student responses about chemistry content through the lens of teacher beliefs, three broad categories of teaching/learning beliefs were uncovered for college student outreach practitioners: 1) beliefs about the audience, 2) beliefs about the teaching process/pedagogy, and 3) beliefs about the scope and sequence of the content. Some beliefs are aligned with learning theories and literature recommendations (such as *context is a valuable teaching tool* and *valuing understanding audience prior knowledge*), while many beliefs are contrary to their goal of *audience learning* (such as *OK to teach wrong content*, *2^{nd} & 8^{th} graders will not care about the accuracy of content*, and *anthropomorphism is a useful teaching tool*). When the expressed beliefs were analyzed for similarities and differences by targeted age level/audience, some beliefs crosscut all three audience levels (*e.g.*, *need to use representations/drawings, numbers/quantitative ideas*, and *atomic particles)*. The greatest difference was the number of unique teaching/learning ideas; many ideas were expressed for 2^{nd} graders, and this number gradually decreased moving from 8^{th} graders to general chemistry students. Additionally, beliefs aligned specifically with the audience members were only expressed for the lower levels, not for general chemistry students (*i.e.*, *beliefs about 2^{nd} graders*/*8^{th} graders*). Lastly, some ideas became less prevalent moving from talking about 2^{nd} graders to general chemistry students, including *use of fake, implausible context* and believing that it is *OK to teach wrong content*. Despite these differences, it is clear than many beliefs stem from either personal or private empiricism or from experiences as a chemistry student (Cooper, 2007; Cooper & Stowe, 2018). No instances in which participants specifically stated the use of theory or literature to support their beliefs were in the data corpus.

With respect to the training experiences of these college student outreach practitioners, a variety of training experiences were expressed. Some are formal (such has a dedicated training day), while the majority are informal (observations, sharing tips). The commonality across all ideas was that older, more experienced students act as experts in the training of new students (novices). Chapter advisors have very little involvement in outreach training or implementation. When compared to the Cognitive Apprenticeship Theory, there is only clear alignment between training experiences and the early stages of the theory (modeling and coaching). In fact, almost all of the training experiences may be a way to help facilitate a student progress directly to the final phase of Cognitive Apprenticeship Theory (exploration), and bypassing the rest of the phases. No matter the interpretation, there is little evidence to suggest that metacognitive aspects of Cognitive Apprenticeship Theory are considered in current training practices of college student outreach practitioners. When the training experiences expressed by the students are viewed in light of the previous findings (lacking understanding of the chemistry content and teaching/learning beliefs not aligned with audience learning), these training results become not surprising. There is little emphasis in current training practices on understanding chemistry or being able to explain it to kids. In addition, students expressed a number of training gaps that ACS and/or ΑΧΣ could address, including providing procedures for demonstration with accompanying age-appropriate explanations, providing information on safety, and providing information on how to successfully conduct outreach training.

Limitations

Investigation 1:

This study provides the first step in characterizing the chemistry outreach practices of organizations that heavily promote and conduct chemistry outreach events each year. Given the growing focus on informal science education, chemistry education researchers can respond by turning their attention to these informal environments. Since chemistry outreach, one such informal science learning environment, drastically lacks scholarly investigation, this initial study was limited. The extant literature was lacking and could not provide a basis for developing the survey questions or a lens to analyze the data. The use of survey-only data collection also limited the type of responses obtained and the depth of analysis possible. The extended responses could only be analyzed *via* content analysis (*i.e., what* was said), since survey results do not provide thick descriptions. The short survey responses tended to lack context and supporting details that could aid in interpretation. Even with these limitations, the survey results provide a knowledge base from which researchers can begin to investigate outreach settings, events, facilitators, and participants.

Investigation 2:

While the investigation of students' conceptual understanding suggests a need to look critically at outreach practices and formal instruction of undergraduate chemistry students, this study had several limitations. First and foremost, despite the total sample size (N = 37) being based on data saturation (Patton, 2002), the subsample sizes for elephant toothpaste (n = 26) and making liquid nitrogen ice cream (n = 15) were small. While this may detract from potential transferability of the findings (Lincoln & Guba, 1985; Shenton, 2004), the increased sample diversity, which has not been seen before in previous in-depth qualitative studies in CER, help to alleviate this concern. Additionally, it is possible that the demographics of the sample do not transfer to all outreach practitioners. Another limitation is that there were many instances where students chose not to provide comments about the accuracy of some of the statements. While this limits the conclusions that can be drawn about the overall sample, the lack of patterns or trends in responses (including no single students being the ones not providing comments) suggests that the task was mostly successful in eliciting student ideas. This, combined with the elicitation of other idiosyncratic incorrect chemical ideas, adds to the rich description of student ideas and supports the conclusions drawn about student understanding of the elephant toothpaste reaction and making liquid nitrogen ice cream. Lastly, it is important to note the differences in the explanations/prompts between the elephant toothpaste reaction and making liquid nitrogen ice cream. Approximately a third of the elephant toothpaste statements and two-thirds of the liquid nitrogen ice cream statements were chemical correct. The difference in the ratio between chemical correct *vs* incorrect statements embedded in the critiqued explanations pose limitations in the conclusions that can be drawn from comparing data from elephant toothpaste to that from liquid nitrogen ice cream. Combined with the subsample size differences mentioned above, it is important that readers not draw many conclusions that relate elephant toothpaste findings with liquid nitrogen ice cream findings. Rather, conclusions should be made about student understanding of content underlying elephant toothpaste and liquid nitrogen ice cream separately.

While the findings of students' teaching and learning beliefs shed light on outreach practices and suggest a critical examination of potential outreach impacts, there are some key limitations. First and foremost, while the total sample size (N = 37) was based on data saturation, only 35 participants were included in this analysis. This is because of the necessity for participants to have previous experience teaching elephant toothpaste and/or making liquid nitrogen ice cream. Despite this smaller sample, the diversity of the participants minimizes this concern. Additionally, the prompt asked students to consider how age appropriate previously written explanations were for 2nd graders, 8th graders, or general chemistry students. It did not specifically probe teaching beliefs or the underlying rationales of such beliefs. All student discussions were by-products of their considerations of the content's appropriateness for the audience. This explains the lower sample sizes for individual beliefs. However, the fact that these ideas emerged from the data and were robust when subjected to multiple trustworthiness considerations (*e.g.*, interrater coding, peer scrutiny, testing on different data sets) support these findings as novel and useful for future outreach investigations.

The analysis of students' outreach training experiences were limited as students lacked consensus on their definitions of training. Some students would indicate that they had no training, but then proceed to talk about observing older students. While this is an implication that students may not be viewing observations (*i.e.*, modeling) as a training technique, it posed issues during coding. In the end, this led to students being double coded to include their perspective (*i.e.*, thinking they had no training experiences), while also accurately characterizing current training practices (*i.e.*, observing older students). Additionally, some students would discuss training from two lens: 1) when they, themselves were trained and 2) the current training practices now that they are more experienced. This once again posed issues during coding and resulted in students being coded into multiple codes/categories to accurately reflect all of the training experiences they discussed. All of these limitations led to codes/categories not being mutually exclusive; the number of students expressing each training idea are characteristic of all ideas students expressed during the interviews.

Implications for Research

Investigation 1:

Fully characterizing and understanding the outreach practices of collegiate chemistry organizations requires in-depth qualitative studies. As illustrated by the findings from this investigation, particular attention needs to be given to, at a minimum, why the purposes discussed are important and how events are designed to address these intended purposes (including the chemistry content included in events). Future studies that examine what prior knowledge and experiences influence students' and faculty/staff members' purpose(s) of outreach would shed light on the nature of outreach event design and implementation. Additionally, the teacher-centered nature of facilitating demonstrations, a prevalent pedagogy in outreach, warrants investigating the content knowledge and pedagogical expertise of college students running events. The first steps in understanding these ideas were completed as part of Investigation 2.

Findings regarding commonly used activities have implications for researchers, since future investigations are needed to examine in more detail the pedagogical elements of outreach. Of particular research interest is the discrepancy between students' and faculty/staff members' discussion of demonstrations and hands-on activities. Future studies could investigate the relationships among event goals, facilitation, activity choices, audience type, and event settings, and how these vary among students and faculty/staff members.

Meaningful data about evaluating the success of outreach events were minimal. As such, implications for research include targeted investigations of these evaluation ideas, and the connections between perceived purposes/goals of outreach events and ways that these organizations evaluate events. Additionally, there is a need to understand how the framework proposed by the National Academies' report (National Academies of Sciences Engineering and Medicine, 2016) is viewed by outreach practitioners in terms of comprehension and utility, as well as investigating the extent to which, and the ways in which, the framework is put into practice.

Investigation 2:

In the development and evaluation of the novel qualitative method, evidence suggested that technology-enhanced studies have the potential to change how chemistry education researchers design and carry out qualitative studies. However, more research needs to be conducted to further test this method, provide details on the differences between multimedia-based interviews and in-person interviews in CER, and to optimize the method to identify when limitations of multimedia-based interviews preclude answering particular CER questions. As technology is continuously changing, investigations of using other tools in these electronic environments, and developing new elicitation tasks tailored specifically to online interviews, are needed to advance the field and increase understanding of best practices when conducting online, multimedia-based interviews.

Results from the analysis of students' conceptual understanding have important implications for researchers. These findings support expanding qualitative studies to include multiple institutions for increased sample diversity. By increasing the diversity of samples included in investigations of student understanding of chemistry, qualitative studies can shed light on student understanding that crosscut institutional and instructional contexts. Additionally, based on the findings presented in this study, targeted interventions focused on kinetics, thermodynamics, and catalysis implemented across multiple institutions are needed. Lastly, since these college students focus on their audiences learning chemistry, investigations of younger students/children attending outreach events and the resulting learning is needed. Such investigations are warranted, as evidence from formal learning environments suggests that teachers with misconceptions pass them on to their students, which likely transfers to instruction in informal settings (Ameh & Gunstone, 1986; Fensham, 1984; Kikas, 2004; Lee, 1999).

Students' diverse teaching and learning beliefs support investigating attendees' learning outcomes and college students' teaching efficacy. As this investigation was a by-product of discussing content, there is also a need for more targeted study of the prevalence of these teaching/learning beliefs with different samples. Additionally, identifying sources that influence the beliefs development is needed. As this study used findings from formal learning environments to understand teaching/learning in informal environments, further examinations of the alignment between teaching chemistry in formal and informal environments, and in what instances the two deviate, are also needed.

Cognitive Apprenticeship Theory is a useful lens for viewing current outreach training practices. It helped categorizes different training experiences, and explain some of the training deficiencies that may manifest in misconceptions and teaching/learning beliefs that are contrary to audience learning. Additionally, students themselves discussed gaps in their outreach training where the national organizations may be able to help. As such, there is a clear need for interventions from experts to target conceptual understanding and beliefs about teaching/learning. Cognitive Apprenticeship Theory can be directly incorporated into outreach training as one way to address these concerns by emphasizing metacognition and student reflection, particularly on their chemistry understanding and teaching/learning beliefs.

Implications for Teaching and Learning

Investigation 1:

Results regarding the perceived purposes of outreach have implications for practitioners of chemistry outreach. The variety of purposes suggest that the goals for outreach may not be unified, and may not even be a topic for discussion within the organizations. The purposes generated by this study provide a data-derived collection of purposes native to the outreach environment. This compilation can serve organizations in implementing the framework proposed by the National Academies by providing language for them to clearly articulate the purpose(s) for their events, and provide more focus to their outreach programming (National Academies of Sciences Engineering and Medicine, 2016). Not only can a well-articulated set of purposes better guide individual chapters in working toward their goals, but it can also provide an authentic and context- and research-based description of outreach goals to external stakeholders, such as funding agencies and the national organizations that support these chapters. Additionally, these purposes may help faculty in designing learning experiences and outcomes for service learning courses (*e.g.,* Donaghy & Saxton, 2012) and/or professional service experiences (*e.g.,* Morgan Theall & Bond, 2013).

The lack of meaningful data about event evaluation stresses the need to align outreach evaluation with the purposes/goals of an event, which is called for by the National Academies' report (National Academies of Sciences Engineering and Medicine, 2016). The findings also suggest to national organizations that evaluation may not be a common practice in outreach, despite the organizations awarding recognitions for outreach programming. Organizations can promote more and better outreach evaluation by focusing awards criteria on event quality and alignment with the framework proposed by the National Academies, which emphasizes evaluating events.

Investigation 2:

The findings presented about student understanding of chemistry underlying common outreach activities have important implications for teaching and learning in chemistry. Because the sample includes a variety of institutions, and likely instruction types, the prevalence of misconceptions found in this study (including exothermic bond breaking) suggest a need for increased dissemination of the misconceptions literature and curricular reform efforts. Additionally, since these college student outreach practitioners have of the goal of *audience learning* during outreach, a close examination of what children/younger students are actually learning and taking away from their outreach experiences is needed. Outreach planners, including faculty soliciting college student organizations for outreach experiences, must carefully consider their desired goals for outreach events and how those are achieved by those facilitating the events. Since teacher content knowledge is related to having the skills to successfully teach the content, the likelihood that younger students/children are actually learning during these events is low. Considering the number of misconceptions these college students may be bringing to their outreach teaching, it is further likely that if younger students/children are learning during these events, they are learning the misconceptions of the college students rather than accurate chemical concepts. Additionally, the assumption that a student who passed a college chemistry course meaningfully learned the material must be challenged. College students must carefully consider their goals for outreach events, the training they have in teaching and learning, and how well they understand the chemistry embedded in the activities they are facilitating. Becoming aware of the connection between content knowledge and pedagogical content knowledge is one step in improving college student training for teaching and learning in outreach, which may help to improve the impacts of their informal chemistry teaching.

The diversity of teaching/learning beliefs, particularly those contrary to learning theories, suggest the need for training that targets the mechanisms of learning and best practices for teaching. Students also express a need for help from ACS and ΑΧΣ to address training deficits that may be leading to college students teaching misconceptions during their outreach events. As such, the national organizations ACS and ΑΧΣ need to critically examine the resources and support they provide these college students/chapters, and provide more guidance to support their outreach efforts.

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APPENDIX A: COGNATE PROJECT

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Pratt, Justin. M.; Birk, James P.; Tierney, David L.; Yezierski, Ellen J. (2017) Combining Novel Visualizations and Synthesis to Explore Structure–Property Relationships Using Cobalt Complexes. *Journal of Chemical Education*, *94* (12), 1952–1959.
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Author Contributions:

Pratt was the lead researcher in charge of synthesizing other author comments, creating HTML webpage for the modules, implementing the activity, analyzing results, and drafting the manuscript.

Birk provided inorganic expertise, and was in charge of turning storyboard drawings into animated graphics used in the modules.

Tierney provided inorganic expertise and helped ensure that the Molecular Orbital Diagrams were accurate.

Yezierski provided pedagogical expertise, and was in charge of helping Pratt construct the modules with appropriate scaffolding by using the Learning Cycle approach.

JOURNAL OF CHEMICAL EDUCATION

Laboratory Experiment

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Combining Novel Visualizations and Synthesis To Explore Structure–Property Relationships Using Cobalt Complexes

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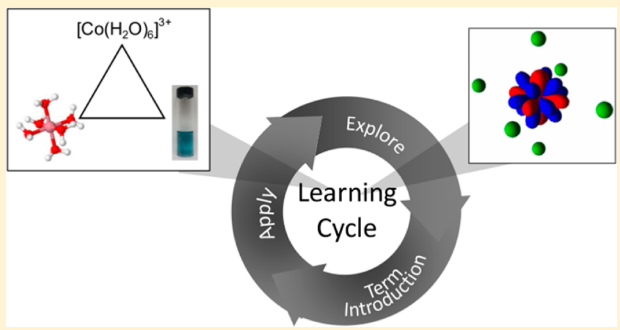
Supporting Information

ABSTRACT: Animations and static visualizations can greatly help students think about concepts on the particulate level. A laboratory activity introducing Crystal Field Theory and Ligand Field Theory was developed based on multiple theories of science learning and pedagogies and combined multiple learning cycles with particulate, macroscopic, and symbolic representations. Through a combination of self-paced online modules and in-class inorganic syntheses, the majority of students met the learning goals relating structure to properties for cobalt(III) complexes.



KEYWORDS: *Second-Year Undergraduate, Upper-Division Undergraduate, Inorganic Chemistry, Laboratory Instruction, Inquiry-Based/Discovery Learning, Multimedia-Based Learning, Aqueous Solution Chemistry, Crystal Field/Ligand Field Theory, UV–Vis Spectroscopy, Misconceptions/Discrepant Events*

INTRODUCTION

A new activity introducing Crystal Field Theory (CFT) and Ligand Field Theory (LFT) was developed and tested. The activity combined two new multimedia modules with a laboratory experiment adapted from Riordan, Jansma, Fleischman, Green, and Mulford.[1] Multiple theories of science learning and pedagogy, including one specific to chemistry, guided the development of the activity and are described in the following section.

Animations and Multimedia

As noted by Johnstone, chemistry requires thinking on three different levels (particulate, symbolic, and macroscopic).[2,3] Research in chemistry education has shown that teaching with all three levels leads to more conceptual understanding and less misconceptions for students.[4−6] However, depicting the particulate level of chemistry can be difficult due to the highly abstract, unobservable nature of atoms, ions, and molecules. Creating animations and multimedia simulations to represent the particulate level and using them in instruction[4−13] requires far less technical expertise compared to even ten years ago.

Research on animations and simulations has produced guiding principles for the development of multimedia that promotes student understanding. Mayer summarized the literature and outlines principles that lead to deeper learning based on the Cognitive Theory of Multimedia Learning.[14] Principles applicable to this activity are

(1) Multimedia principle: using both pictures/animations and words.
(2) Coherence principle: using pictures/animations simultaneously not successively.
(3) Personalization principle: using conversational style words/language rather than formal style.
(4) Interactivity principle: letting learners control the rate of the presentation.
(5) Signaling principle: signaling key portions or aspects of the animations to focus the learner's attention.

In this activity, these five principles were used in the development of the multimedia modules to encourage deeper learning for students.

Learning Cycle and Discrepant Events

The learning cycle proposed by Robert Karplus relies heavily on a feedback loop between students and the content under study.[15,16] The cycle consists of three steps: (1) exploration, (2) term introduction, and (3) application. As chemistry content is very abstract and relies heavily on meaningful connections among Johnstone's three levels, the learning cycle encourages students to use science practices and learn naturally in accordance with what neuroscience has shown as how the brain learns.[15−18]

In the first step of the cycle (exploration), students learn through their interactions with new material or phenomenon. This step prompts students to use their prior knowledge and helps them develop interest and curiosity in the content. The

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second step (term introduction) helps answer questions that arise during the first phase that students cannot answer. By introducing the concepts after exploration, students have concrete experiences to apply the new content to and make meaningful connections.[19−21] The final step of the cycle (application) has students apply the new concept(s) to additional examples or new situations. As new situations arise, the cycle then repeats itself such that students explore new material now equipped with relevant prior knowledge. The iterative nature of this pedagogical approach enables students to quickly build conceptual understanding as they move from concrete, simple ideas to more abstract, complex ones. The learning cycle guided the development of the multimedia modules as multiple iterations of the cycle were needed to build concrete ideas that bridge to more complex concepts.

A discrepant event was also used in this activity as a means of creating a "need-to-know" for students and helping drive student exploration of new content. This approach has been used successfully in laboratory activities in this *Journal* before, as the approach helps students learn.[22−24] The mechanism by which learning occurs in a discrepant event is explained by Conceptual Change Theory.[25] In this theory, accommodating new information refers to a learner changing their mental model, as new information does not fit their existing understanding. One condition required for this change to occur is that a learner must experience some dissatisfaction with their existing understanding, which discrepant events purposefully create. In this activity, this dissatisfaction helped motivate students to accommodate new information by exploring abstract concepts on the particulate level to explain their laboratory-collected data.

Experiments in Coordination Chemistry

Since the 1960s, many different laboratory activities have been published to help students explore concepts underlying coordination chemistry.[1,26−39] Ranging from general chemistry to advanced courses, coordination complexes provide interesting chemistry for students to explore accompanied by highly colored, macroscopic phenomena. However, these experiments merely provide procedures with a "cookbook" approach where students verify that they obtained the desired (already known) result. Although this verification approach may be aligned with the application phase of the learning cycle, it does not allow for exploration, using science practices, and concept development. In this new activity, the learning cycle pedagogy has been combined with multimedia/animations and multiple representations to promote concept development and meaningful understanding of CFT and LFT.

■ EXPERIMENTAL OVERVIEW

Coordination chemistry requires mastery of CFT and LFT. Textbook representations used to teach these topics are highly symbolic in nature with a wealth of prior knowledge assumed.[40−42] This laboratory activity introduces students to the core structural concepts underlying CFT and LFT through the use of novel visualizations, which employ Johnstone's three levels, and a learning cycle framework coupled with hands-on inorganic syntheses. The students first complete a prelab module designed to elicit prior knowledge and introduce CFT. The students then synthesize five cobalt(III) complexes through various techniques and obtain UV−vis spectroscopic data. Finally, the students complete a postlab module where data are analyzed and LFT is introduced to give students explanatory power. The entire activity specifically helps students make connections between complex structure and properties by analyzing particulate and macroscopic data. To evaluate the efficacy of the aforementioned design features as well as students meeting the learning objectives for the activity, Institutional Review Board (IRB) approval to collect student data was obtained. Twelve students completed the activity and data from consenting students (N = 11) are presented throughout the experimental overview to better illustrate particular aspects of the instructional design and to provide evidence of students meeting the learning objectives. For the purposes of this manuscript, the multimedia-based prelab and postlab assignments are referred to as modules. Laboratory experiment or experimentation refers to the in-lab portion in which students synthesize complexes and gather data. Activity refers to the entire experience (prelab module, experiment, and postlab module). The following sections describe the learning goals (LG) for the overall activity as well as explain each of the components.

Learning Goals of Activity

Upon the completion of this activity, students will be able to

(1) Explain what gives rise to the colors of complexes.
(2) Synthesize various cobalt(III) complex ions.
(3) Interpret UV−vis spectroscopy and its relationship to *d*-orbital splitting.
(4) Construct spectrochemical series from UV−vis data and observations and evaluate them using literature.
(5) Describe the differences between Crystal Field Theory and Ligand Field Theory in terms of orbital overlap.

The activity was originally designed for an upper-division advanced synthesis laboratory course with prior knowledge from general chemistry and organic chemistry assumed; no lecture was associated with the course, and the activity was designed to be self-contained/standalone and build on students' prior knowledge. The careful design of the experiment using tested pedagogical designs makes it easily adaptable to a sophomore-level foundations of inorganic chemistry course as well as an upper-division advanced inorganic course as a means to introduce CFT and LFT.

Prelab Module

The prelab module is online and self-paced with embedded guiding questions that students complete individually prior to experimentation. The module is self-paced in accordance with the interactivity principle, and the structure of the module combines animations and text on the same page with coloring and shading used to key students to specific aspects (multimedia, coherence, and signaling principles). The text and questions also use conversational language aligned with the personalization principle.[14] Incorporating these multimedia principles helps decrease cognitive load for the students while also promoting deeper learning. A learning cycle framework was also used in the development of the module in which multiple cycles were embedded throughout to help students apply their prior knowledge to new material and facilitate the construction of concepts by building up from concrete to abstract.[15,16]

The prelab module begins by first eliciting students' prior knowledge regarding orbitals, electron configurations, and complex colors through the lens of CFT; the students are guided through Lewis bonding and how it is applied to CFT.

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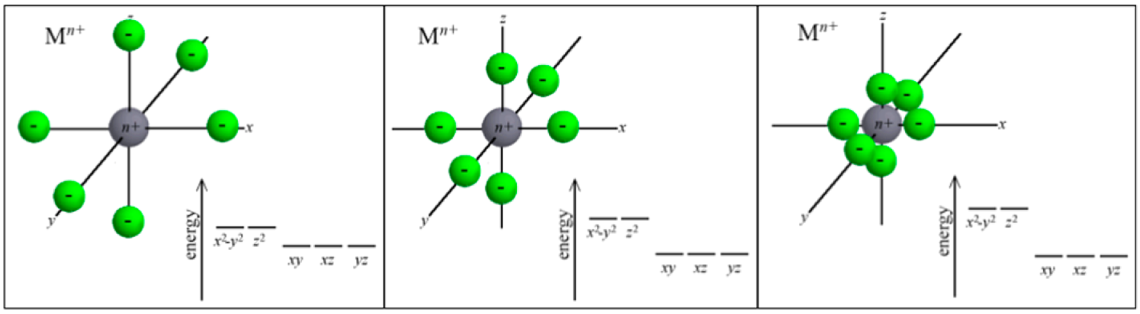

Figure 1. Time-lapsed image of an animated graphic that shows how *d*-orbital potential energies change as negatively charged point charges approach a positively charged metal center (M^{n+}).

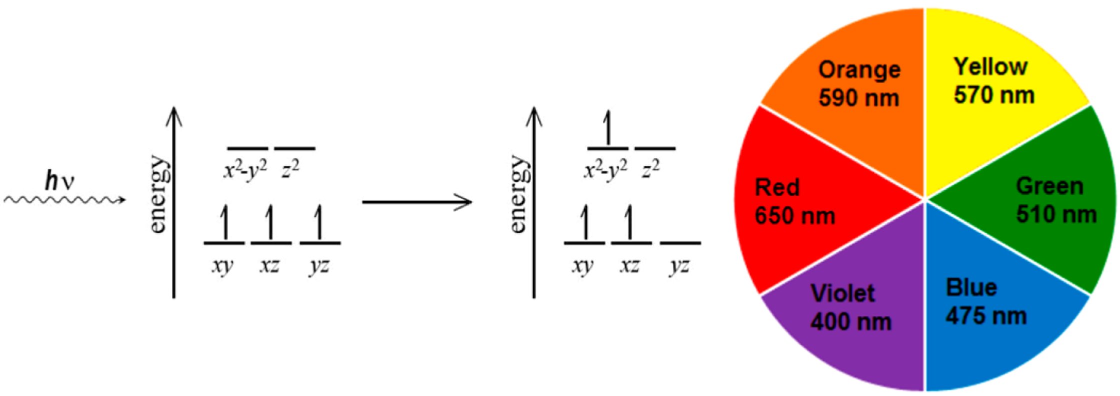

Figure 2. Representative visualizations from the prelab activity detailing absorption and the color wheel.

The structure of the questions focuses students' attention on energy and its relationship to structural changes (specifically *d*-orbital energy changes). Figure 1 shows a time-lapsed image of an animated graphic which introduces students to a crystal field and how *d*-orbital energy levels change as point charges approach the metal center. Students then apply the idea of *d*-orbital energy changes to absorption, emission, and observable complex ion color (see Figure 2 for representative graphics).

By using a color wheel, transmittance of light is introduced to help students relate observable complex color (macroscopic level) to the wavelength(s) of light being absorbed and structural features of the complexes (particulate level). The prelab module culminates in a student-generated prediction that summarizes CFT and relates observable complex color to the energies of the metal's *d*-orbitals. Because of the limitations of CFT, the activity is purposefully designed such that students relate geometry to color by only considering sigma bonding interactions. As such, students predict that different complex-ion colors are caused by different complex geometries (meaning different *d*-orbital splitting patterns/arrangements) as shown in the example student quote, "If all of the complexes were different colors, I would assume that different geometries are being assumed when the ions are formed. This is due to the fact that different geometries give rise to different differences in d-orbital energy levels and therefore this would cause the absorbed wavelengths of the complexes to be different."

Data collected during the laboratory experiment test this prediction leading to a discrepant event where data do not support their prediction, as complex geometry does not accurately predict complex color. This discrepant event provides a "need-to-know" for students and primes them for learning a theory that does accurately explain their results, LFT: the focus of the postlab module.

Laboratory Experiment

Once students have completed the prelab module, students synthesize five different octahedral cobalt(III) complex ions during the laboratory experiment portion of the activity. The ligands used for the syntheses are glycine (gly), oxalate (ox), water, phenanthroline (phen), and cyanide (CN). All five syntheses were modified from Riordan et al.[1] to ensure that five complexes could be synthesized and analyzed with UV−vis spectroscopy during a single three-and-a-half-hour laboratory period; major modifications were incorporated to minimize waste for a more cost-effective laboratory experience. Overall, the syntheses the students perform are fairly simple as they are not air sensitive and use laboratory techniques not uncommon to general chemistry experiments (making a standard solution, filtration, decanting, stirring, and heating). The five complexes students synthesize are shown in Figure 3.

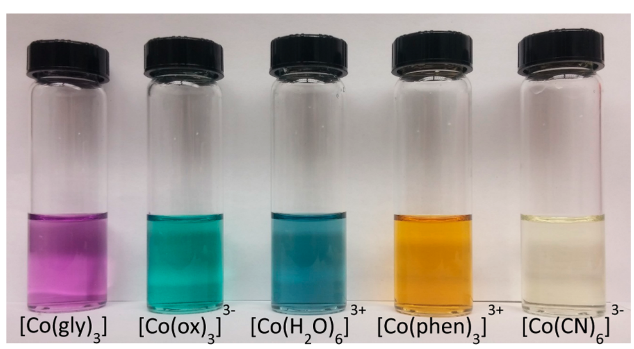

Figure 3. Image of the five cobalt(III) complexes synthesized during the experiment. From left to right: glycine complex, oxalate complex, water complex, phenanthroline complex, and cyanide complex.

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Throughout the experiment, the students are not provided with formulas for the complexes; they are only told the name of the ligand (e.g., the glycine complex, the cyanide complex, etc.). This was done purposefully so as not to reveal structural information about the complexes since predictions made required students to relate complex color to structure. Noticeably, the five complexes are strikingly different in color, which, according to the students' predictions, indicates that each complex has a different geometry. Representative student UV−vis data are shown in Figure 4; peaks obtained for each complex match data from Riordan et al.[1]

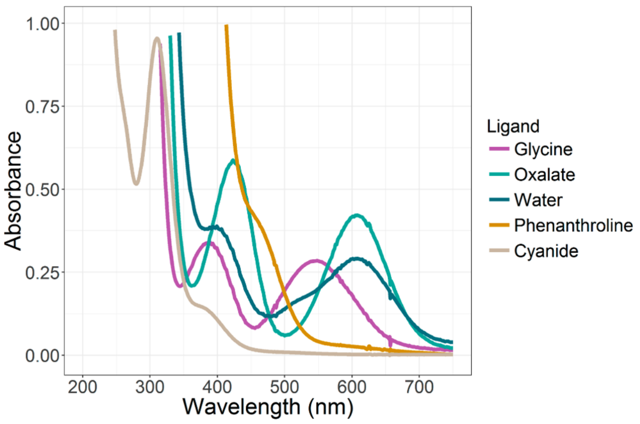

Figure 4. Representative student UV−vis data for all five cobalt(III) complexes.

Postlab Module

The postlab module, like the prelab module, was also guided by the principles of multimedia learning, includes multiple learning cycles, and is completed independently online. The postlab module includes an introduction to LFT, quantitative and qualitative data analysis, discussion of assumptions and errors, and a comparison of results to relevant literature.

Students first analyze their predictions from the prelab module. On the basis of their predictions, students determine that all five cobalt(III) complexes must be of different geometries since they are all different colors. This conclusion is illustrated by this example quote, "I would deduce that each of the complexes had different geometries about the central atom so the d-orbitals differed in energy levels."

Students then analyze symbolic and particulate representations (Figure 5) for all five complexes to determine geometry from coordination number (including introducing monodentate and bidentate ligands).

This leads to cognitive dissonance; students realize their predictions were incorrect (and that CFT is limited): "My prediction was incorrect, because I believed that different structures led to changes of color. In fact, the structures of the complexes were all the same, but they were still different colors."

To resolve this dissonance, LFT is introduced. Students first review CFT and connect it to orbital overlap and σ bonding interactions (Figure 6).

However, to understand why octahedral complexes can be different colors, the full complexity of metal−ligand interactions must be considered including both σ and π bonding interactions (Figure 7).

LFT was explored in more depth through the introduction of Molecular Orbital (MO) Theory and MO diagrams. As prior knowledge of general and organic chemistry was assumed, a brief overview of MO theory was given before students apply it to the σ and π interactions for their synthesized complexes. This was done stepwise through multiple learning cycles where students were introduced piece-by-piece to MO diagrams, via signaling, with the specific example of carbon monoxide (Figure 8).

Students then apply their understanding of MO diagrams to a new situation (oxygen) to identify the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO). This learning cycle framework continues throughout the postlab module to introduce π-donating and π-accepting ligands and how ligands affect the *d*-orbital splitting value (Δ). Representative graphics from the MO section of the postlab module are shown in Figures 9 and 10.

Once students complete the section addressing LFT, they are introduced (or reintroduce from general chemistry) to the spectrochemical series emphasizing the relationship between ligand strength and Δ values. Students calculate approximate Δ values for the five complexes they synthesized and rank them into a data-derived spectrochemical series. Students also construct a spectrochemical series qualitatively using the observable (macroscopic) colors of the complexes and the color wheel. Example student-derived spectrochemical series are shown in Figure 11.

Students also summarize their spectrochemical series through the lens of LFT (emphasizing orbital overlap and HOMO/LUMO). One student discussed the strongest ligand, cyanide: "Cyanide was the strongest ligand, so it has the greatest energy difference Δ between the split d-orbitals. This means that this molecule [cyanide] is bonding to the metals' LUMO but then accepting pi density in the molecule's HOMO."

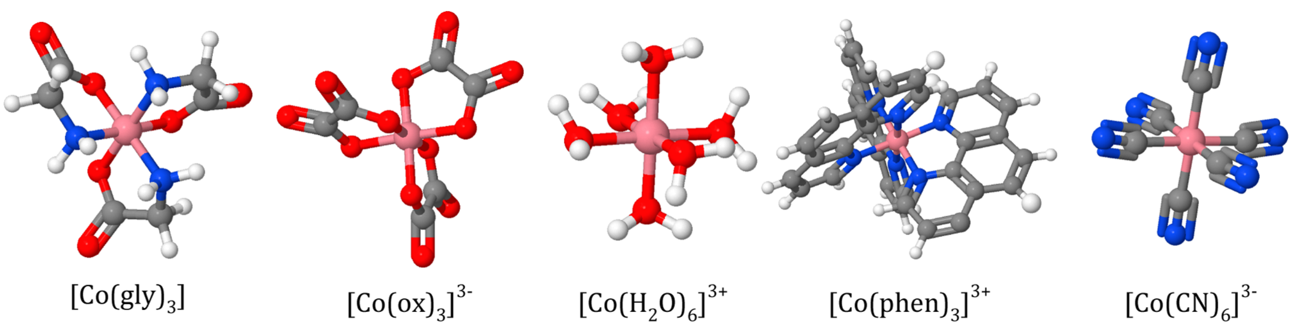

Figure 5. Particulate representations of the five cobalt(III) complexes synthesized during the experiment (created using Jmol).[43]

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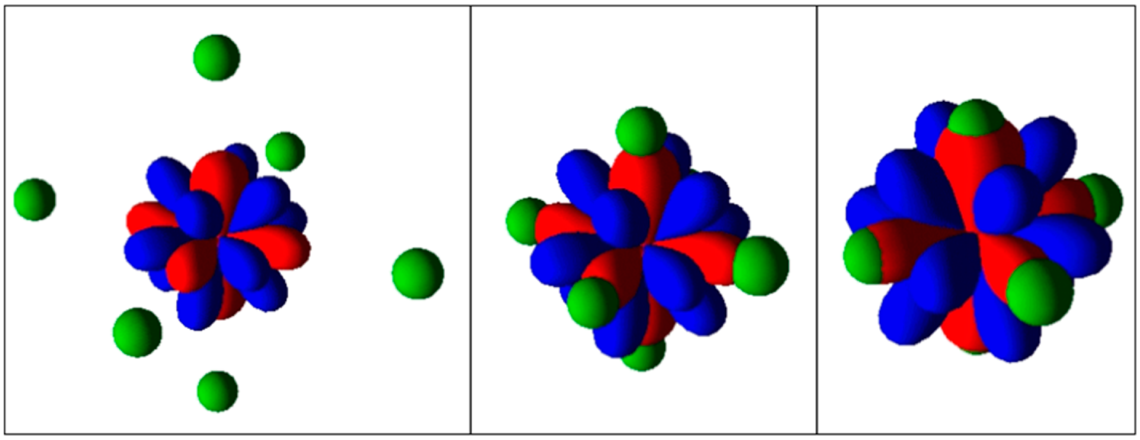

Figure 6. Time-lapsed image of an animated graphic that shows how *s* orbitals of six monodentate ligands overlap with the *d*-orbitals of a metal center illustrating σ bonding; as the six ligands approach the metal center, the graphic zooms in and rotates to help students clearly see all of the interactions occurring.

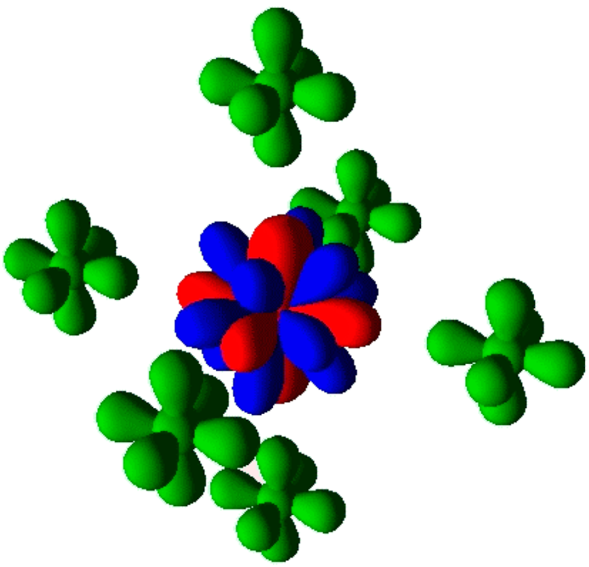

Figure 7. One frame from an animated graphic showing the overlap between *s*- and *p*-orbitals of six monodentate ligands and the *d*-orbitals of a metal center to illustrate σ and π bonding.

The quantitative and qualitative data students obtained lead to two different spectrochemical series. Spectrochemical series from the literature and Δ values determined from Tanabe-Sugano diagrams are provided for students for comparison. This leads students to discuss assumptions, error, and limits of detection, as Δ values for water and oxalate are very similar,[1,42,44−47] thus giving evidence that supports both spectrochemical series.

■ HAZARDS

Standard laboratory safety procedures should be followed including the use of appropriate personal protective equipment (PPE) such as wearing gloves and goggles. All syntheses should be performed in a well-ventilated area (in a fume hood or underneath a snorkel duct). Potassium cyanide is very hazardous, and prolonged or repeated exposure may cause damage to organs. It is also very toxic to aquatic life and proper disposal must be carried out. Contact with acids liberates a very toxic gas. Nitric acid and hydrogen peroxide are corrosive and may cause irritation to skin and eyes. Approaches for handling or omitting potassium cyanide to address these safety precautions are included in the Supporting Information.

■ RESULTS AND DISCUSSION

This activity was conducted by 12 students during the spring of 2016 in an upper-division advanced synthesis course. Students worked in pairs during the experimentation portion and completed the pre- and postlab modules individually.

Prior to implementation, the activity was pilot tested; two undergraduate students tested the pre- and postlab modules (with author-collected data), while four graduate students tested the procedures for the syntheses and data collection. Minor modifications to the handouts were made to ensure clarity of questions and procedures. The results from these tests were not presented here, as the target audience of the course differed greatly from those who pilot tested the activity. However, it is worth noting that minimal modifications were necessary adding to the quality of the activity design.

During implementation, all students were able to complete the online prelab module (and accompanying handout) prior to class. All six pairs of students completed the syntheses and UV−vis data collection during a single laboratory meeting (3.5 hr). Student data were drawn from student responses and observations made during the experimentation portion as well as student responses to two final exam questions aligned with learning outcomes from the activity (LG 1 and 5). These responses were evaluated to determine which (and to what extent) learning goals for the activity were met by students.

Achievement of Learning Goals

The numbers of students who met each of the five learning goals for the activity are shown in Table 1. The majority of the students either met or exceeded expectations for every LG. Failing to meet a LG meant students either did not provide a correct answer or left a question blank. Meeting a LG meant students provided the correct answer without any detail or explanation. Exceeding a LG meant that students not only provided a correct answer, but also explained with great detail. As a note, LG 2 could only be failed or met as it refers to completing the five syntheses in the experimentation portion; the rest of the LGs were assessed using responses from the pre- and postlab modules and the final exam, which were evaluated with an answer key (included in the Supporting Information).

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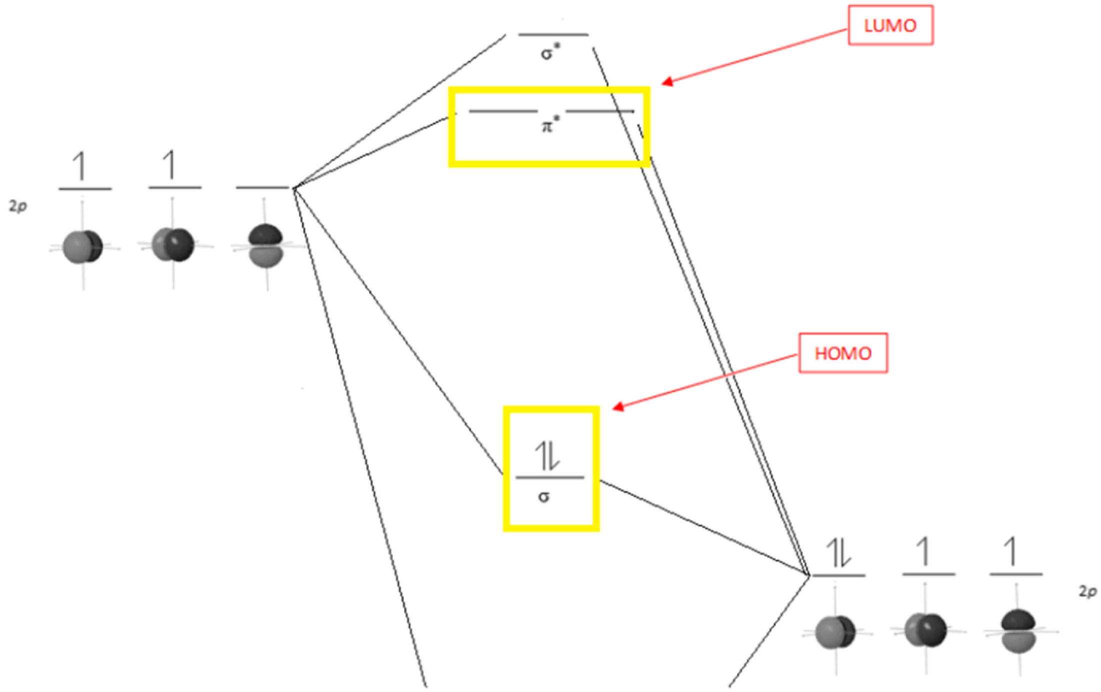

Figure 8. Excerpt from MO diagram for carbon monoxide illustrating how students are signaled to focus on key aspects of the diagram.

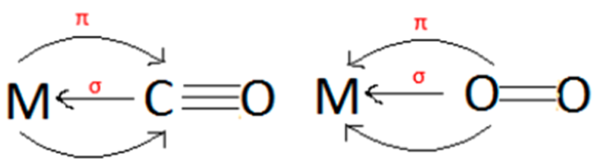

Figure 9. Symbolic representations conceptually illustrating π-accepting (left) and π-donating (right) ligands bonding to a metal center (M).

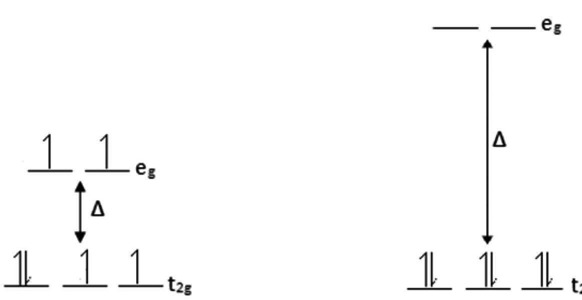

Figure 10. Symbolic representations illustrating relative Δ values for π accepting (left) and π donating (right) ligands.

Student-derived Spectrochemical Series

Quantitative using UV-vis data:

Cyanide > Phenanthroline > Glycine > Water > Oxalate

Qualitative using observational data:

Cyanide > Phenanthroline > Glycine > Oxalate > Water

←

Increasing ligand strength

Figure 11. Representative student-derived spectrochemical series.

Table 1. Achievement of Learning Goals[a]

Learning Goal	Fails	Meets	Exceeds
1. Students will be able to explain what gives rise to the colors of complexes.	1	4	6
2. Students will be able to synthesize various cobalt(III) complexes.	0	11	n/a
3. Students will be able to interpret UV−vis spectroscopy and its relationship to *d*-orbital splitting.	3	4	4
4. Students will be able to construct spectrochemical series from UV−vis data and observations and evaluate them using literature.	2	8	1
5. Students will be able to describe the differences between Crystal Field Theory and Ligand Field Theory in terms of orbital overlap.	1	4	6

[a]Students' answers from the postlab activity and final exam ($N = 11$) were analyzed holistically for evidence of achieving the LGs. Students who provided an incorrect answer or left it blank failed to meet the LG. Meeting the LG was providing accurate answers/correct ideas without detail or explanation. Exceeding the expectation was providing accurate answers/correct ideas with clear detail and explanations.

While some students did fail to meet a few of the LGs, these results are promising as learning and connecting CFT and LFT with Molecular Orbital Theory and symmetry/Group Theory typically span the majority of the semester in the advanced inorganic chemistry course at this university. With the majority meeting or exceeding expectations when these ideas were introduced for the first time (in a week timespan), these results are very positive. Many students even asked if there were opportunities for more in-depth treatment of the material and were told about the advanced inorganic course at the university.

■ SUMMARY AND CONCLUSIONS

This new multimedia and laboratory based activity was designed and successfully implemented in an advanced synthesis laboratory course. Students were able to complete the pre- and postlab modules to learn the new content as well

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as analyze data obtained through experimentation. The learning cycle structure that was used in the modules helped students quickly build conceptual understanding, apply it to new situations, think on the particulate level, and relate structure to properties. These results were illustrated by students' remarks, "I quickly learned something I didn't know before!" and "It was nice to think about orbitals for a change."

The Supporting Information contains all of the materials needed to make the experiment ready for implementation in both laboratory settings (as implemented by the authors) or in lecture settings as a dry lab. With the learning cycle framework, this activity can easily be used in a foundations of inorganic chemistry course or in an advanced inorganic chemistry course to introduce CFT and LFT. The authors welcome any information about the performance of this activity in other contexts.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00193.

> Instructor's guide; student hand-outs; example data packet; links to online pre- and postlab modules (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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Instructor Guide

Combining Novel Visualizations and Synthesis to Explore Structure-Property Relationships using Cobalt Complexes

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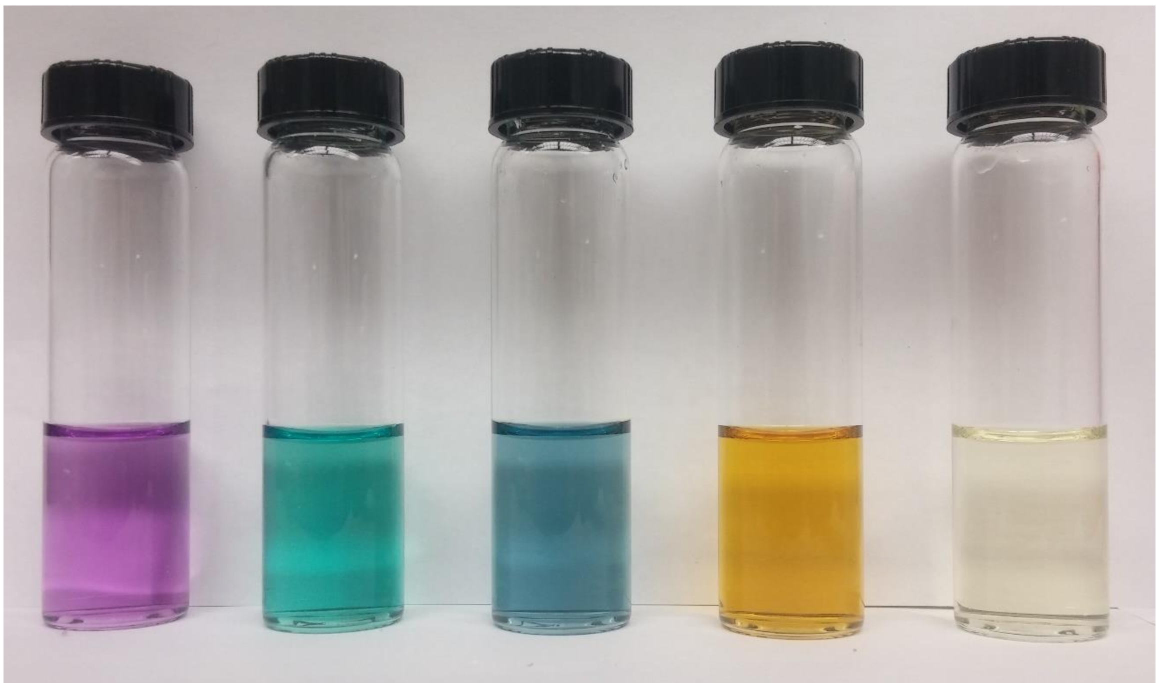


From Left to Right:
Glycine Complex, Oxalate Complex, Water Complex, Phenanthroline Complex, and Cyanide Complex

Table of Contents

Student Learning Goals (LGs):

Upon the completion of this experiment, students will be able to:

1. Explain what gives rise to the colors of complexes
2. Synthesize various cobalt(III) complex ions
3. Interpret UV-Vis spectroscopy and its relationship to *d*-orbital splitting
4. Construct spectrochemical series from UV-Vis data and observations and evaluate them using literature
5. Describe the differences between Crystal Field Theory and Ligand Field Theory in terms of orbital overlap

Prior Knowledge:

Prior knowledge related to geometries of compounds, electron configuration and order of electrons lost during cation formation, and UV-Vis spectroscopy are all necessary. These are all typically addressed in General Chemistry and Organic Chemistry.

The pre-lab portion of this experiment covers Crystal Field Theory, complex color, and reviews UV-Vis spectroscopy.

Assessment:

The assessment is built into the pre-lab and post-lab modules. Students are asked questions throughout each module which are designed to help them make sense of representations and data to synthesize conceptual understanding of structure-property relationships. Student handouts and keys have been provided.

Example Exam Questions:

1. In the experiment "Synthesizing and Investigating Cobalt Complexes: UV-Vis and Structure-Property Relationships," Crystal Field Theory (CFT) hindered you in fully explaining the interactions in complex ion formation. Ligand Field Theory (LFT) provided more information to help you explain the structure-property relationships in these complex ions. What are the differences between CFT and LFT? Explain how you used these theories to examine your data.

   Answer: CFT only views ligands as point charges which are similar to sigma interactions between the metal and the ligands. LFT examines both sigma and pi interactions between the metal and the ligands. LFT allowed the students to explain pi-donating and pi-accepting ligands and how they affect *d*-orbital splitting.

2. Explain what gives rise to the colors of complex ions.

   Answer: *d*-orbital splitting changes what wavelength of light is absorbed by the complex; the larger the 'split' (energy difference) the higher the energy of light absorbed (and therefore smaller wavelength of light). We observe the color being reflected by the complex (the complimentary color/wavelength of what is being absorbed).

Assessment for this activity should be done holistically, as the questions in both the pre lab and post lab build on each other through the learning cycle framework. However, specific questions should be weighted more heavily when assessing the learning goals as outlined below:

LG 1 – Example exam question 2

LG 2 – Only assessed based on student completion of the syntheses

LG 3 – Post lab questions 18 and 19

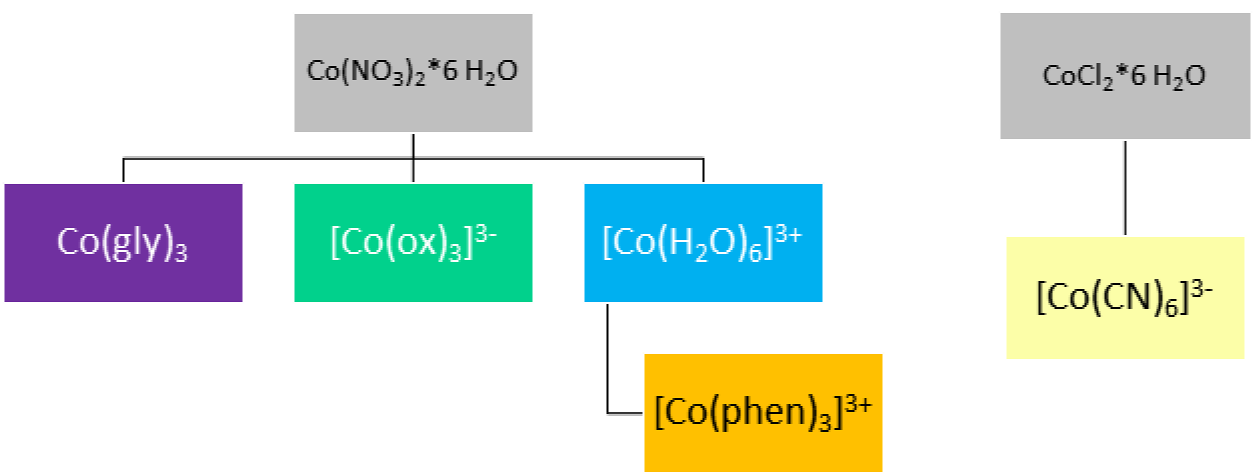
LG 4 – Post lab questions 21-28

LG 5 - Example exam question 1

Outline of Experiment

1. Pre-lab Module – Students complete this module prior to coming to class using a worksheet that accompanies the modules. This can be turned in online via a class website or at the beginning of the lab period.

2. Syntheses – Students synthesize five cobalt(III) complexes from two cobalt(II) salts. [See below for outline of procedure including which complexes are synthesized from what salt and their colors]



3. Spectroscopy – Students obtain UV-Vis data for all five cobalt(III) complexes using water as a blank and a quartz cuvette.

4. Post-lab Module – Once students have synthesized all five complexes and obtained spectroscopic data, students complete the post-lab module. The post-lab module includes data reporting as well as data analysis so no extra report is required. This can be turned in online via a class website or at the beginning of the next lab period.

Hints for Implementation:

This procedure works best if students work in pairs and share the work (i.e. one student can be working on step 2 while another works on step 3). This procedure was implemented in a single 3.5-hour class period; if students do not split up the work, the students may not be able to complete everything during the allotted time. Depending on the course, the synthesis and the spectroscopy may be split into two different class periods to alleviate some of the time concerns. The experiment can also be implemented as a dry lab/in-class activity with the accompanying example data given to students to analyze rather than collecting the data themselves. More detail about possible modifications to the experiment to fit various instructional contexts can be found in the Possible Modifications section.

The following paragraphs provide specific procedural guidelines for the synthesis and spectroscopy portions of the experiment:

- When students are performing steps 5 and 6 (Water Complex Part 1 and 2), the syntheses must be performed quickly, as the saturated solution of sodium bicarbonate can create an excess of hydroxide ion causing cobalt(II) hydroxide to form. $Co(OH)_2$ is very insoluble in water and will precipitate as a brown solid. If this happens students must start over at the beginning of step 5 (Water Complex Part 1).
- For some of the complexes, it is difficult to discern the location of the local maximum/peaks. Students may need help determining the peaks. Depending on the software being used, students may also need to graph data to create their own spectra. It is recommended to analyze wavelengths from 200-900 nm; important peaks will not appear outside of this range. Wavelengths on the lower end of the spectrum (closer to the UV range) become hard to discern depending on how well the complexes were made as well as the precision/accuracy of the instrument. Using a quartz cuvette and blocking as much extra light as possible will help students obtain well-defined peaks. If absorbances are too high, dilutions may also need to be performed in order to obtain peaks.

Possible Modifications

This activity has applicability in various contexts including synthesis-focused courses (as was implemented by the authors), foundational inorganic courses, and even advanced inorganic courses. Each of these possible environments requires modifications to fit the instructional needs, intended learning outcomes, and prior knowledge of the students. Below are possible ways the activity can be modified to be implemented in contexts other than a synthesis-focused course:

1. The activity can easily be implemented as a dry lab at any level of instruction (foundational or advanced). An example data packet is provided as part of this Instructor's Guide that models the data students see when actually conducting the experiment (macroscopic image of the complex and accompanying UV-vis spectrum).
2. While the syntheses have been optimized to work well for a single 3.5-hour class period, the syntheses could easily be spread across multiple days (or performing syntheses one day and spectroscopy another day). We found all of the complexes to be stable up to one week following the synthesis; after a week the complexes started to reduce back to Co^{2+} which is easily noted by pink solutions.
3. One possible variation is to introduce students to Crystal Field Theory prior to implementing this activity. This variation minimizes the use of the Pre-lab Module, since the students have already been introduced to the content. The activity can then be implemented beginning with the syntheses (or as a dry lab with the sample data packet). However, one key pedagogical design element is the prediction students make at the end the Pre-lab Module that is then evaluated with the data collected. This prediction leads to cognitive dissonance using a discrepant event that provides students a 'need-to-know,' which is addressed in the Post-Lab Module. If the content introduced in the Pre-Lab Module does not match the prior knowledge of the students, the prediction should still be made to be in accordance with how the content is addressed in the Post-Lab Module.
4. In more advanced courses, students can develop (or apply) their skills in searching the literature as part of the Post-Lab Module. Rather than providing the structures of the complexes students synthesized, students can be instructed to search the literature to determine the appropriate structures of the complexes. Adjustments to how the Post-Lab Module is implemented would then need to be made (e.g., skipping some of the beginning pages that address the structures and geometries of the complexes).

<u>Limitations of Activity:</u>

1. This activity was purposefully designed to be an *introduction* to some advanced topics in inorganic chemistry (including Crystal Field Theory, Molecular Orbital Theory, and Crystal Field Theory). As such, it does not discuss every possible consideration of metal-ligand interactions when students approach analyzing data. Specifically, the metal ion (and therefore *d*-electron count) is kept constant throughout the experiment. Therefore, *d*-electron count effects are not addressed. Likewise, effects due to metal charge and metal identity are not addressed in this activity. These constraints cause CFT to be limited to considering only complex geometry in how *d*-orbitals split in energies. Simplifying the content allows the big ideas to be introduced in a week-long activity. It is possible to add an expansion to the end of this activity that explores metal considerations in more detail; however, it was not a learning goal of this activity.
2. Graphics illustrating interactions with metal orbitals and ligand orbitals purposefully do not include the phasing of the orbitals. This was done to minimize cognitive load for students (giving them less information to process) as well as to simplify the interactions between orbitals. As an introductory activity, its goal is to help students develop an overall understanding of CFT and LFT without considering every possible nuance (similar to the

limitations listed in #1). Although this pedagogical choice makes the graphics limited in their use, the graphics can provide a useful starting point to help student visualize the particulate level and orbital interactions.

3. Inorganic chemists operationalize CFT and LFT differently as noted by stark differences in textbook descriptions of the two theories (see Miessler, Fischer, & Tarr, 5th ed. vs Housecroft & Sharpe, 4th ed.). These differences arise from the diversity in simplification, generalization, and explanation in textbooks to convey new information. This activity offers a model that connects student prior knowledge about bonding by pointing out the similarity between the electrostatic approach in CFT and sigma bonding interactions in Valence Bond Theory. This comparison is suitable for this activity as the learning cycle pedagogy is dependent on students connecting new data and observations with prior knowledge.

Ordering Information:

Below is a detailed list for chemical/equipment necessary for this lab. All product numbers and prices come from Sigma Aldrich. Feel free to use other retailers, but we recommend ACS reagents whenever possible. The total cost does not accurately reflect cost per year as many items are bought in bulk and are not required to be purchased every year.

Product Name	Formula	Amount needed for 1 pair/2 students	Amount needed for 6 pairs/12 students	Sigma Aldrich Product Number	Price
Cobalt (II) Nitrate Hexahydrate	$Co(NO_3)_2$* 6 H_2O	0.6306 g	3.784 g	239267-5G	$44.60
Glycine Sodium Salt Hydrate*	$H_2NCH_2CO_2Na$ * 1 H_2O	0.75 g	4.5 g	219517-100G	$59.50
30% Hydrogen Peroxide*	30% H_2O_2	4-6 drops (0.2-0.3 mL)	24-36 drops (1.2-1.8 mL)	216763-100ML	$43.90
3% Hydrogen Peroxide	3% H_2O_2	30 mL	180 mL	(Dilute from 30%)	(Dilute from 30%)
Potassium Oxalate Monohydrate*	$K_2C_2O_4$*H_2O	1.55 g	9.3 g	223425-500G	$80.70
Sodium Bicarbonate*	$NaHCO_3$	4.52 g	27.12 g	S6014-500G	$41.30
4 M Nitric Acid*	4 M HNO_3	40 mL	240 mL	438073-500ML (Must dilute stock solution)	$70.00
1,10-phenanthroline*	$C_{12}H_8N_2$	0.115 g	0.69 g	131377-2.5G	$24.90
Cobalt (II) Chloride Hexahydrate*	$CoCl_2$*6 H_2O	2.55 g	15.3 g	255599-100G	$67.60
Potassium Cyanide	KCN	4.55 g	27.3 g	07810-25G (QUANTITY 2)	2($42.10) = $84.20
Quartz Cuvette*		1	1	Z600288-1EA	$118
				Total:	**$634.70**

*will not have to be purchased annually

Recommended Equipment

In student lab drawers:

Graduated cylinders:

- 10 mL
- 100 mL

Beakers:

- 2 100 mL beakers
- 2 30 mL beakers
- 3 50 mL beakers
- 1 250 mL beaker
- 1 500 mL beaker

Pipette bulb(s)

Permanent marker (for labeling)

Stir rod

Scoopula

Spatula or Microspatula

2 magnetic stir bars (1 small and 1 medium size recommended)

Vacuum filtration apparatus:

- 500 mL Buchner flask (filtration flask)
- Buchner funnel with rubber stopper (70 mm recommended)
- Hose to connect to sink aspirator

Common items:

2 stir plate/hotplate combinations for each pair [Must have one that both heats and stirs, the other one can only stir depending on available equipment]

Filter paper for vacuum filtration (size depends on Buchner funnel; 70 mm is recommended)

D.I. water bottles

Weigh boats (medium and small sized recommended)

Disposable pipettes

Label tape or labels

Vials for storage/transfer to instrumentation (8 dram recommended)

Gloves

Fume hood or snorkel duct for each group

Balance

Quartz cuvette

Lab Preparation

4 M HNO_3 must be prepared from stock solution

Each pair (2 students) needs 40 mL of 4 M HNO_3

For 6 pairs (12 students) you will need 240 mL

3% H_2O_2 must be prepared from 30% solution

Each pair (2 students) needs 30 mL of 3% H_2O_2

For 6 pairs (12 students) you will need 180 mL

An alternative would be to purchase 3% H_2O_2 so dilution/extra preparation is not required. 3% H_2O_2 can be purchased from most drug stores and is rather inexpensive. Diluting the 30% solution may be more cost efficient depending on the size of the course.

Treatment of Reagents

Depending on the laboratory setting, the potassium cyanide can be premeasured for students to ensure proper safety precautions are taken and minimal spilling/waste occurs. Each pair (2 students) will need two separate vials containing:

- 1.56 g potassium cyanide
- 2.99 g potassium cyanide

Student must be encouraged to properly read labels and ensure they are using the correct mass during each step of the procedure. *Alternatively, cyanide may be excluded from the ligands used in this experiment as the color and spectrum observed for the phenanthroline complex should be an adequate example of a strong-field ligand. We encourage instructors to make their own decisions about the use and treatment of cyanide depending on the laboratory set up, availability of fume hoods/snorkel ducts, etc.*

All other reagents/solids can be provided to students to measure out themselves. Larger classes may wish to portion out the materials into smaller bottles to ensure minimal contamination as well as to allow multiple stations for groups to gather materials from.

Ice/Chilled Water

Each pair (2 students) needs to chill 5-10 mL of distilled water

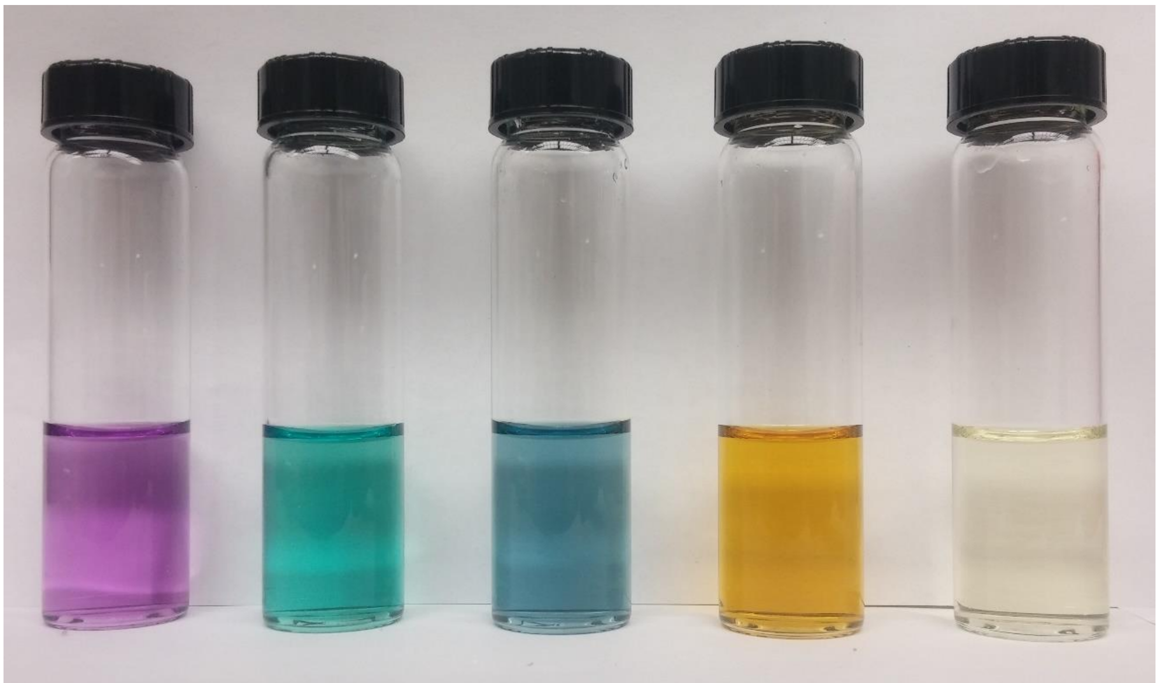
For 6 pairs (12 students) you will need 30-60 mL

One large bucket of ice can be provided for the students to use to create ice baths for their pairs. An alternative is to create one large ice bath to chill distilled water that student groups can sample from.

Example Student Data

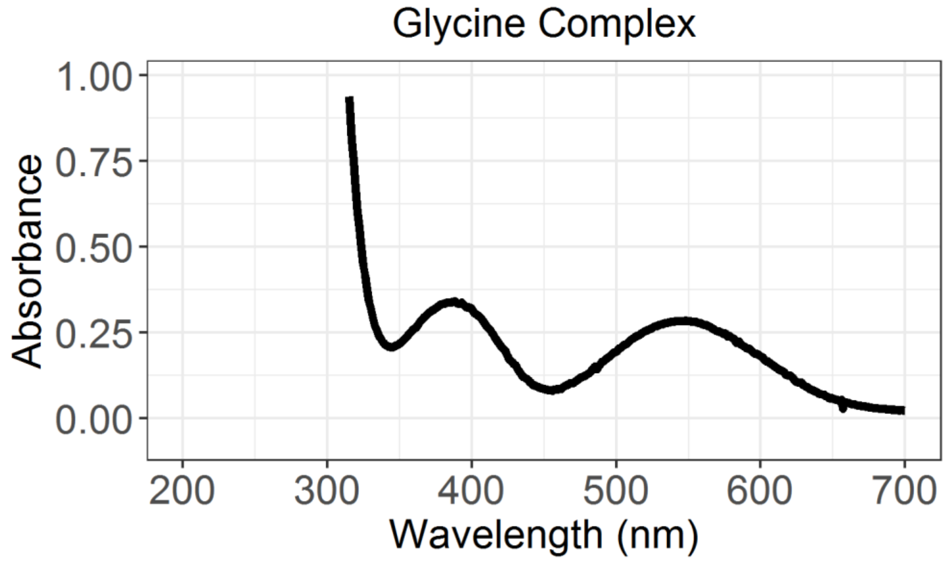
Combining Novel Visualizations and Synthesis to Explore Structure-Property Relationships using Cobalt Complexes

Justin M. Pratt, James P. Birk, David L. Tierney, and Ellen J. Yezierski

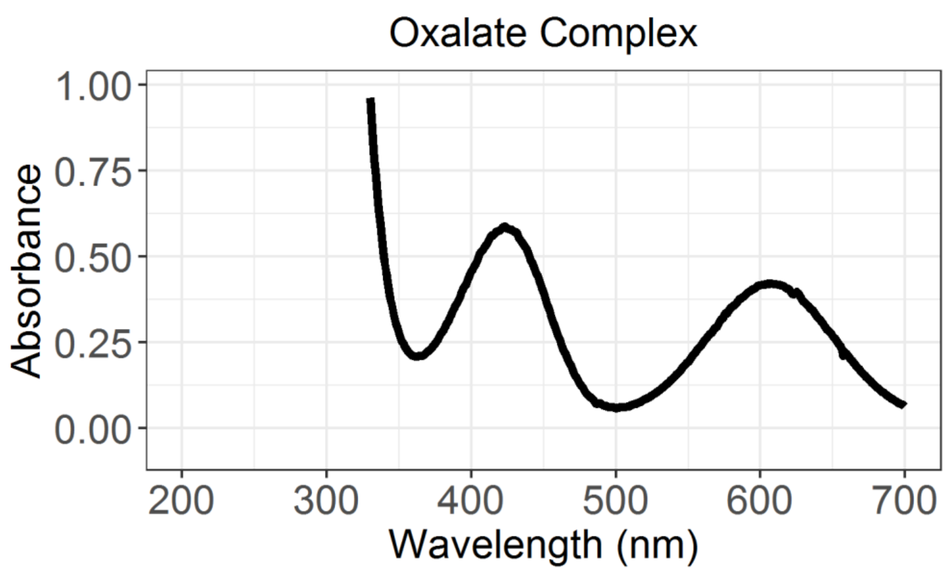


From Left to Right:
Glycine Complex, Oxalate Complex, Water Complex, Phenanthroline Complex, and Cyanide Complex

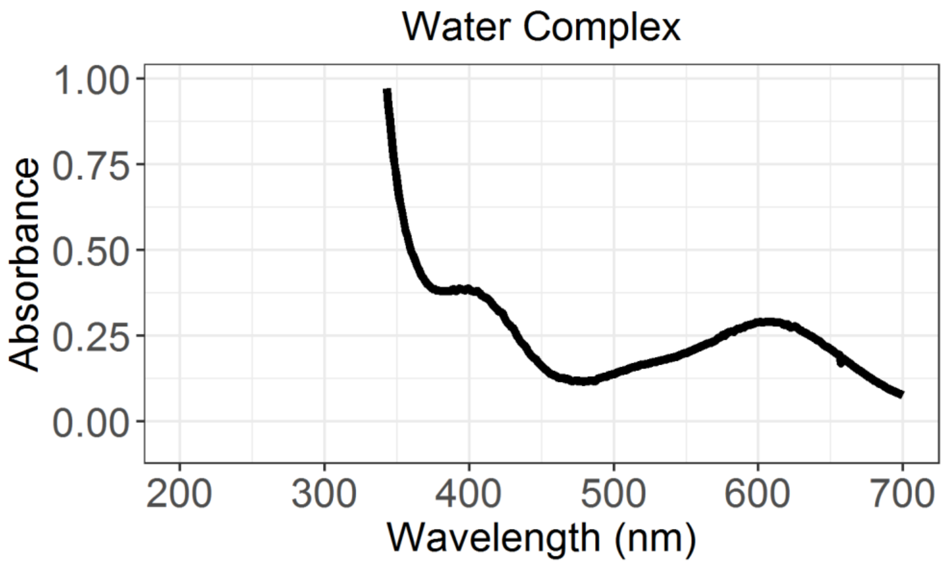
Glycine Complex



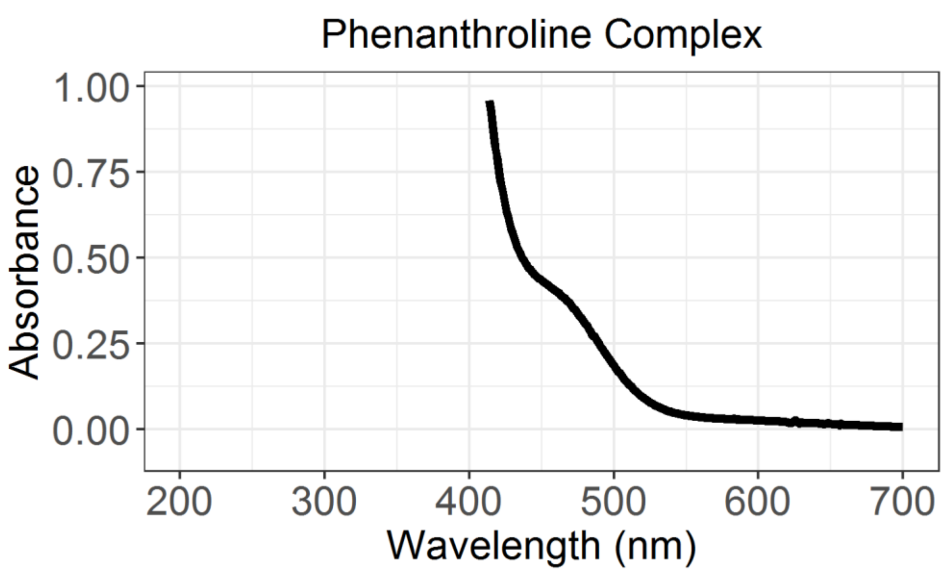
Oxalate Complex



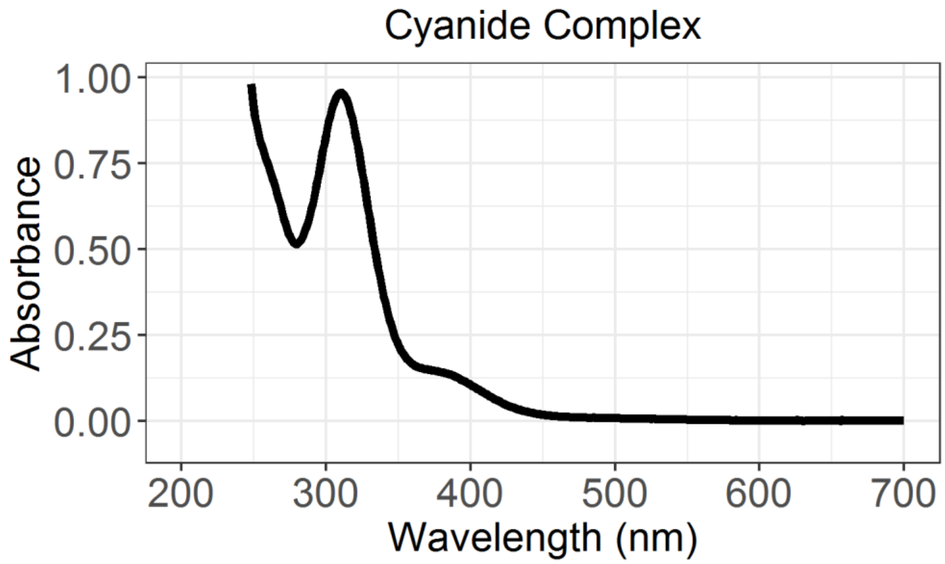
Water Complex



Phenanthroline Complex



Cyanide Complex



Combining Novel Visualizations and Synthesis to Explore Structure-Property Relationships using Cobalt Complexes

Pre-Lab Activity

Directions:

Below is a link to an online module. Progress through the activity answering the questions below *as they appear in the module*. The module is designed to answer the questions in the order they are presented as you build up from prior knowledge to more complex chemical ideas (note: taking notes as you advance through the module may help you complete the assignment). We recommend using Google Chrome, Mozilla Firefox, or Safari as other browsers do not load the module very well.

When you have completed the module (and answered every question), upload this file **that includes your answers** to the course website.

Website: http://chemistry.miamioh.edu/yezierski/PrattCognateWebsite/Prelab.html

1. Using your knowledge from previous courses, describe what is meant by a Lewis base. Give one example and explain why it is a Lewis base.
Answer:

2. How many electrons does V have in its *d* orbitals in this complex (hint: does a first row transition metal lose electrons from the 3*d* orbitals or the 4*s* orbital first?)
Answer:

3. What determines the wavelength of a photon that is absorbed?
Answer:

4. Suppose you have two different products: a green and an orange product. Which absorbs the smallest wavelength?
Answer:

5. Take the $[V(H_2O)_6]^{2+}$ compound from earlier that is a deeper purple, what color and wavelength of light is actually being absorbed by the complex?
Answer:

6. How many ligands would be around the metal center in each of the above arrangements?
Answer: a) Linear: b) Square planar: c) Tetrahedral: d) Octahedral:

7. Based on this information, rank order the various geometries in order of likelihood of absorbing high-energy photons (ranging from lower-energy photons to higher-energy photons), assume V (II) ion with three electrons in the *d* orbitals.
Answer:

8. Using Crystal Field Theory, summarize what gives rise to the different colors of complexes.
Answer:

9. During this laboratory experiment, you will be synthesizing different cobalt complex ions. Using Crystal Field Theory and the ideas behind geometry and complex color, what predictions would you make about the structures of the complexes if all of them were different colors?
Answer:

KEY

Combining Novel Visualizations and Synthesis to Explore Structure-Property Relationships using Cobalt Complexes

Pre-Lab Activity

Directions:

Below is a link to an online module. Progress through the activity answering the questions below *as they appear in the module*. The module is designed to answer the questions in the order they are presented as you build up from prior knowledge to more complex chemical ideas (note: taking notes as you advance through the module may help you complete the assignment). We recommend using Google Chrome, Mozilla Firefox, or Safari as other browsers do not load the module very well.

When you have completed the module (and answered every question), upload this file **that includes your answers** to the course website.

Website: http://chemistry.miamioh.edu/yezierski/PrattCognateWebsite/Prelab.html

1. Using your knowledge from previous courses, describe what is meant by a Lewis base. Give one example and explain why it is a Lewis base.
Answer: **A Lewis base is an electron pair donor. A Lewis acid is an electron pair acceptor. In HCl, the hydrogen ion (H^+) is a Lewis acid because it accepts electrons from Cl^- (Lewis base) to form the bond.**

2. How many electrons does V have in its *d* orbitals in this complex (hint: does a first row transition metal lose electrons from the 3*d* orbitals or the 4*s* orbital first?)
Answer: **3** **V electron configuration: $[Ar]4s^2 3d^3$** **V^{2+} electron configuration: $[Ar]3d^3$**

3. What determines the wavelength of a photon that is absorbed?
Answer: **The energy difference between higher energy orbitals and ground state orbitals.**

4. Suppose you have two different products: a green and an orange product. Which absorbs the smallest wavelength?
Answer: **Orange absorbs the smallest wavelength (~475 nm) while green absorbs a larger wavelength (~650 nm)**

5. Take the $[V(H_2O)_6]^{2+}$ compound from earlier that is a deeper purple, what color and wavelength of light is actually being absorbed by the complex?
Answer: **Absorbs yellow or ~570 nm**

6. How many ligands would be around the metal center in each of the above arrangements?
Answer: e) Linear: **2** f) Square planar: **4** g) Tetrahedral: **4** h) Octahedral: **6**

7. Based on this information, rank order the various geometries in order of likelihood of absorbing high-energy photons (ranging from lower-energy photons to higher-energy photons), assume V (II) ion with three electrons in the *d* orbitals.
Answer: **One way (going from lowest orbital to highest orbital in each arrangement):** **tetrahedral (lowest), octahedral, linear, square planar (highest)** **Another way (going from lowest orbital to next higher orbital in each arrangement):** **square planar (lowest), linear, tetrahedral, octahedral (highest)** **Obtaining a correct answer to this question isn't very important. The goal is to help students understand that different energy photons can be emitted (different wavelengths can be absorbed) by the different complexes.**

8. Using Crystal Field Theory, summarize what gives rise to the different colors of complexes.
Answer: **In their own words something along the line of d-orbital splitting into different energies due to orbital interactions. Larger splitting means more energy required to excite electrons meaning smaller wavelengths of light absorbed/emitted (and vice versa).**

9. During this laboratory experiment, you will be synthesizing different cobalt complex ions. Using Crystal Field Theory and the ideas behind geometry and complex color, what predictions would you make about the structures of the complexes if all of them were different colors?
Answer: **Their own predictions. Hoping for a prediction along the lines of different colors means different geometries/arrangements.**

Student Guide

Combining Novel Visualizations and Synthesis to Explore Structure-Property Relationships using Cobalt Complexes

Justin M. Pratt, James P. Birk, David L. Tierney, and Ellen J. Yezierski
Department of Chemistry and Biochemistry, Miami University, Oxford, OH 45056

Materials

Cobalt (II) nitrate hexahydrate	Vacuum filtration set-up
3% and 30% Hydrogen peroxide	Filter paper
Glycine sodium salt	Hot plate / stir plate
Potassium oxalate monohydrate	Magnetic stir bars
Sodium bicarbonate	8-dram vials
4 M nitric acid	Ice bucket & ice
1,10-phenanthroline	Weigh boats
Cobalt (II) chloride hexahydrate	Quartz cuvette
Potassium cyanide	Gloves
Common glassware	USB Flash Drive (provided by the student)

Safety and Hazards

Gloves and safety goggles must be worn at all times through this experiment. All chemical waste must be disposed of in the appropriate waste container. No chemical waste may be washed down the drain.

Nitric Acid and *Hydrogen Peroxide* are corrosive and may cause irritation to skin and eyes. In case of contact, flush area immediately with plenty of water for at least 15 minutes.

Potassium Cyanide is very hazardous. Prolonged or repeated exposure may cause damage to organs. It is also very toxic to aquatic life and **must not be washed down the drain**. Contact with acids liberates a very toxic gas. Handle in well-ventilated areas only (fume hood or underneath a snorkel duct). In case of contact, flush area with plenty of water and seek immediate medical attention.

Syntheses and Spectroscopy

Syntheses adapted from Riordan et al. *Chem. Educator.* **2005**, 10, 115-119.

You are provided with common glassware. You must make the decision on what glassware is appropriate to perform the following syntheses. Be sure to record any observations (especially the colors of the complex ions) throughout your syntheses.

1. Complete Pre-Lab assignment via the class website prior to coming to lab.

2. Cobalt Stock Solution
   a. Prepare a 25 mL solution of 0.0042 M cobalt (II) nitrate hexahydrate
   b. Place in a vial labeled "Cobalt Stock Solution"

3. Glycine Complex
   a. While stirring, combine 10 mL of the solution prepared in Step 1 (Cobalt Stock Solution) with 0.75 g of glycine sodium salt and 10 mL of **3% hydrogen peroxide**. Stir until bubbling stops and color stays constant. While reaction proceeds, continue on with Step 4 (Oxalate Complex).
   b. Store this solution in a vial labeled "Glycine Complex."

4. Oxalate Complex
   a. While stirring, combine 10 mL of the solution prepared in Step 2 (Cobalt Stock Solution) with 1.55 g of potassium oxalate monohydrate and 10 mL of **3% hydrogen peroxide**. Gently heat the solution to 30° - 40°C (10-15 min). If solution boils, set aside on a cool stir plate and let cool (while stirring) to room temperature. Reaction is complete when color stays constant and bubbling does not occur when stirred/swirled. While solution heats, finish the "Glycine Complex" and continue on with step 5 (Water Complex Part 1).
   b. Store this solution in a vial labeled "Oxalate Complex."

Steps 5 and 6 (Water Complex Parts 1 and 2) must be done quickly. It is recommended that you gather all necessary materials before you start Step 5 to ensure that you can quickly move through both steps.

5. Water Complex Part 1
   a. Combine 0.60 g cobalt (II) nitrate hexahydrate with 10 mL H_2O and 2-3 drops of **30% hydrogen peroxide.**
   b. Combine 4.52 g sodium bicarbonate with 10 mL H_2O and 2-3 drops of **30% hydrogen peroxide** (not all of the solid may dissolve). Heat this solution while stirring until just boiling.
   c. In a large enough beaker to allow for rapid gas evolution, combine solution 5.a with 5.b. Use a stir bar and a stir plate to mix the two solutions. Stir until bubbling stops (there may be undissolved sodium bicarbonate remaining, that is ok)

d. Move quickly to Step 6 as the solution precipitates and degrades quickly.

6. Water Complex Part 2
    a. Measure out 10 mL of the solution prepared in Step 5 (you may need to decant the solution if precipitate has started to form).
    b. A few milliliters at a time, add 40 mL of 4 M nitric acid to solution 6.a. Do this *slowly* to prevent bubbling over. Stir the solution until it no longer bubbles and color stays constant (at least 5-10 minutes).
    c. If the solution turns brown/black and does not change after ten minutes of stirring, you must start over at the beginning of Step 5. Move quickly through Steps 5 and 6 to ensure that the solution does not degrade.
    d. Save a portion of this solution in a vial labeled "Water Complex." Save the remaining solution for Step 7.

7. Phenanthroline Complex
    a. Measure 10 mL of the remaining solution from Step 6 (Water Complex) and combine it with 0.115 g 1,10-phenanthroline. Add 10 mL **3% hydrogen peroxide** and stir for ten minutes. While this stirs, continue on with Step 8 (Cyanide Complex).
    b. Save this solution in a vial labeled "Phenanthroline Complex."

8. Cyanide Complex
    a. Prepare an ice bath to chill a small beaker with 5-10 mL of distilled water.
    b. Combine 2.55 g cobalt (II) chloride hexahydrate with 75 mL of H_2O and bring to a boil while stirring.
    c. Combine 1.56 g potassium cyanide with 30 mL of H_2O and stir until dissolved.
    d. Remove Solution 8.b from the hot plate and, while stirring, slowly add Solution 8.c to Solution 8.b. (Note: Solution 8.b must be boiling hot before adding Solution 8.c).
    e. Use vacuum filtration to separate the precipitate and wash it with the ice-cold water prepared in step 8.a.
    f. Using a spatula, carefully combine the washed-precipitate with 2.99 g potassium cyanide and 50 mL H_2O while stirring.
    g. While stirring, bring the solution to a boil and notice a green/lime-green solution covert to a yellow solution. (Note: as solution stirs and heats, any solid should dissolve into solution. You may need to use a stir rod to help break up any solid that remains).
    h. Save the warm solution in a vial labeled "Cyanide Complex."

9. UV-Vis Spectroscopy
    a. Read all of the instructions below before starting your analyses.

b. For each complex (from steps 3,4,6,7, and 8), obtain a UV-Vis spectrum and record λ_{max} for all peaks. (Note: At least one peak should be seen for each complex, many will have multiple peaks)
c. Bring pipettes (enough for each solution), a pipette bulb, a waster beaker, and your samples with you to the instrumentation lab. Be sure to use a snorkel hood to capture any fumes from your waster container.
d. You will be using an Agilent 8453 Spectrometer. Be sure the instrument has had ample time to warm up (at least 15 minutes) prior to gathering your data.
e. Water should be used as a blank solution and your cuvette should be rinsed with water between samples.
f. A quartz cuvette must be used the Agilent 8453 Spectrometer. Be sure to wipe the sides of the cuvette between samples.
g. Data for the Cyanide Complex should be obtained first as it must be hot (a yellow solution) when the complex is analyzed.
h. Some solutions may need to be diluted to obtain clear peaks. Perform serial dilutions in the cuvette and save all spectra for each complex. Start by obtaining data for your samples prepared in the lab (100% synthesized solution). If clear peaks are not determined, dilute your samples. Recommended diluted samples to obtain spectra for are:
   i. 50% synthesized solution/50% water
   ii. 25% synthesized solution/75% water.
i. A USB Flash Drive must be used to take spectra/data from the computer with you as the instrumentation computers do not have internet access. The instructor or TA will help you save your spectra and transfer them to your USB Flash Drive. You may need to graph the data in excel for your analyses.

10. Dispose of all chemicals in the labeled waste container. **Nothing should be disposed of down the drain.** Be sure to rinse glassware into the waste container prior to cleaning in a sink.

11. Clean ALL GLASSWARE with soap as many of the complexes are toxic and could contaminate future experiments if not properly disposed of and cleaned.

12. When you have collected your data, disposed of your chemicals, and cleaned your glassware/bench top, check with the instructor or TA prior to leaving lab.

13. Complete the Post-Lab assignment via the class website.

Combining Novel Visualizations and Synthesis to Explore Structure-Property Relationships using Cobalt Complexes

Post-Lab Activity

Directions:

Below is a link to an online module. Progress through the activity answering the questions below *as they appear in the module*. The module is designed to answer the questions in the order they are presented as you build up from prior knowledge to more complex chemical ideas (note: taking notes as you advance through the module may help you complete the assignment). We recommend using Google Chrome, Mozilla Firefox, or Safari as other browsers do not load the module very well.

When you have completed the module (and answered every question), upload this file **that includes your answers** to the course website.

Website: http://chemistry.miamioh.edu/yezierski/PrattCognateWebsite/Postlab.html

1. Examine the colors of the complexes you synthesized, were they the same or different?
Answer:

2. Based on your predictions, what conclusions would you draw about the structure(s) of your complexes?
Answer:

3. What are the coordination numbers of all of the complexes you synthesized?
Answer:

4. What are the geometries of all of the complexes you synthesized?
Answer:

5. Consider your prediction about the relationship between structure and color in light of these models. Was your prediction supported by the models? Why or why not?
Answer:

6. When a ligand bonds to a metal, the ligand's orbitals overlap with the metal's orbitals. What type of bond is being formed in this graphic?
Answer:

7. In a single bond, according to valence bond theory, what type of interaction occurs between the metal's *d*-orbitals and the ligand's orbitals? (Think in terms of orbital overlap.)
Answer:

8. According to valence bond theory, what is another type of interaction between orbitals that results in a bond?
Answer:

9. What is the HOMO?
Answer:

10. What is the LUMO?
Answer:

11. Which ligand causes the largest energy difference between the sets of *d*-orbitals (Δ)?
Answer:

12. Describe, in your words, how Δ affects how electrons occupy *d*-orbitals.
Answer:

13. Notice in Image B there are more electron pairs than in Image A, why?
Answer:

14. Explain the differences in Image A and Image B in terms of the relative energies of the electrons.
Answer:

15. Which Image represents a High Spin Complex?
Answer:

16. Water is a special ligand as it has no π interactions with a metal; it only has σ interactions. Based on this, where would π-accepting ligands be placed?
Answer:

17. Where would π-donating ligands be placed?
Answer:

18. What are the λ_{max} values you determined for each of the complexes you synthesized? (Note: You may not have determined two λ_{max} values for each complex)

Answer:

Complex	**λ_{max} 1 (nm)**	**λ_{max} 2 (nm)**
Glycine Complex $[Co(C_2O_2NH_4)_3]$		
Oxalate Complex $[Co(C_2O_4)_3]^{3-}$		
Water Complex $[Co(H_2O)_6]^{3+}$		
Phenanthroline Complex $[Co(C_{12}H_8 N_2)_3]^{3+}$		
Cyanide Complex $[Co(CN)_6]^{3-}$		

19. Convert your wavelengths to frequencies in the form of wavenumbers (cm^{-1}) using the equation Wavenumbers = 1×10^7 / wavelength in nanometers

Answer:

Complex	**ν 1 (cm^{-1})**	**ν 2 (cm^{-1})**
Glycine Complex $[Co(C_2O_2NH_4)_3]$		
Oxalate Complex $[Co(C_2O_4)_3]^{3-}$		
Water Complex $[Co(H_2O)_6]^{3+}$		
Phenanthroline Complex $[Co(C_{12}H_8 N_2)_3]^{3+}$		
Cyanide Complex $[Co(CN)_6]^{3-}$		

20. Rank your five ligands into an experiment spectrochemical series going from strongest to weakest.
Answer:

21. Using the information regarding orbital interactions and bonding, summarize your spectrochemical series. Be sure to discuss σ and π interactions, π-accepting/donating, HOMO, and LUMO.
Answer:

22. Using your eyes as the detector and the complimentary color wheel, what color of light is each complex absorbing?

Answer:

Complex	**Complex Color**	**Color of Light Absorbed by the Complex**
Glycine Complex $[Co(C_2O_2NH_4)_3]$		
Oxalate Complex $[Co(C_2O_4)_3]^{3-}$		
Water Complex $[Co(H_2O)_6]^{3+}$		
Phenanthroline Complex $[Co(C_{12}H_8N_2)_3]^{3+}$		
Cyanide Complex $[Co(CN)_6]^{3-}$		

23. Using the color of the complexes as an approximation for Δ, construct a spectrochemical series that is based on using your eyes as the detector (going from strongest to weakest).
Answer:

24. What similarities and/or differences do you notice between the two data-derived spectrochemical series you constructed in questions 20 and 23?
Answer:

25. Discuss any possible sources of error and any estimations made that may have influenced your results.
Answer:

26. Below are two different spectrochemical series that can be derived from the literature.* How do your experimental spectrochemical series compare?

Cyanide > Nitrite > Phenanthroline > Ethylenediamine > Ammonia > Glycine > Water > Oxalate > Carbonate

Cyanide > Nitrite > Phenanthroline > Ethylenediamine > Ammonia > Glycine > Oxalate > Water > Carbonate

*Based upon data from:

- Jørgensen, C. K. *Advances in Chemical Physics.* **1963**, *5*, 65.
- Jørgensen, C. K. *Advances in Chemical Physics.* **1963**, *5*, 94-95.
- Kiss, A.; Czegledy, D. Z. *Anorg. Allg. Chem.* **1938**, *235*, 407-426.
- Mead, A. *Trans. Faraday Soc.* **1934**, *30*, 1052-1058.
- Miessler, G.L.; Tarr, D. A. *Inorganic Chemistry*, 2nd ed.; Wiley-Interscience: New York; p 334.
- Riordan et al. *Chem. Educator*. **2005**, *10*, 115-119
- Shimura, Y.; Tsuchida, T. *Bull. Chem. Soc. Jpn.* **1956**, *29*, 311-316.

Answer:

Use the table below to help you answer questions 27 and 28:

Complex	**Δ value (cm^{-1})***	**Your Estimated Δ value (cm^{-1})**
Cyanide complex	33909	
Glycine complex	20266	
Oxalate complex	18153	
Phenanthroline complex	26198	
Water complex	18406	

*From Riordan et al. *Chem. Educator*. **2005**, 10, 115-119.

27. Above are calculated Δ values using Tanabe-Sugano diagrams reported for the Cobalt (III) complex ions studied by Riordan et al. Copy your estimated Δ values (frequencies in wavenumbers) into the table and compare your estimated Δ values to the literature values. As you compare, note the relative magnitudes of the values as well as their rank order from lowest to highest.

Answer:

28. Based on your answers to questions 26 and 27, explain why there are differences (if any) among all four spectrochemical series.
Answer:

KEY

Combining Novel Visualizations and Synthesis to Explore Structure-Property Relationships using Cobalt Complexes

Post-Lab Activity

Directions:

Below is a link to an online module. Progress through the activity answering the questions below *as they appear in the module*. The module is designed to answer the questions in the order they are presented as you build up from prior knowledge to more complex chemical ideas (note: taking notes as you advance through the module may help you complete the assignment). We recommend using Google Chrome, Mozilla Firefox, or Safari as other browsers do not load the module very well.

When you have completed the module (and answered every question), upload this file **that includes your answers** to the course website.

Website: http://chemistry.miamioh.edu/yezierski/PrattCognateWebsite/Postlab.html

1. Examine the colors of the complexes you synthesized, were they the same or different?
Answer: **Different**

2. Based on your predictions, what conclusions would you draw about the structure(s) of your complexes?
Answer: **Must all be different geometries**

3. What are the coordination numbers of all of the complexes you synthesized?
Answer: **6**

4. What are the geometries of all of the complexes you synthesized?
Answer: **Octahedral**

5. Consider your prediction about the relationship between structure and color in light of these models. Was your prediction supported by the models? Why or why not?
Answer: **Likely their prediction will not be supported by the models because they all have the same geometry but are different colors.**

6. When a ligand bonds to a metal, the ligand's orbitals overlap with the metal's orbitals. What type of bond is being formed in this graphic?
Answer: **Single bond**

7. In a single bond, according to valence bond theory, what type of interaction occurs between the metal's *d*-orbitals and the ligand's orbitals? (Think in terms of orbital overlap.)
Answer: **Sigma interactions/single overlaps**

8. According to valence bond theory, what is another type of interaction between orbitals that results in a bond?
Answer: **Pi interactions/overlaps are above and below the bond axis**

9. What is the HOMO?
Answer: **π***

10. What is the LUMO?
Answer: **σ***

11. Which ligand causes the largest energy difference between the sets of *d*-orbitals (Δ)?
Answer: **π-acceptor / CN^-**

12. Describe, in your words, how Δ affects how electrons occupy *d*-orbitals.
Answer: **Large Δ, pair up. Smaller Δ, do not pair up first**

13. Notice in Image B there are more electron pairs than in Image A, why?
Answer: **Image B has a larger Δ than Image A. Therefore, in Image B the electrons are more likely to occupy the lower set of orbitals as pairs first.**

14. Explain the differences in Image A and Image B in terms of the relative energies of the electrons.
Answer: **The y-axis is potential energy. In Image A, the sets of orbitals are closer in potential energy than in Image B. Therefore, the electrons in Image A are at lower potential energy when they occupy the orbitals singly than in pairs. In Image B the opposite is true. Because the Δ is so large, the arrangement of lowest potential energy is where the electrons occupy the orbitals as pairs.**

15. Which Image represents a High Spin Complex?
Answer: **Image A**

16. Water is a special ligand as it has no π interactions with a metal; it only has σ interactions. Based on this, where would π-accepting ligands be placed?
Answer: **To the left of water**

17. Where would π-donating ligands be placed?
Answer: **To the right of water**

18. What are the λ_{max} values you determined for each of the complexes you synthesized? (Note: You may not have determined two λ_{max} values for each complex)

Answer:

***Wavelengths are from Riordan et al. *Chem. Educator*. 2005, 10, 115-119**

****Wavelengths are from author-obtained data**

Complex	**λ_{max} 1 (nm)**		**λ_{max} 2 (nm)**		
Glycine Complex $[Co(C_2O_2NH_4)_3]$	382*	380**	538*	540**	
Oxalate Complex $[Co(C_2O_4)_3]^{3-}$	425*	425**	602*	602**	
Water Complex $[Co(H_2O)_6]^{3+}$	394*	405**	607*	607**	
Phenanthroline Complex $[Co(C_{12}H_8 N_2)_3]^{3+}$	273*	270**	451*	390**	
Cyanide Complex $[Co(CN)_6]^{3-}$	256*	262**	309*	315**	380**

19. Convert your wavelengths to frequencies in the form of wavenumbers (cm^{-1}) using the equation Wavenumbers = 1 x 10^7 / wavelength in nanometers

Answer:

***Frequencies for data from Riordan et al. *Chem. Educator*. 2005, 10, 115-119**

****Frequencies for data from author-obtained data**

Complex	**ν 1 (cm^{-1})**		**ν 2 (cm^{-1})**		
Glycine Complex $[Co(C_2O_2NH_4)_3]$	26178.01*	26315.79**	18587.36*	18518.52**	
Oxalate Complex $[Co(C_2O_4)_3]^{3-}$	23529.41*	23529.41**	16611.30*	16611.30**	
Water Complex $[Co(H_2O)_6]^{3+}$	25380.71*	24691.36**	16474.46*	16474.46**	
Phenanthroline Complex $[Co(C_{12}H_8 N_2)_3]^{3+}$	36630.04*	37037.04**	22172.95*	25641.03**	
Cyanide Complex $[Co(CN)_6]^{3-}$	39062.50*	38167.94**	32362.46*	31746.03**	26315.79**

20. Rank your five ligands into an experiment spectrochemical series going from strongest to weakest.
Answer: **<u>For Riordan et al. *Chem. Educator*. 2005, 10, 115-119</u>** **Cyanide, Phenanthroline, Glycine, Oxalate, Water** **<u>For author-obtained data:</u>** **Cyanide, Phenanthroline, Glycine, Oxalate, Water**

21. Using the information regarding orbital interactions and bonding, summarize your spectrochemical series. Be sure to discuss σ and π interactions, π-accepting/donating, HOMO, and LUMO.
Answer: **Cyanide has the largest Δ while water has the smallest Δ. All (excluding water) are π-accepting ligands because they are all stronger than water. This means that the LUMO of all of the ligands are π molecular orbitals. Both σ and π interactions occur amongst all of them. However, cyanide has the most π accepting ability which explains why it has the largest Δ.**

22. Using your eyes as the detector and the complimentary color wheel, what color of light is each complex absorbing?

Answer:

Complex	Complex Color	Color of Light Absorbed by the Complex
Glycine Complex $[Co(C_2O_2NH_4)_3]$	**Purple**	**Yellow**
Oxalate Complex $[Co(C_2O_4)_3]^{3-}$	**Green**	**Red**
Water Complex $[Co(H_2O)_6]^{3+}$	**Blue**	**Orange**
Phenanthroline Complex $[Co(C_{12}H_8 N_2)_3]^{3+}$	**Orange/Yellow**	**Purple/Blue**
Cyanide Complex $[Co(CN)_6]^{3-}$	**Pale Yellow**	**Purple/UV**

23. Using the color of the complexes as an approximation for Δ, construct a spectrochemical series that is based on using your eyes as the detector (going from strongest to weakest).

Answer:

Cyanide > Phenanthroline > Glycine > Water > Oxalate

24. What similarities and/or differences do you notice between the two data-derived spectrochemical series you constructed in questions 20 and 23?

Answer:

Almost the same except Water and Oxalate have flipped positions

25. Discuss any possible sources of error and any estimations made that may have influenced your results.
Answer: **The Δ value they are using are estimated from frequencies so they are not exact. Students may discuss other possible sources of error including spectra that are not very clean which may cause difficulty determining peaks.**

26. Below are two different spectrochemical series that can be derived from the literature.* How do your experimental spectrochemical series compare?

Cyanide > Nitrite > Phenanthroline > Ethylenediamine > Ammonia > Glycine > Water > Oxalate > Carbonate

Cyanide > Nitrite > Phenanthroline > Ethylenediamine > Ammonia > Glycine > Oxalate > Water > Carbonate

*Based upon data from:

- Jørgensen, C. K. *Advances in Chemical Physics.* **1963**, *5*, 65.
- Jørgensen, C. K. *Advances in Chemical Physics.* **1963**, *5*, 94-95.
- Kiss, A.; Czegledy, D. Z. *Anorg. Allg. Chem.* **1938**, *235*, 407-426.
- Mead, A. *Trans. Faraday Soc.* **1934**, *30*, 1052-1058.
- Miessler, G.L.; Tarr, D. A. *Inorganic Chemistry*, 2nd ed.; Wiley-Interscience: New York; p 334.
- Riordan et al. *Chem. Educator*. **2005**, *10*, 115-119
- Shimura, Y.; Tsuchida, T. *Bull. Chem. Soc. Jpn.* **1956**, *29*, 311-316.

Answer:

UV-vis derived series will likely match one of them while the eye as the detector method will likely match the other one.

Use the table below to help you answer questions 27 and 28:

Complex	**Δ value (cm^{-1})***	**Your Estimated Δ value (cm^{-1})****
Cyanide complex	33909	**31746.03**
Glycine complex	20266	**18518.52**
Oxalate complex	18153	**16611.30**
Phenanthroline complex	26198	**25641.03**
Water complex	18406	**16474.46**

*From Riordan et al. *Chem. Educator*. **2005**, 10, 115-119.
****Based on author-obtained data**

27. Above are calculated Δ values using Tanabe-Sugano diagrams reported for the Cobalt (III) complex ions studied by Riordan et al. Copy your estimated Δ values (frequencies in wavenumbers) into the table and compare your estimated Δ values to the literature values. As you compare, note the relative magnitudes of the values as well as their rank order from lowest to highest.
Answer: **Estimated values are all less than the actual literature values. The accepted values for water and oxalate are very close together. This explains why the data the students obtain places water and oxalate into different orders. Because the numbers are already so close, any error introduced to the experiment could easily explain why the two are placed into a different order when literature values are compared to the obtained values.**

28. Based on your answers to questions 26 and 27, explain why there are differences (if any) among all four spectrochemical series.
Answer: **Everything is the same except the order for water and oxalate. Because the values are already so close, any error introduced during the experiment can explain why different spectrochemical series are explained based on the two different methods. In addition, instrumentation calibration and limit of detection can explain why the literature has two different spectrochemical series that can be derived.**

APPENDIX B: INSTIUTIONAL REVIEW BOARD APPROVALS

This appendix provides a list of all applicable IRB approvals and modifications.

B.1 EXEMPT NATIONAL SURVEY

MIAMI UNIVERSITY

Research Compliance Office
102 Roudebush Hall
Miami University, Oxford, OH 45056

8-Apr-15

To: Justin Pratt and Ellen Yezierski (prattjm5@miamioh.edu; yeziere@miamioh.edu) RE:

Exploration of Informal Science Experiences

Project reference number is: 01638e
(please refer to this ID number in all correspondence to compliance administration)

The project noted above and as described in your application for registering Human Subjects (HS) research has been screened to determine if it is regulated research or meets the criteria of one of the categories of research that can be exempt from approval of an Institutional Review Board (per 45 CFR 46). The determination for your research is indicated below.

The research described in the application is regulated human subjects research, however, the description meets the criteria of at least one exempt category included in 45 CFR 46 and associated guidance.

The Applicable Exempt Category(ies) is/are: 2

Research may proceed upon receipt of this certification and compliance with any conditions described in the accompanying email message. When research is deemed exempt from IRB review, it is the responsibility of the researcher listed above to ensure that all future persons not listed on the filed application who i) will aid in collecting data or, ii) will have access to data with subject identifying information, meet the training requirements (CITI Online Training).

If you are considering any changes in this research that may alter the level of risk or wish to include a vulnerable population (e.g. subjects <18 years of age) that was not previously specified in the application, you must consult the Research Compliance Office before implementing these changes.

Exemption certification is not transferrable; this certificate only applies to the researcher specified above. All research exempted from IRB review is subject to post-certification monitoring and audit by the compliance office.

Jennifer Sutton, MPA
Associate Director of Research Compliance
Office for the Advancement of Research and Scholarship
102 Roudebush Hall
Miami University
Oxford, OH 45056
Phone: 513-529-0454
http://www.miamioh.edu/compliance

B.2 EXEMPT IN-DEPTH QUALITATIVE STUDY

MIAMI UNIVERSITY

Research Compliance Office
102 Roudebush Hall
Miami University, Oxford, OH 45056

17-Sep-15

To: Justin Pratt and Ellen Yezierski (prattjm5@miamioh.edu; yeziere@miamioh.edu)
Department: Biochemistry and Chemistry

RE: Characterizing the Chemistry Content Knowledge and Instructional Practices of Collegiate Students Facilitating Informal Chemistry Learning

Project reference number is: 01747e
(please refer to this ID number in all correspondence to compliance administration)

The project noted above and as described in your application for registering Human Subjects (HS) research has been screened to determine if it is regulated research or meets the criteria of one of the categories of research that can be exempt from approval of an Institutional Review Board (per 45 CFR 46). The determination for your research is indicated below.

The research described in the application is regulated human subjects research, however, the description meets the criteria of at least one exempt category included in 45 CFR 46 and associated guidance.

The Applicable Exempt Category(ies) is/are: 2

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If you are considering any changes in this research that may alter the level of risk or wish to include a vulnerable population (e.g. subjects <18 years of age) that was not previously specified in the application, you must consult the Research Compliance Office before implementing these changes.

Exemption certification is not transferrable; this certificate only applies to the researcher specified above. All research exempted from IRB review is subject to post-certification monitoring and audit by the compliance office.

Neal H. Sullivan, PhD
Director of Research Compliance
Office for the Advancement of Research and Scholarship
102E Roudebush Hall
Miami University
Oxford, OH 45056
neal.sullivan@MiamiOH.edu
(513) 529-2488

B.3 MODIFICATION TO INCLUDE COMPENSATION AND SURVEY DURING INTERVIEW

Tue, Oct 6, 2015, 3:13 PM

To: Justin Pratt and Ellen Yezierski (prattjm5@miamioh.edu; yeziere@miamioh.edu)

Your application Research Compliance Office to modify or amend protocol titled:

Characterizing the Chemistry Content Knowledge and Instructional Practices of Collegiate Students Facilitating Informal Chemistry Learning

(Reference Number 01747e)

Nature of Modification: Added compensation and survey during interview

was determined to not alter the determinination the activities qualify for exempt status (per 45 CFR 46) and your procedures for the protection of human subjects are sufficient. The previously issued certificate remains valid.

Thank you for checking with us regarding the changes to your project.

This email message constitutes the modification approval document.

Neal Sullivan, PhD.

Director of Research Compliance

Miami University

102e Roudebush Hall

Oxford, OH 45056

sullivnh@MiamiOH.edu (513) 529-2488 Fax: (513) 529-3762

B.4 MODIFICATION TO ADJUST SURVEYS FOR ADA COMPLIANCE

Tue, Sep 27, 2016, 3:17 PM

To: Justin Pratt and Ellen Yezierski (prattjm5@miamioh.edu; yeziere@miamioh.edu)

Your application Research Compliance Office to modify or amend protocol titled:

Characterizing the Chemistry Content Knowledge and Instructional Practices of Collegiate Students Facilitating Informal Chemistry Learning

(Reference Number 01747e)

Nature of Modification: Adjusting instruments for ADA compliance

was determined to not alter the determinination the activities qualify for exempt status (per 45 CFR 46) and your procedures for the protection of human subjects are sufficient. The previously issued certificate remains valid.

Thank you for checking with us regarding the changes to your project.

This email message constitutes the modification approval document.

Neal Sullivan, PhD.

Director of Research Compliance

Miami University

102e Roudebush Hall

Oxford, OH 45056

sullivnh@MiamiOH.edu (513) 529-2488 Fax: (513) 529-3762

B.5 MODIFICATION TO INCLUDE COLLECTION OF DATA THROUGH VIEWING PRE-EXISTING ONLINE VIDEOS

Wed, Jan 11, 2017, 12:39 PM

To: Justin Pratt and Ellen Yezierski (prattjm5@miamioh.edu; yeziere@miamioh.edu)

Your application Research Compliance Office to modify or amend protocol titled:

Characterizing the Chemistry Content Knowledge and Instructional Practices of Collegiate Students Facilitating Informal Chemistry Learning

(Reference Number 01747e)

Nature of Modification: Collection of data through viewing pre-existing online videos

was determined to not alter the determinination the activities qualify for exempt status (per 45 CFR 46) and your procedures for the protection of human subjects are sufficient. The previously issued certificate remains valid.

Thank you for checking with us regarding the changes to your project.

This email message constitutes the modification approval document.

Neal Sullivan, PhD.

Director of Research Compliance

Miami University

102e Roudebush Hall

Oxford, OH 45056

sullivnh@MiamiOH.edu (513) 529-2488 Fax: (513) 529-3762

APPENDIX C: PERMISSIONS FOR REPUBLICATION

This appendix includes relevant documents providing permissions for republication of submitted, in review, accepted, and/or published articles included in the dissertation.

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10/10/03, 01/15/04, 06/07/06, 04/07/10, 08/24/10, 02/28/11

Pratt, Justin <prattjm5@miamioh.edu>

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m: 618-531-2665 | e: prattjm5@miamioh.edu

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Mary Saecker <msaecker@jce.acs.org> Thu, Nov 8, 2018 at 11:38 AM

To: "Yezierski, Ellen" <yeziere@miamioh.edu>

Cc: "Pratt, Justin" <prattjm5@miamioh.edu>

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Sincerely,

Mary

Mary Saecker

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Title: Combining Novel Visualizations and Synthesis To Explore Structure–Property Relationships Using Cobalt Complexes

Author: Justin M. Pratt, James P. Birk, David L. Tierney, et al

Publication: Journal of Chemical Education

Publisher: American Chemical Society

Date: Dec 1, 2017

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Author: Justin M. Pratt, Ellen J. Yezierski

Publication: Journal of Chemical Education

Publisher: American Chemical Society

Date: Oct 1, 2018

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A novel qualitative method to improve access, elicitation, and sample diversification for enhanced transferability applied to studying chemistry outreach

J. M. Pratt and E. J. Yezierski, *Chem. Educ. Res. Pract.*, 2018, **19**, 410
DOI: 10.1039/C7RP00200A

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APPENDIX D: CONSENT FORMS

This appendix includes all consent forms used for both the national survey study and the in-depth qualitative study.

D.1: CONSENT FORM FOR NATIONAL SURVEY

MIAMI UNIVERSITY

Please read the following consent form before completing the survey.

The following survey is for a research project by Justin Pratt and Dr. Ellen Yezierski at Miami University. The purpose of this study is to characterize the experiences and practices of people that participate in informal chemistry education/outreach. Participation in this survey is voluntary and you may quit the survey at any time. All responses will remain anonymous, and only the researchers will have access. The results will only be used for research purposes. Upon completion of the survey, you will be able to enter your name and email address for a drawing of a $50 Amazon.com gift card (Odds 1:50). Your name and email will not be linked to your responses.

If you have any questions about this research, you may contact the researchers at prattjm5@miamioh.edu or yeziere@miamioh.edu. If you have questions or concerns about the rights of research subjects, you may contact the Research Compliance Office at Miami University at (513) 529-3600 or humansubjects@miamioh.edu.

By consenting to participate in this study, you certify that you are voluntarily participating and that you are 18 years of age or older.

○ I consent to participate in this research project and certify that I am at least 18 years of age.

○ I do not consent to participate in this project.

D.2: CONSENT FORM FOR IN-DEPTH QUALITATIVE STUDY – INTERVIEWS

MIAMI UNIVERSITY

Please read the following consent form before completing this survey.

The purpose of the study "Characterizing the Chemistry Content Knowledge and Instructional Practices of Collegiate Students Facilitating Informal Chemistry Learning" is to characterize the experiences and practices of college students that participate in chemistry outreach. The results of this study will provide a description of the teaching and learning practiced in informal chemistry environments and could help researchers and outreach organizations improve the way chemistry outreach is practiced across the country.

Eligibility: To be eligible to participate in this study, you must be at least 18 years of age and have participated in at least one (1) chemistry outreach event.

Survey: The following survey seeks to solicit volunteers to participate in an hour-long interview about experiences performing chemistry outreach. The survey asks demographic information as well as general questions about experiences with outreach.

Interview: Data from the survey will be used to select participants for an audio-recorded interview (60 minutes). The audio will only be used for accurate note taking and will not be used publicly unless given explicit permission from the participant.

All data collected by the research team will be kept confidential and no identifying information (name, institution affiliation, etc.) will be included in any publications or presentations of this investigation; all names will be coded to pseudonyms and all identifying information will be removed.

Risks: Risks to the participants are minimized through the removal of all identifying information from the data obtained. Names will not be linked to data; all data will be coded to ensure confidentiality.

Benefits: Benefits to the participant are maximized by ensuring that the interview will help the participant further understand their own ideas about chemistry outreach and the activities therein. In addition, the results have the potential to guide future research on informal chemistry education as well as improve the way chemistry outreach is practiced. **Participants that complete both the survey and the interview will be offered a $15 Amazon.com gift card as compensation for their time.**

Participants are free to withdraw from the study at any time without any penalty. To withdraw, send an email to Justin Pratt (prattjm5@miamioh.edu) or Dr. Ellen Yezierski (yeziere@miamioh.edu) notifying them of your intention to withdraw. No questions will be asked and all data tied to you will be destroyed.

Questions regarding the investigation may be directed to Justin Pratt (prattjm5@miamioh.edu) or Dr. Ellen Yezierski (yeziere@miamioh.edu). For questions or concerns about the rights of research subjects or the voluntariness of this consent procedure, please contact the Research Compliance Office at Miami University: (513) 529-3600 or humansubjects@miamioh.edu.

- ○ I consent to participate in this research project. I have read the description of the project and certify that I am 18 years of age and have participated in at least one (1) outreach event.

- ○ I do not consent to participate in this research project.

D.3: CONSENT FORM FOR IN-DEPTH QUALITATIVE STUDY – VIDEO RECORDING RESEARCH PARTICIPANT

The purpose of the study "Characterizing the Chemistry Content Knowledge and Instructional Practices of Collegiate Students Facilitating Informal Chemistry Learning" is to characterize the experiences and practices of college students that participate in chemistry outreach. The results of this study will provide a description of the teaching and learning practiced in informal chemistry environments and will help researchers and outreach organizations improve the way chemistry outreach is practiced across the country.

Eligibility: To be eligible to participate in this study, you must have participated in the interview phase of this study.

Video-recording: You will be asked to capture on video an outreach event and send it to the researchers. The outreach event will be part of the normal activities of the organization and not occurring due to this research project or Miami University. Videos will focus on the research participant and the activity itself (facilitation and chemistry content). Only consented individuals may appear in the video. Videoing children is strictly prohibited unless consent is granted from a parent or guardian. More details regarding videoing (including detailed instructions) will be provided prior to the event.

All data collected by the research team will be kept confidential and no identifying information (name, institution affiliation, etc.) will be included in any publications or presentations of findings. Videos will only be viewed by the research team and will only be used for research purposes.

All paper data will be stored in a locked filing cabinet in Hughes 360 at Miami University in Oxford, OH. All electronic data will be stored in a password-protected computer as well as an external hard drive that is also stored in a locked filing cabinet. Only members of the research team will have access to the data collected.

Risks: Risks to the participants are minimized through the removal of all identifying information from the data obtained. Names will not be linked to data; all data will be coded to ensure confidentiality.

Benefits: Benefits to the participant are maximized by ensuring that the interview will help the participant further understand their own ideas about chemistry outreach and the activities therein. In addition, the results have the potential to guide future research on informal chemistry education as well as improve the way chemistry outreach is practiced. Compensation in the form of a $10 Amazon gift card will be provided upon the completion of this phase.

Participants are free to withdraw from the study at any time without any penalty. To withdraw, send an email to Justin Pratt (prattjm5@miamioh.edu) or Dr. Ellen Yezierski (yeziere@miamioh.edu) notifying them of your intention to withdraw. No questions will be asked and all data tied to you will be destroyed.

Questions regarding the investigation may be directed to Justin Pratt (prattjm5@miamioh.edu) or Dr. Ellen Yezierski (yeziere@miamioh.edu). For questions or concerns about the rights of research subjects or the voluntariness of this consent procedure, please contact the Research Compliance Office at Miami University: (513) 529-3600 or humansubjects@miamioh.edu.

Sign this page; Keep the first page for your reference and return the second page to the research team.

I agree to participate in this study about chemistry outreach events. I have had the study explained to me and I have read the description of the project. I know that my participation is voluntary and that I will receive a $10 Amazon gift card as compensation for participating in this project. I certify that I am at least 18 years of age and have participated in at least one chemistry outreach event prior to this study. I know that my name and institution name will not be associated with my responses and will remain confidential. I agree to provide a video of me participating in a chemistry outreach event and know that the recording will be kept confidential and used by the research team for research purposes only. I further agree to review the video prior to providing it to the research team to ensure that identifying imagery of minors is not included.

______________________________ ____________________________
Participant's Signature Date

____
Participant's Name (Please Print)

D.4: CONSENT FORM FOR IN-DEPTH QUALITATIVE STUDY – VIDEO RECORDING NON-RESEARCH PARTICIPANT

_________________________ is participating in a research project with Justin Pratt and Dr. Ellen
Research Participant Name

Yezierski at Miami University with the purpose of characterizing the experiences and practices of college students that participate in chemistry outreach. Part of the study requires video recording the research participant participating in an outreach event.

The video will allow researchers to understand how activities are facilitated in a real setting. The research team is solely focused on the research participant and not activity participants or other students. The research participant will take all necessary precautions to only capture him or herself, his/her audio, and the activity/demonstration table. However, there is a chance that your likeness may be captured during this process. The video will be given to the research team and will be used for research purposes only. It will be kept on a locked computer and backed up on an external hard drive that is locked in a filing cabinet; only the research team will have access to the material and it will remain confidential with no identifying information included in any publication or presentation. The knowledge gained from the video has the potential to guide future research on informal chemistry education and to improve the way chemistry outreach is practiced.

For questions or concerns about the rights of research subjects or the voluntariness of this consent procedure, please contact the Research Compliance Office at Miami University: (513) 529-3600 or humansubjects@miamioh.edu. Questions regarding the investigation itself may be directed to the contacts below.

Researcher Contact Information

Graduate Student Investigator:

Justin Pratt
PhD Candidate
Department of Chemistry & Biochemistry
Miami University
Oxford, OH 45056
Email: prattjm5@miamioh.edu

Faculty Advisor:

Dr. Ellen Yezierski
Professor of Chemistry
Department of Chemistry & Biochemistry
Miami University
Oxford, OH 45056
Email: yeziere@miamioh.edu

✂ ——

Cut at the line, keep the top section and return the bottom section to the research participant

I understand the purpose of this study, and I understand that my likeness may be captured despite all preventative measures taken. No compensation will be provided to me for consenting to this video, and I understand that the video will be kept confidential and used by the research team for research purposes only.

_________________________ _________________________
Signature Date

____
Printed Name

APPENDIX E: RECRUITMENT MATERIALS

This appendix includes example recruitment materials for both the national survey study and the in-depth qualitative study.

E.1: RECRUITMENT EMAIL FOR NATIONAL SURVEY – SAMPLE

Subject: Survey Invitation $50 Amazon.com Gift Card

Dear ΑΧΣ Chapter Advisor,

I am conducting a research project with Dr. Ellen Yezierski at Miami University about the experiences and practices of organizations that participate in informal chemistry education. Alpha Chi Sigma and many other organizations perform outreach events that engage the public in chemistry activities. We are seeking to understand these types of activities and the practices of the people involved.

We are asking that you and your chapter members take approximately 15 minutes to complete a survey that we have developed. Upon completion, you will have the option of entering your name in a drawing for a **$50 Amazon.com gift card**! One gift card will be drawn for every fifty completed survey responses. Click the link below in order to participate in the survey:

[Qualtrics Link Here]
(This survey link will be active from today's date until DATE HERE).

As the chapter advisor, we are seeking your help in disseminating this survey to the students in your chapter (and professional members who also participate in these activities). Please forward this survey on to any and all brothers so that we can obtain a representative sample and an accurate account of practices.

Any questions regarding this message can be directed to the contact below. We truly thank you for your participation and aid in this study!

Justin Pratt
Delta Delta 2012
Doctoral Student, Miami University
Department of Chemistry and Biochemistry
Prattjm5@miamioh.edu

Ellen Yezierski
Beta Omega 2000
Associate Professor, Miami University
Department of Chemistry and Biochemistry
Yeziere@miamioh.edu

E.2: RECRUITMENT EMAIL FOR IN-DEPTH QUALITATIVE STUDY – SAMPLE

Subject: Gift Card Opportunity! Research Invitation for Your Students

Dear ACS Chapter Advisor,

Previously you were sent an email about a research project being conducted by me and Dr. Ellen Yezierski at Miami University about the experiences and practices of organizations that participate in informal chemistry education. The results from this survey were very informative and have guided us in designing a more focused and in-depth study to further understand what is going on in this unique setting.

We are seeking collegiate students who are willing to help us explore this area in greater depth. Our study requires students to participate in a one-hour interview about the types of activities they participate in during chemistry outreach events and possibly to video record an event for us to see. Participation in this study will help the college students understand their own knowledge of chemistry outreach activities as well as help researchers and organizations like Alpha Chi Sigma and the American Chemical Society create more guidelines, best practices, and content-embedded activities to help improve chemistry outreach across the country. **In addition, those who participate in the interview will receive a $15 Amazon.com gift card as a thank you for their time.**

We are asking your chapter members to consider volunteering for our study. Below is a link to a survey that describes more about the study, allows students to indicate their interest in participation, and asks a few questions about specific activities they have experience with. The survey should take **no longer than 10 minutes** to complete. Click the link below in order to participate in the survey:

[Qualtrics Link Here]
(This survey link will be active from today's date until DATE HERE).

As the advisor, we are seeking your help in disseminating this survey to the students in your organization. Please forward this survey on so that we can obtain as many interested students as possible. Without enough volunteers we cannot hope to fully understand chemistry outreach or to improve it for future generations.

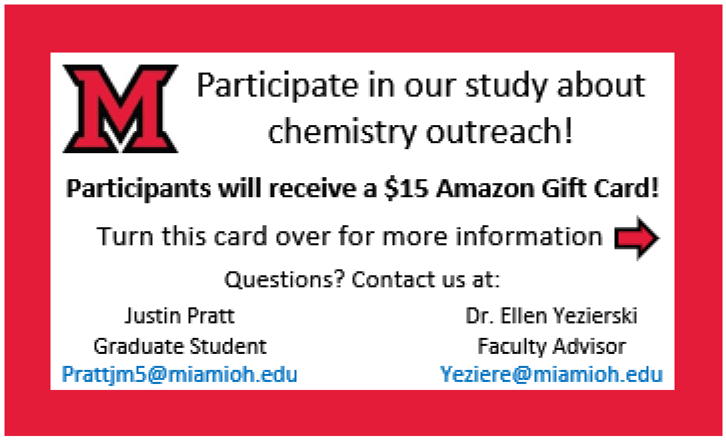
Any questions regarding this message can be directed to the contact below. We truly thank you for your aid in this study!

Justin Pratt
Doctoral Student, Miami University
Department of Chemistry and Biochemistry
Prattjm5@miamioh.edu

Ellen Yezierski
Professor, Miami University
Department of Chemistry and Biochemistry
Yeziere@miamioh.edu

E.3: ACS MEETING RECRUITMENT FOR IN-DEPTH QUALITATIVE STUDY – BUSINESS CARD HANDOUT

Front



Back

E.4: ACS MEETING RECRUITMENT FOR IN-DEPTH QUALITATIVE STUDY – HALF PAGE HANDOUT

MIAMI UNIVERSITY

Do you participate in chemistry outreach?
Be part of our study!

We are characterizing the teaching and learning in chemistry outreach and what activities are done across the country.

Participants will receive a $15 Amazon gift card!

Go to this link or scan this QR Code for more information about this study and to volunteer:

http://bit.ly/ACSOutreach

Questions? Contact us:	Justin Pratt Graduate Student Prattjm5@miamioh.edu	Dr. Ellen Yezierski Faculty Advisor Yeziere@miamioh.edu

E.5: RECRUITMENT SURVEY FOR IN-DEPTH QUALITATIVE STUDY

Directions: Please answer every question as fully and honestly as possible. Results from this survey will be used to select participates for interviews. Completion of this survey does not guarantee that you will be asked to participate in the study, it merely indicates your interest to do so. Only those who complete both this survey and the interview will be awarded a $15 Amazon.com gift card.

Demographic information:

- Name
- Email address
- Gender
- Year in school
- College/University
- Major
- Chemistry Organization that you perform chemistry outreach with:
- Number of SEMESTERS involved with chemistry outreach (estimate)
- Number of OUTREACH ACTIVITIES you have participated in (estimate)
- Which describes how you have participated in chemistry outreach (select all that apply):
    1. Scheduled/planned events
    2. Prepared materials
    3. Facilitated with children

- Select all that apply, what is the purpose of doing chemistry outreach:
    a. Teach younger students/children chemical concepts
    b. Expose younger students/children to chemistry to spark their interest in the sciences
    c. Expose younger students/children to chemistry to help them decide if they want to study it/pursue a career in it
    d. Combat negative stereotypes about the subject (such as "chemistry is hard," "girls/underrepresented groups cannot do it," "it is scary/dangerous," etc.)
    e. Develop younger students'/children's scientific literacy skills
    f. Provide role models for younger students/children (give them someone to look up to)
    g. Help younger students/children have fun
    h. Help college students enjoy themselves/have fun

- Is there anything not in the above list that you think should be? If yes, please add your addition here: ______________

- Of the ones you selected, rank them from most important to least important. [macros used to pull selected answers into a list]

- Select all of the demonstrations/activities you have done with younger students/children:
    - Elephant Toothpaste
    - Making slime
    - Making oobleck/non-Newtonian fluid
    - Liquid nitrogen ice cream
    - Other liquid nitrogen demonstrations (not ice cream making)
    - Fire demonstrations (colored flames, flammable bubbles, gummy bear, grain elevators, flaming dollar, whoosh bottle, etc.)
    - Clock reactions (iodine or Halloween/Nassau)
    - Dry ice demonstrations (bubbles, indicator color changes, etc.)
    - Chemiluminescence (luminol, etc.)
    - Lather printing (shaving cream)
    - Natural indicators (red cabbage)
    - Other: _____

- Of the ones selected, rank them in order from most commonly done to least commonly done in your group. [macros used to pull selected answers into a list]

*Upon the closer of the survey this will be displayed:

Thank you for volunteering to participate in our study! We will contact participants individually with more information regarding interviewing.

APPENDIX F: MATERIALS FOR IN-DEPTH QUALITATIVE STUDY

This appendix includes materials used to conduct the in-depth qualitative study/collect data.

F.1: INTERVIEW SCHEDULING EMAIL

Subject: Scheduling Interview about Chemistry Outreach

Hello ______,

Thank you so much for filling out our survey and volunteering to help us with our study regarding chemistry outreach! We have selected you to participate in the interview **and receive a $15 Amazon.com gift card in exchange for your time.**

Attached is a copy of my schedule showing the times that I am available and unavailable. The interview should only last an hour (via Skype) but I prefer to schedule an hour and a half (90 minutes) just to be safe. Please look at your schedule and mine and let me know a day and time that works for you. Just as a note, my schedule is in Eastern Standard Time; if you are in a different time zone adjustments will need to be made (so ______ from the times I am available). If none of these times fit into your schedule, we can look into alternatives. Please let me know if there is any confusion!

Thank you again for agreeing to help us with our study. Please let me know if you have any questions or concerns. I look forward to hearing from you! **If I haven't heard from you by [DATE], I will be offering this opportunity to someone else.**

Justin Pratt

F.2: INTERVIEW CONFIMRATION EMAIL

Subject: RE: Scheduling Interview about Chemistry Outreach

Hello _____,

Thank you for your quick response! I have you scheduled for [DATE AND TIME].

The interview will cover your experiences doing chemistry outreach as well as the specific activities you have done before. You may wish to have access to a writing utensil and paper during the interview, but it is not required.

Note, all information gained from the interview will remain confidential; your name and school will not be linked to your responses.

My Skype information is:

- Username: [username]
- Email: Prattjm5@miamioh.edu

Please let me know if you have any questions. I look forward to speaking with you on ______!

Justin

F.3: INTERVIEW PREPARATION CHECKLIST

Coded Name: ____________________ Date of Interview: _______________

Interview Checklist

To Print/Have

- [ ] Recruitment Survey
- [ ] Interview guide
- [ ] List of purposes/mostly blank page
- [ ] **Bolded** inaccurate explanations for the activities they have done before
  - [ ] Slime
  - [ ] LN_2
  - [ ] Elephant Toothpaste
- [ ] Expert explanations for the activities they have done before
  - [ ] Slime
  - [ ] LN_2
  - [ ] Elephant Toothpaste
- [ ] Tape recorder
- [ ] Folder

To Have Open on Computer

- ☐ Interview guide
- ☐ List of purposes
- ☐ UN-bolded inaccurate explanations for the activities they have done before
    - ☐ Slime
    - ☐ LN_2
    - ☐ Elephant Toothpaste
- ☐ Amolto skype call recorder
- ☐ Skype

POST-Interview Checklist

- ☐ Save Amolto recording
- ☐ Save Recorder recording & delete from recorder
- ☐ Download RAW Success Criteria survey
    - ☐ CODE Success Criteria survey
    - ☐ Print coded Success Criteria survey for folder
- ☐ Send Follow-Up email about snowball and gift card & update excel sheet
- ☐ Received receipt for payment ________________ & Print/Sign/Scan it
  Date
- ☐ Send Amazon gift card & Print receipt

Phase 2 Checklist

- ☐ Send Phase 2 email with participant consent form & update excel sheet
- ☐ Send Video Recording Instructions, non-participant consent form, and parent/guardian information card & update excel sheet
- ☐ Reminder emails about getting video recording & update excel sheet
- ☐ Received video recording ________________ & update excel sheet
  Date
- ☐ Received receipt for payment ________________ & Print/Sign/Scan it
  Date
- ☐ Send Amazon gift card & Print receipt

F.4: SEMI-STRUCTURED INTERVIEW GUIDE

<u>Directions:</u>

We're just going to have a really informal conversation about your experiences doing chemistry outreach and the activities you do. There really are no correct answers, we just want to understand what you guys do and why you do it. We just want to learn things from you and understand what you think.

And just as a reminder, your name and school will not be associated with your data so no one will know that you said 'x' or someone from your school said 'x'. Do you have any questions before we begin?

<u>Warm Up:</u>

Just to start out, I'm going to ask you some general demographic questions. Some of these were on the survey you took volunteering to participate, but it's helpful to have them on the recording so I can easily pair up your data. So to begin…

1) What school do you go to?
2) What's your major?
3) Have you conducted undergraduate research before?
    a. Can you tell me a little bit about it?
4) How long have you been involved with your organization/doing outreach?
5) What do you like about your organization and doing outreach?

<u>INTERVIEW</u>

So now we're going to talk about just outreach in general.

<u>ROLE AND PURPOSE OF OUTREACH:</u>

1) So what do you think the role of learning is in chemistry outreach?
    a. Would you say younger students/children learning is part of a successful event?
        i. If it is, how do you know that the younger students/children have learned something?
2) In the survey you took to volunteer for this study, you selected some purpose of outreach and then ranked them from most important to least important. I'm going to message you your ranked list and I just want you to read through them and talk me through your thought process. Like why are these purposes important, why are they in this order, why is this one more important than this one. I just want to get an idea of you were thinking and how you think about these ideas. *(Send List through Skype Chat)*

EVALUATION AND INTEREST:

1) How do you know when an event is successful?
    a. How are you defining success?
2) How do you know when an event is unsuccessful/not going well?

3) ***QUALTRICS SURVEY: Criteria for Success. Have them talk out loud as they complete the survey.***
   [LINK TO QUALTRICS DURING INTERVIEW SURVEY]

4) What do you think you need to learn *more* about in order to have *more* successful events?

5) What would you say are your strengths in doing outreach events?

6) What are your weaknesses/could improve at?

CONTENT TEACHING:

Now I want to talk a little bit more about the specific activities you've done at these events. So according to the volunteer survey, you said you have experience with _________ *(say activity)*?

1) What is the typical age group(s) that you do this activity with?

2) How do you normally perform/do _______ activity?
    a. Is it a demo? Hands-on? What materials do you use?

3) What learning do you expect the participants to gain from this activity?

4) Now I want you to pretend that I'm a *(insert typical audience member here from question 1)* attending your events and you are doing ________, how would you explain it to me?

5) What about for a fellow undergrad? Like a new member joining your organization…How would you explain the chemistry behind ______ to them?

(Repeat content questions for all activities they have experience with)

CRITIQUE EXPLANATIONS:

We've done a lot of these interviews and we've received a lot of different answers for the way different people explain these activities (some accurate and some inaccurate). What I want you to do is read some of these explanations and evaluate them for 2 things: how age appropriate are they and how accurate the science is. We really just want to understand what you think about these activities and get a sense of what is age appropriate so we can help write better explanations, but it's definitely a mixture of accurate and inaccurate.

So I'm going to send you a *(Grade Level)* explanation for *(Activity).* I want you to read through and go line-by-line and talk with me about how age appropriate is it and the accuracy of the science.

Message them explanations for activities they talked about for the age level they discussed (as well as gen. chem.)

1) Overall Impression of it in terms of **scientific accuracy**?
    a. Something wrong? How would you re-word it?

2) Anything missing from the explanation?

3) Go line-by-line and talk me through each sentence for accuracy?

4) Overall impression of it for **age appropriateness?**
    a. Anything missing from it?
    b. Anything just too much/not age appropriate?

REPEAT FOR MULTIPLE ACTIVITIES AND MULTIPLE AGE LEVELS

TRAINING:

Now I want to talk a little bit about how you kind of trained or learned to facilitate these activities

1) So how did you learn how to facilitate____ activity?
    a. What is your role in facilitating them?

2) How did you learn the chemistry behind _____ activity?

3) How did you learn how to explain ______ activity to different audiences?

4) Is it the same for ________ activity(s)? Does something different happen?

5) How do you prepare for an event?
    a. Do you practice? Do you just show up and do it?

6) What is the role of your faculty advisor in planning/doing outreach events?

7) How does your group get new members up-to-speed so they can lead and explain the activities to kids?

8) If *(insert organization name here)* was to make a handbook for chapters about outreach, what do you think should be included?

Conclusion

Those are really all of the questions that I have.

1) Is there anything else you want to add or think we should know about your experiences with chemistry outreach?

2) Do you have any questions?

Please discard the explanations I sent you. We received these confidentially from other students so we want to keep them confidential and not circulated for public use. We will be sending you scientifically accurate, corrected explanations once we have collected all of your data for you to use in your future events.

Well I just want to thank you doing this interview. The only thing I really have left is some book keeping kind of things.

OBSERVATIONS:

First, we have a Phase 2 to this study where we are looking to see what happens at actual outreach events. I know it's a little inauthentic to have you sitting here pretending I'm like a 2nd grader, so we think it's really important to be able to see what it looks like in 'real life' like when there are five kids at the table. It would really give us a better idea of what these events look like. If you do, I can give you another $10 to Amazon (so a total of $25). You don't have to, it's not required, but the video would really help us understand what outreach looks like in the real setting. Of course if you do do this, the video will only be used to help us understand what is going on in this environment; no one else will see it.

So would you be interested in doing this part of the study?

It has to be one of the activities we talked about today just so we can have more understanding of what we talked about in the interview.

I know National Chemistry Week is coming up at the end of October so I know a lot of events tend to happen around then…

Gift Card:

For your gift card, in order for me to get you the $15 Amazon gift card, there's a form you have to fill out so the university knows how the money was spent…so I'm going to be sending you an email with a form in it. All you have to do it fill it out, sign it, and email it back to me. As soon as I get the form, I can email you the gift card.

Snow ball:

Would you be willing to send our survey link to two more people to try to get more people to do these interviews? Or is there anyone you would recommend for us to contact?

[LINK TO QUALTRICS SNOWBALL RECRUITMENT SURVEY]

F.5: DURING INTERVIEW SUCCESS CRITERIA SURVEY

What is your first and last name? ____________________

Select all that apply, at a successful event:

- the audience had fun
- the audience learned chemistry/science content
- the audience learned that chemistry/science is fun
- the audience learned that chemistry/science is not scary/anyone can do it
- the audience had high attendance
- the audience left smiling
- the audience had a good time/enjoyed themselves
- the audience was engaged
- the audience thanked presenters
- the audience was excited
- the **presenters** had high attendance
- the **presenters** had no safety concerns
- the **presenters** enjoyed themselves
- the **presenters'** demonstrations worked
- the **presenters** used good presentation skills
- the **presenters** gave good explanations

Of the ones you selected above, please rank them in order of most important to least important by dragging and dropping the items (most important on top):

[macro to pull responses from above question]

F.6: EXPERT EXPLANATION – ELEPHANT TOOTHPASTE

Reaction is the decomposition of H_2O_2

$2H_2O_2\,(l) \rightarrow 2H_2O\,(l) + O_2\,(g)$ Rate = Very slow (spontaneous)

$\Delta G = -237$ kJ/mol | $\Delta H = -190$ kJ/mol

Light increases the rate of decomposition (that is why it is sold in brown bottles at the store)

$2H_2O_2 + hv \rightarrow 4\ {\cdot}OH$

$4\ {\cdot}OH \rightarrow 2H_2O + O_2$

A catalyst changes the mechanism of a reaction by reacting to create intermediates. The Activation Energy for the catalyzed reaction is smaller than the original pathway. The catalyst is reproduced at the end of the reaction.

Two catalysts can be used: inorganic (KI/NaI) and biological (catalase enzyme/yeast).

Iodide catalyst:

$H_2O_2 + I^- \rightarrow H_2O + OI^-$ (Rate limiting step = slow)

H_2O_2 = Oxidizing agent
O = reduced (1e^- gain x 2)

I^- = reducing agent | I = oxidized (2e^- loss)

OI^- = hypoiodite ion

$H_2O_2 + OI^- \rightarrow H_2O + O_2 + I^-$ (fast)

Enzyme catalyst:

Alfonso-Prieto, M.; Biarnes, X.; Vidossich, P.; and Rovira, C. *J. Am. Chem*. Soc. 9 VOL. 131, NO. 33, 2009

Erman, J.; and Vitello, L. *Biochimica et Biophysica Acta.* 1597 (2002) 193-220.**

Must proof/activate the yeast before using it by placing it in lukewarm water (too hot or too cold could kill the yeast)

1) The outer coating of the yeast dissolves releasing the yeast to the solution (coating protects the yeast until you are ready to use it)
2) Add a pinch of sugar, the yeast will start the fermentation process:

   $C_6H_{12}O_6 \rightarrow 2CO_2 + 2\ CH_3CH_2OH$

3) Bubbles (CO_2) in the water/yeast mixture indicate that it is working and ready to use

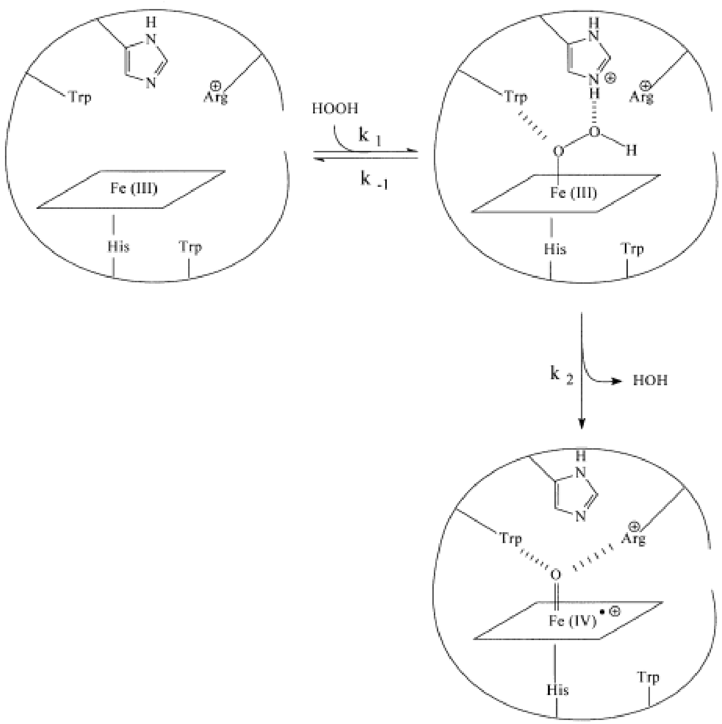
$Por\text{-}Fe^{III} + H_2O_2 \rightarrow Por^{\cdot+}\text{-}Fe^{IV}{=}O + H_2O$ * (slow = rate limiting)

Por loses 1 electron (oxidized)

Fe^{III} loses 1 electron (oxidized)

Both oxygens gain 1 electron (reduced)

$Por\text{-}Fe^{III}$ = reducing agent | H_2O_2 = oxidizing agent

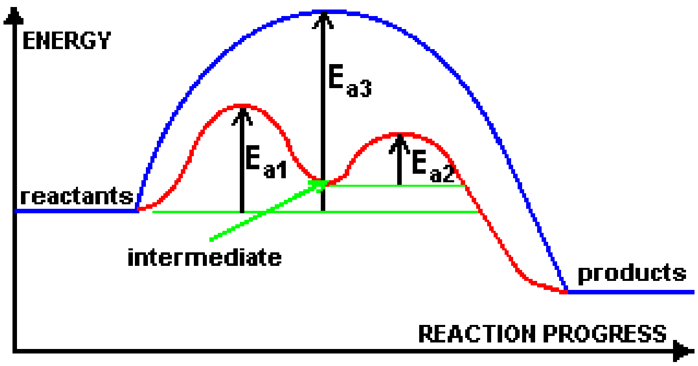


**

$Por^{\cdot+}\text{-}Fe^{IV}{=}O + H_2O_2 \rightarrow Por\text{-}Fe^{III} + H_2O + O_2$* (fast)

Exothermic reaction = enthalpy of products is *less than* the enthalpy of the reactants (net difference is the release in heat energy). Overall enthalpy change is negative ($-\Delta H$).

Entropy increases [Reactants = 2 molecules (liquid), products = 3 molecules (liquid/gas)].



Example Energy Diagram (http://www.docbrown.info/page07/SSquestions/catprofile.gif)

Water is produced which mixes with the dish soap creating suds. When oxygen is produced, the suds trap the gas in bubbles. Soap is only there to capture the gas being produced (it does not participate in the reaction). Without the soap, gas would be made but only bubbled through the liquid (not captured). Heat released from the reaction allows for a phase change of the water (from liquid to gas); this is why you see steam.

Food coloring is used as a dramatic effect to color the soap bubbles. It is not part of the reaction.

F.7: EXPERT EXPLANATION – LIQUID NITROGEN

Liquid Nitrogen

- Liquid nitrogen boils at -198 °C (75 K, -324.4 °F)
- At room temperature, liquid nitrogen boils and undergoes a phase change from liquid to gas.
    - Boiling is when vapor pressure is greater than atmospheric pressure
    - In a closed system, equilibrium between molecules converting from liquid to gas AND number of molecules converting from gas to liquid (does not boil because vapor pressure of liquid will go into equilibrium with atmospheric pressure of closed container)
    - When contain is open, the vapor pressure of the liquid is much greater than the atmospheric pressure of the surroundings, so it boils
- N_2 is a gas at room temperature because of the weak intermolecular forces between the N_2 molecules
    - Induced dipoles/London dispersion forces are not very strong forces
- During a phase change, the temperature of the liquid stays the same (Kinetic energy is not changing)
- Heat energy is absorbed from the surroundings increasing the Potential Energy of the system.
- Enough Potential Energy allows the liquid N_2 to convert to gaseous N_2 (convert potential energy to kinetic energy).
- A phase change from liquid to gas increases entropy as there are more microstates/arrangements/positions possible.

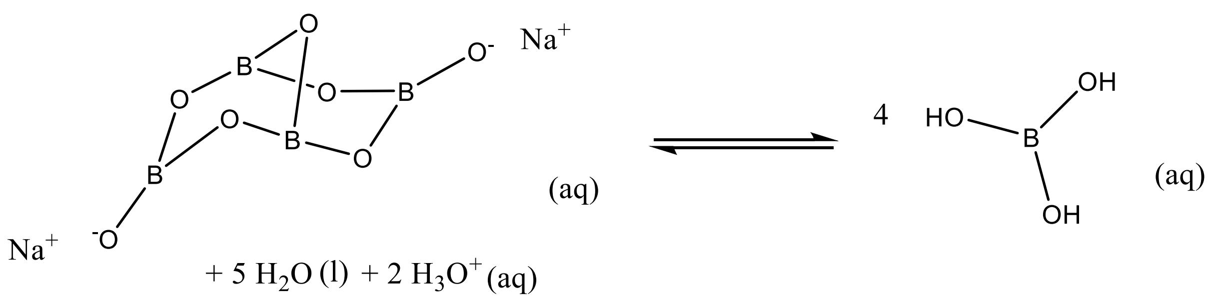
Demonstrations (flowers, bananas, etc.)

- When _____ is placed in liquid nitrogen, heat energy is absorbed from the item by the N_2 molecules. The process is rapid due to the large temperature difference between the item and liquid N_2.
- The water molecules in the item freeze (phase change from liquid to solid) rapidly as the heat energy is absorbed by N_2. Entropy of the water decreases during the phase change due to more order/structure (i.e. less available microstates/arrangements).
- For a flower, the entire item becomes brittle/easily broken because all of the water molecules are frozen and have expanded. As the water expands, the cell walls/internal structure of the flower break leaving no internal structure holding it together. Any outside force will cause it to crumble easily because the petals/leaves/stem are very thin meaning the amount of force required to break it is small.
- For the banana, the same thing happens; water molecules freeze and expand. However, the banana is much thicker than a flower. Therefore, the amount of force required to shatter it is much more. It can be used as a hammer because the amount of force required to break it is so high.

F.8: EXPERT EXPLANATION – SLIME

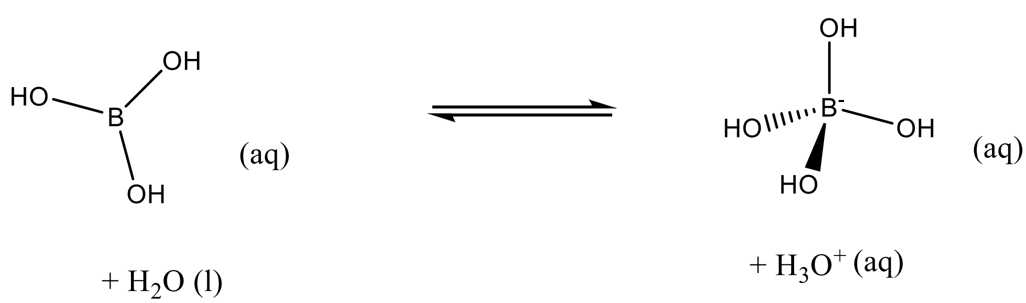
Borax = (di) Sodium tetraborate decahydrate ($Na_2B_4O_7$ *10 H_2O)
When dissolved in water, it gives boric acid:

$$B_4O_7^{2-}(aq) + 5H_2O(l) + 2H_3O^+(aq) \rightleftharpoons 4H_3BO_3\ (aq)$$



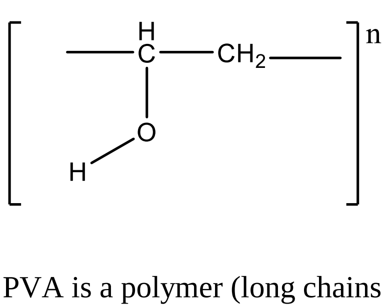
Boric acid is in equilibrium with the tetrahydroxyborate ion:

$$B(OH)_3\ (aq) + H_2O(l) \rightleftharpoons B(OH)_4^-(aq) + H_3O^+(aq)$$



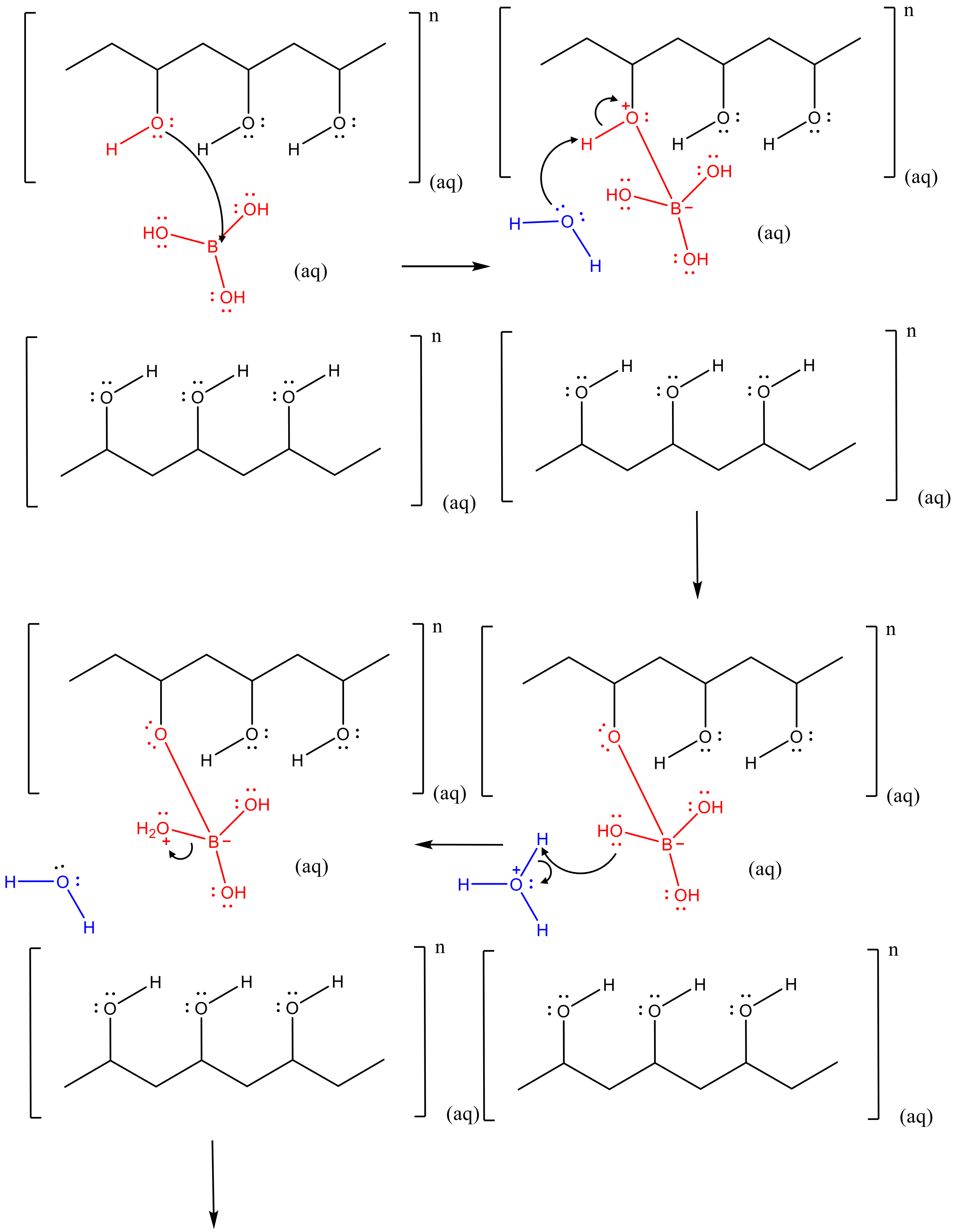
This equilibrium is what makes the slime formation possible.

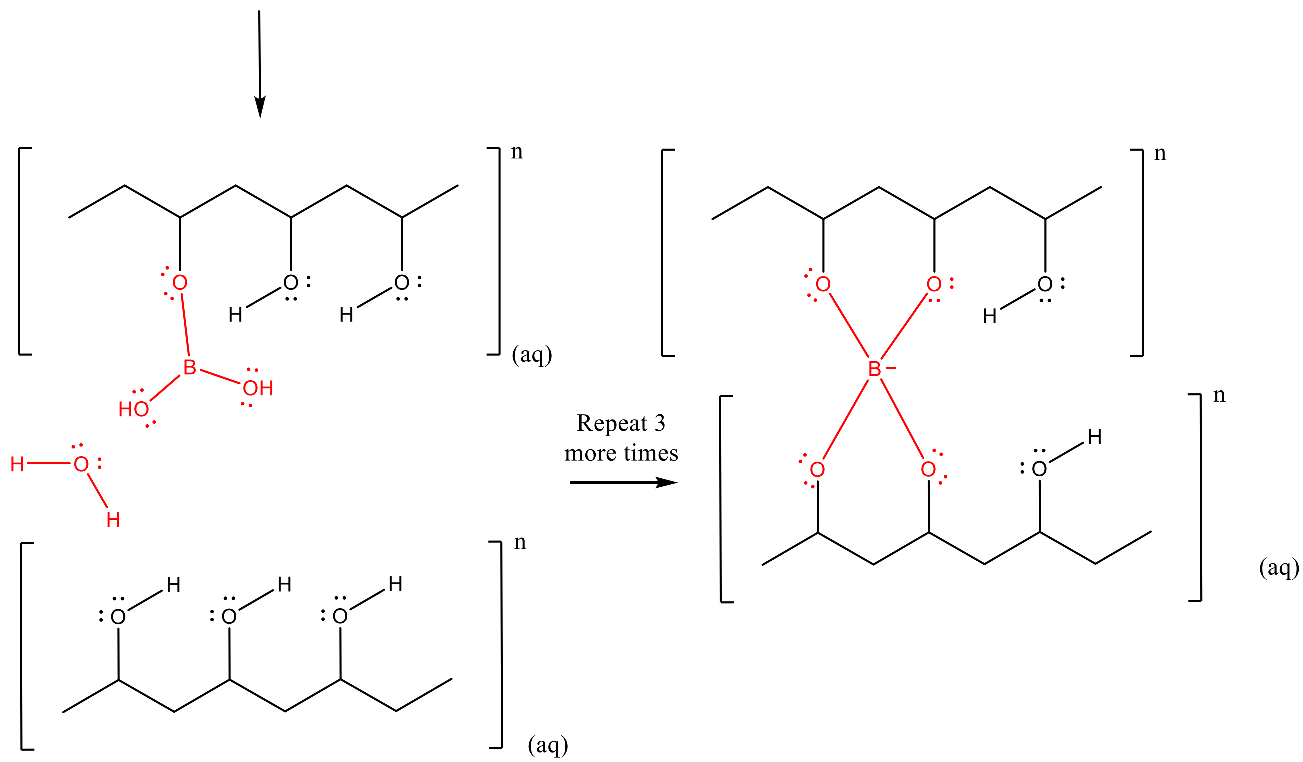
Glue is PVA based (polyvinyl alcohol):



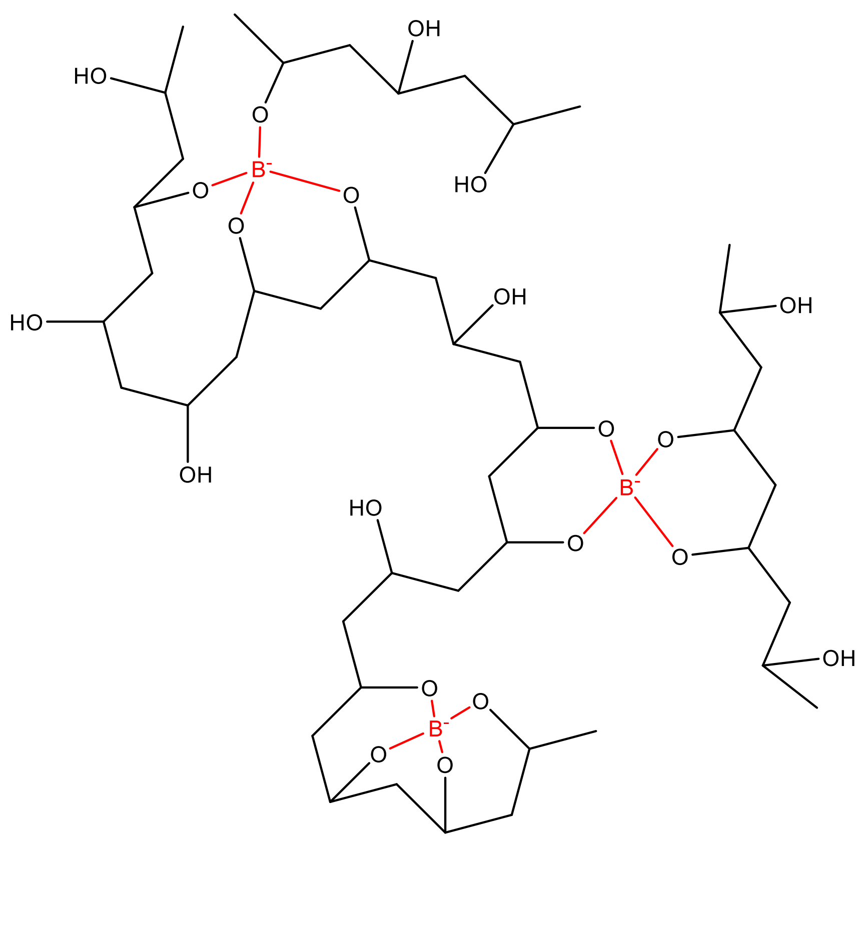
PVA is a polymer (long chains of repeating units) in solution. This makes it a viscous liquid, but the chains can easily slide past each other when small force is applied (i.e. squeezing the bottle of glue causes it to flow out of the bottle).

When the borax solution is added to the polymer, the boric acid can crosslink chains of the polymer together through multiple condensation reactions:

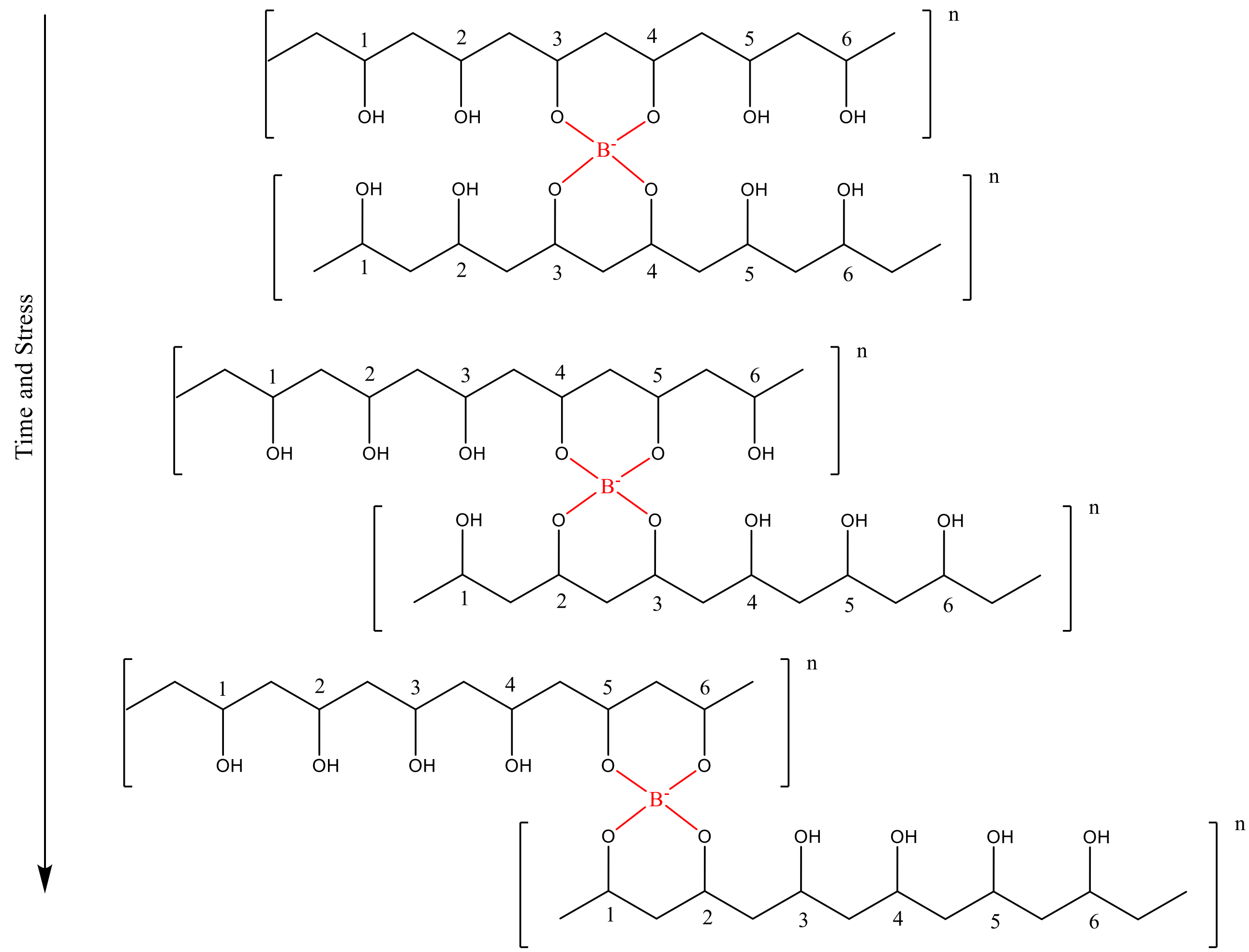




These crosslinks can be formed between polymer chains as well as within a single polymer chain:



The crosslinks add rigidity to the polymer causing it to behave less like a liquid and more like a solid. However, the B-O bonds are very dynamic and can easily brake and reform on different parts of the polymer chain. (Similar to the dynamic acid base equilibrium between $B(OH)_3$ and $B(OH)_4^-$) This explains why the slime can flow like a liquid under small amounts of stress. The B-O bonds can break allowing the polymer chains to slide (therefore the slime can flow). The B-O bonds can then reform with other hydroxyl groups (and water will protonate the remaining O^- recreating the hydroxyl group):



These dynamic bonds allow for both the liquid and solid characteristics of the slime. The more concentrated the borate ion is, the more crosslinks that will occur, and therefore more solid the slime behaves.

It is important to note that the B-O bond has a characteristic timescale of dynamic exchange (time needed to break and reform). Under high stress (quickly stretching the slime or dropping it), the timescale of the "experiment" or timescale of applied force is faster than the timescale of exchange for the B-O bond. Therefore, there is negligible exchange of the B-O bonds under these conditions (when force is applied); this causes the slime to behave more like a solid (i.e. breaks into pieces or bounces). When the slime pieces are folded back into each other, the dynamic characteristics of the B-O bond allows the slime to 'self-heal' and recreate one piece of slime as the B-O bonds are reformed and reconnect the pieces of slime together.

Materials that behave in this manner (both as solids and as liquids) are called non-Newtonian fluids or viscoelastic materials. These are materials that change their flow behavior (viscosity) under stress and/or time. Liquid water is an example of a Newtonian fluid because it always flows the same way (it does not become more viscous or less viscous when you hit it or drop it).

F.9: FOLLOW-UP TO INTERVIEW EMAIL – SAMPLE

Hello ______,

Thank you again for participating in our study! As we discussed, this is the link for you to send to others about participating in this project. Helping us obtain as many interested people as possible is the only way we can be sure that we can help improve chemistry outreach across the country. Hopefully now that you've experienced this *super fun interview*, you can encourage someone else to participate :)

Here is a link for you to forward to those you think may be interested:
[LINK TO QUALTRICS SNOWBALL RECRUITMENT SURVEY]

For the Amazon gift card, the form for you to fill out is attached. The information that you need to fill in is below. Please fill it in, sign your name on the "Research Participant Line" and date it, and then scan and email it back to me. Once I receive it, I will sign the "Principal Investigator/Researcher" line and email you the gift card information.

Participant ID Code: Your First and Last Name
Date of Participation: [date of interview]
Permanent Address: Your mailing address
Amount paid: $15.00

Since we've received a lot of different explanations for the outreach activities, we've crafted some scientifically accurate explanations for multiple age levels. The explanations for _____ are attached. I hope these are helpful for you, and the rest of your organization, with your future outreach events.

Please let me know if you have any questions. Thank you again for participating in our study!

Note: In case you have limited access to a scanner, I believe that there are phone apps you can download that allow you to take a picture of the document and it'll convert it to a PDF. For Android, there is an app called CamScanner. For Apple there is an app called Genius Scan. Both are free and should allow you to easily "scan" the hard copy straight from your phone (like taking a picture).

Justin

F.10: CORRECTED/ACCURATE EXPLANATIONS EMAILED TO PARTICIPATES AFTER INTERVIEW – ELEPHANT TOOTHPASTE

General Chemistry

This reaction involves the catalytic decomposition of hydrogen peroxide into water and oxygen gas. This oxidation-reduction reaction is an exothermic reaction because the newly formed bonds are lower in potential energy than the bonds that were broken. A catalyst is used because the decomposition proceeds very slowly. The catalyst makes the reaction rate increase because the mechanistic pathway changes. The catalyzed pathway has two steps with lower activation energies. Overall, the catalyst does not change the overall enthalpy change of the reaction, only the pathway through which reactants become products. The reaction starts off slow because the first step is the rate limiting step. Soap is used to capture the gas being produced. Once all of the catalyst is converted to the intermediate, the reaction dramatically speeds up as noted by the increase in foam being produced. Since the products are gas, the foam expands as the gas is formed.

8th Grade

Hydrogen peroxide spontaneously breaks into water and oxygen. However, this typically happens very slowly. In our reaction, we are going to speed up that decomposition using a catalyst. The water and oxygen produced are gases. Gas molecules spread out and fill their containers. The bubbles that you can see grow and expand out as the gas molecules form and spread out. Heat is produced because the products (water and oxygen) have less energy than the hydrogen peroxide. Because the products are lower in energy, the excess energy is released as heat.

2nd Grade

In this reaction we are converting a liquid into multiple gases. When the particles become gas, they spread out and fill their container. However, most gases are invisible. In order to see this happen, we need to capture the gas. Just like blowing bubbles or bubbles in the bathtub, we use soap here to capture the gas and give us evidence that the gas was produced. As the reaction progresses, you can see the foam grow and expand as the gas particles that are made spread out.

F.11: CORRECTED/ACCURATE EXPLANATIONS EMAILED TO PARTICIPATES AFTER INTERVIEW – MAKING LIQUID NITROGEN ICE CREAM

General Chemistry

The ice cream solution is a mixture of milk, sugar, and flavoring and milk is primarily composed of water. Dissolving the sugar into the milk decreases the freezing point of the milk causing it to freeze at a lower temperature. Nitrogen is a gas at room temperature because of weak intermolecular forces between the nitrogen molecules (London-dispersion interactions). Liquefying nitrogen requires low temperature and high pressure in order to decrease the kinetic energy/slow down the molecules enough to have the intermolecular forces take hold. As soon as the liquid nitrogen's container is opened, it boils because the vapor pressure at room temperature of liquid nitrogen is so high. During boiling, the temperature of the liquid nitrogen stays constant because the energy being absorbed is converted to potential energy, not kinetic energy, as the nitrogen changes from liquid to gas. The heat absorbed by the liquid nitrogen comes from the ice cream solution. Because the temperature difference between the ice cream solution and the liquid nitrogen is so great, the energy transfer is very fast allowing for the ice cream to freeze almost instantly. The water inside the ice cream mixture goes from a liquid state to a solid state because heat is lost and the molecules slow down creating solid ice cream.

8th Grade

Ice cream is primarily made out of milk which is a mixture of fat and water. When we freeze the water, we get solid ice cream. We can use a freezer at your house to do this, but it takes a long time. If we use liquid nitrogen, we can do it in a few minutes. Your freezer at home is around 30°F degrees, liquid nitrogen is around -320°F. Because liquid nitrogen is so cold, it freezes ice cream much faster. When we freeze the ice cream, the mixture goes from a liquid to a solid. In the liquid state, the molecules slide past each other and move around. In the solid state, the molecules are vibrating in an ordered structure. When we add the liquid nitrogen, energy from the ice cream mixture transfers to the liquid nitrogen causing the water in the ice cream mixture to freeze. The liquid nitrogen absorbs the energy from the ice cream and it phase changes from liquid to gas.

2nd Grade

You use a freezer at home to keep ice cream cold. Liquid nitrogen is about 12 times as cold as your freezer so it will let us make ice cream really fast. The liquid ice cream mixture is going to freeze to a solid because the liquid nitrogen absorbs energy from the ice cream making the ice cream very cold. When the ice cream mixture gets really cold, the particles slow down and the mixture becomes solid. The liquid nitrogen, once it absorbs energy from the ice cream, becomes a gas and floats away.

F.12: CORRECTED/ACCURATE EXPLANATIONS EMAILED TO PARTICIPATES AFTER INTERVIEW – MAKING SLIME

General Chemistry

Polymers are long chains of repeating units. White glue is primarily composed of the polymer polyvinyl alcohol (PVA) which has repeating chains of hydroxyl groups (R-OH) in aqueous solution. In solution, the long polymer chains can easily slide past one another with minimal attractions to each other. This is why the glue flows out of the bottle. Borax, when dissolved in water, yields boric acid $B(OH)_3$. The boric acid can form covalent bonds to PVA and link the polymer chains side to side (this is called crosslinking). As more and more crosslinks are formed, the PVA chains do not slide past one another as easily (because they are linked together) making the mixture behave more like a solid.

Under light stress (slowly stretching the slime), these crosslinks can easily break and reform allowing the slime to flow and behave like a liquid. As the amount of stress is increased (quickly stretching the slime), the bonds break and do not reform causing the slime to behave more like a solid and break into pieces.

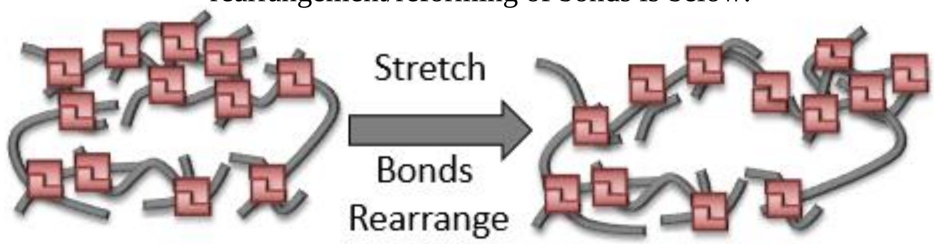
8th Grade

White glue is made up of a polymer. Polymers are long chains of molecules. You use polymers every day; the rubber on your shoes, plastic drink cups, and Styrofoam containers are all different kinds of polymers. Some polymers are elastic and flexible (like rubber) and some are hard and firm (like hard plastics). The polymer in glue is a liquid; the polymer chains can easily slide past one another which is why the glue flows out of the bottle. When we add borax, the polymer chains link together so don't slide as easily. The more links we have, the more the polymer starts behaving like a hard solid rather than flowing like a liquid.

2nd Grade

Solids hold their shape. Liquids do not (they flow). In this experiment, we are going to create a slime that behaves both like a solid and like a liquid. We start with glue which is a liquid. When we add our detergent, we make the glue less like a liquid and more like a solid. Slime made with a small amount of detergent behaves more like a liquid (it flows); slime made with a lot of detergent behaves more like a solid (it holds its shape). In addition, when we push or pull on the slime, it resists the change and starts to behave more like a solid.

A cartoon representation of how slime can stretch (flow like a liquid) due to the rearrangement/reforming of bonds is below:



Courtesy of Dr. Dominik Konkolewicz at Miami University

F.13: PHASE 2 VIDEO OBSERVATIONS CONSENT EMAIL – SAMPLE

Hello **______**,

Thank you for agreeing to participate in Phase 2 of our study (the video observation phase). As we discussed during the interview, we are looking for a recording of you participating in an outreach event that involved one of the activities we talked about (i.e. elephant toothpaste).

Attached is a consent form for you to fill out that details specifically what we are asking you to do. Please read/sign the consent form and email the signed page back to me. Once I have received the signed document, I will email you more specifics about the video recording including guidelines/instructions for video recording, information for fellow presenters, as well as information for parents/guardians who may have questions.

Please let me know if you have any questions or are no longer interested in participating in this phase of the study. If you aren't, we can work on the $15 gift card for participating in the interview.

Note: In case you have limited access to a scanner, I believe that there are phone apps you can download that allow you to take a picture of the document and it'll convert it to a PDF. For Android, there is an app called CamScanner. For Apple there is an app called Genius Scan. Both are free and should allow you to easily "scan" the hard copy straight from your phone (like taking a picture).

Justin

F.14: PHASE 2 VIDEO OBSERVATIONS EMAIL – SAMPLE

Hi **_______**,

Thank you again for agreeing to participate in Phase 2 of our study (the video observation phase). Attached are Video Recording Guidelines that detail more specifically *how* to video record and *what* to focus on as well as a consent form for any other college students that may appear in the video (outside of you). I know that sometimes the setup is a large table with multiple college students so if this is the case, please have them sign the attached form. I have also attached an information card that can be provided to parents/guardians if they have any questions about the video recording.

Just as a reminder, the video recording should be focused on you presenting and explaining the activity we talked about in the interview (i.e. **you** facilitating and explaining **making slime** in English). Please let me know if you have any questions or concerns.

Thanks!

Justin Pratt

F.15: PHASE 2 VIDEO OBSERVATIONS - VIDEO RECORDING GUIDELINES

The research team is solely interested in how you, the research participant, facilitates the outreach activity. We want to understand what skills and best practices are necessary to have successful chemistry outreach events. As such, we need the video to focus on YOU and the ACTIVITY. **No children/outreach participants should be captured. All preventative measures should be taken to ensure only you and the activity are included in the video recording.**

We understand that the video may accidentally capture the likeness of other college students/organization members helping to facilitate the event. Please have those individuals sign the video consent form provided if necessary (and scan/email those forms to us along with your video file).

Children/outreach participant voices should be captured as well as shots that **do not include their faces**. Shots from behind them that do not include their faces or zoomed in shots of a table that only show hands are encouraged. Below are example schematics on how to film the event. Videotaping can be done in many different ways. Choose the method that best matches with your specific event. If unsure of how to set up for videotaping, please contact Justin Pratt to discuss logistics specific to your event.

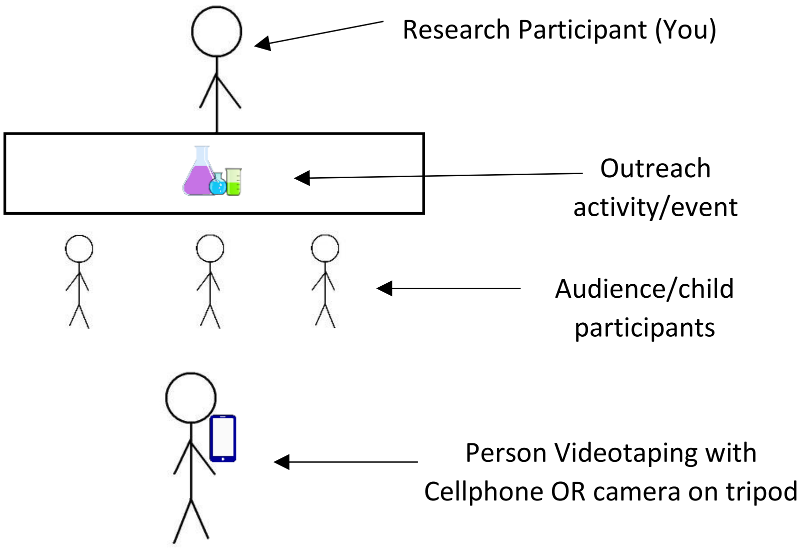
Once the event is finished and the video file has been obtained, please review the video file to ensure that identifying imagery of minors it not included. Once you have reviewed the file, it can be sent to Justin Pratt using cloud sharing services like Google Drive or Drop Box. Zipping the file (compressing it) is also an option in order to be able to email the file. Please also include a **brief** description of the event (e.g. What grade level was your audience? Can you estimate how many people were in attendance? Was the event a large STEM Fair or a smaller individual school activity?)

Other large-file sharing options include:

1) DropSend (send up to 4 GB with free registration)
   http://www.dropsend.com/
2) pCloud Transfer (send up to 5 GB, no registration required)
   https://transfer.pcloud.com/

If you have any issues or questions please contact Justin Pratt (prattjm5@miamioh.edu).

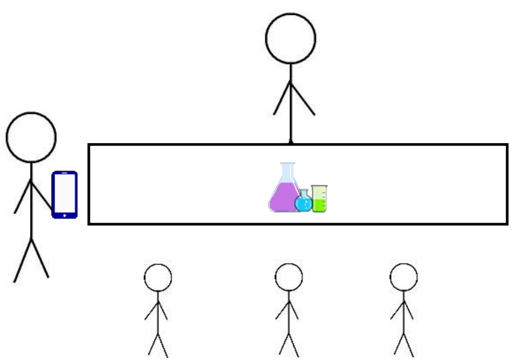
Schematics for Video Recording



<u>Option 1:</u>

This method will ensure that **<u>child participants are only featured in the video from behind</u>** while still providing a good view of the activity itself and the research participant.

<u>Audio of the event is very important</u> so care should be taken to ensure the audio is captured in the video.



<u>Option 2:</u>

This method will ensure that child participants are only featured in the video through audio and **<u>is zoomed in to only show the activity and the research participant.</u>**

(Hands of the child participants can be included in the video as long as faces are not featured)

F.16: PHASE 2 VIDEO OBSERVATIONS - HANDOUT FOR PARENTS/GUARDIANS

MIAMI UNIVERSITY

Hello Parents/Guardians!

This chemistry outreach event is being video recorded as part of a research project at Miami University. The college students have planned this event as part of their normal organization's activities without any involvement with Miami University. The video being recorded is solely focused on the college students running the event and the activity they are doing. Therefore, the video is focused on them. Children will not appear in the video; their voices and/or hands may be captured but precautions are being taken to not capture their faces. Miami University will be provided the video recording and will ensure all precautions have been taken to ensure the privacy of the children/audience.

Questions about this project may be directed to Justin Pratt (prattjm5@miamioh.edu) or Dr. Ellen Yezierski (yeziere@miamioh.edu) at Miami University, Oxford, OH.

✂ ——

MIAMI UNIVERSITY

Hello Parents/Guardians!

This chemistry outreach event is being video recorded as part of a research project at Miami University. The college students have planned this event as part of their normal organization's activities without any involvement with Miami University. The video being recorded is solely focused on the college students running the event and the activity they are doing. Therefore, the video is focused on them. Children will not appear in the video; their voices and/or hands may be captured but precautions are being taken to not capture their faces. Miami University will be provided the video recording and will ensure all precautions have been taken to ensure the privacy of the children/audience.

Questions about this project may be directed to Justin Pratt (prattjm5@miamioh.edu) or Dr. Ellen Yezierski (yeziere@miamioh.edu) at Miami University, Oxford, OH.

APPENDIX G: SAMPLE INTERVIEW TRANSCRIPT

Interview with sophomore, chemistry/biochemistry major Carrie (pseudonym) from a medium sized, private institution on 12/9/2016.

Interviewer:	Hey. Can you hear me?
	Can you hear me now? (laughs)
Carrie:	Can you hear me?
Interviewer:	Yeah.
Carrie:	Is your mic muted?
Interviewer:	(laughs)
Carrie:	I hear like, white noise, but I don't know if that's coming from your end if it ... or if it's just my headphones. Okay.
Interviewer:	Hmm.
	Can you hear me?
Carrie:	Still no.
Interviewer:	(laughs) Um.
Carrie:	Can you try saying something again?
Interviewer:	Can you hear me?
Carrie:	Yes, very faintly.
Interviewer:	Okay. (laughs)
Carrie:	Okay. Um, is there any echo?
Interviewer:	From your end, no.
Carrie:	Okay, then this works.
Interviewer:	Okay. Cool. (laughs) So, we're just gonna have like a really informal conversation about like, your experiences doing outreach and the activities you've done before. So, there's no like, correct answer or anything that I'm looking for. I just want to like, understand what you do and why you do it.

Carrie:	Okay.
Interviewer:	And as just like a, a reminder, your name or your school won't be associated with anything you say. So, no one will know that you said it or even someone from your school.
Carrie:	Mm-hmm (affirmative).
Interviewer:	Do you have any questions or anything before we begin?
Carrie:	Um, no. Let- let's just start.
Interviewer:	Okay. So, just to start out I'm gonna ask some general demographic questions just so I can pair up that survey you took a while ago, um, with what we talk about.
Carrie:	Okay.
Interviewer:	So, what school do you go to?
Carrie:	Um, [School Name].
Interviewer:	And what are you majoring in?
Carrie:	Chemistry.
Interviewer:	Uh, have you done undergrad research before?
Carrie:	No.
Interviewer:	No. Um, how long have you been involved with doing outreach?
Carrie:	Um, so, I forget what I said on the survey, but at [School Name] it's been a year and a half. Um, and it might've been another year before that, if I ...
Interviewer:	Did you like, transfer to [School Name]?
Carrie:	No, so I did some outreach in high school.
Interviewer:	Okay.
Carrie:	Um, but at [School Name] it's been a year and a half.
Interviewer:	What kind of outreach did you do in high school?
Carrie:	Um, so, the, uh, the demonstration heavy outreach was actually through the Carnegie Science Center, where, uh ... which was local where I am from. Um, and

	I was part of the demonstration theater team and we did ... I mean, we had ... We, we did shows in the science center, um, where our audience was mostly families.
Interviewer:	Okay and so, have you done similar things now that you're at [School Name]?
Carrie:	Yeah. Um, so, I did demonstrations in the science center in high school and then here at [School Name], uh, I'm part of the undergrad chemistry association and we do magic shows for local elementary or middle schools or, um, whatever ... whoever contacts us for magic shows.
Interviewer:	Okay.
Carrie:	We also have evolved demos.
Interviewer:	Yeah. So, what, what do you like about doing outreach then?
Carrie:	Um, people's reactions are always fun.
Interviewer:	Yeah.
Carrie:	Um, it's nice to, uh, be able to show kids something that scientifically, can be actually pretty simple, but then they ... they're super excited about what they see.
Interviewer:	Mm-hmm (affirmative). So, it's just kind of, like, seeing their reactions?
Carrie:	Yes.
Interviewer:	Yeah. Okay and so, um, like, when you think about like, an outreach event, what would you say the role of learning is during the event?
Carrie:	Um, from my perspective, my goal is to expose my audience to whatever concept that I'm doing in my demos. Um, I don't necessarily expect that they'll remember everything I teach them, but I would like to get them, kind of, familiar with what is out there and spark their interest, so that they can learn more, um, if they are interested after our shows.
Interviewer:	Okay, and so, you want them to learn something, but if they don't remember all of it that's totally okay?
Carrie:	Yes.
Interviewer:	Okay and so then, I guess, how do you know that they've learned whatever you wanted them to learn at the end of it?

Carrie:	Um, that is hard. Um, especially, since it's mostly us talking and not so much them responding. Um, we always encourage people to ask ... come up and ask questions after the show if they have any. Um, and sometimes, we get some good questions from the audience. Like, "How did this happen?" Or, or, "Why do you put this and this together?" Um, but otherwise, I- I don't that we can really gauge learning. Um, other than maybe, teacher feedback at the end on like, after the show, if we're doing it in a school.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Mm-hmm (affirmative). Yeah.
Interviewer:	Do you normally do it in the school or is there other places you do it?
Carrie:	Uh, it varies. So, we ... sometimes schools will contact us and then we travel to the school for a show in the school. We also do shows, um, at [School Name], whenever there's events on campus or, uh, or even around campus. For example, in the Spring, we're planning to, um, do demonstrations at ... as part of the Cambridge Science Festival, which is not [School Name] specific, but it will be close. So, um, I think we'll do it at a venue that's, that's near campus.
Interviewer:	Okay and so, when you, uh, took that survey to volunteer, there was like, a list of purposes you've selected from and rank ordered.
Carrie:	Mm-hmm (affirmative).
Interviewer:	Does that sound familiar at all?
Carrie:	Um, what are some of the examples of things that were listed?
Interviewer:	I can ... I'm actually gonna message you the ones you picked.
Carrie:	Okay.
Interviewer:	And I want you to basically, read it and walk me through like, what you were thinking.
Carrie:	Okay.
Interviewer:	Like, why did you pick these as important? Why did you put them in this order? Stuff like that.
Carrie:	Okay, sure.
Interviewer:	So, this should send you the list that you, um, put in.
Carrie:	Okay. Um-

Interviewer:	And just walk me through like, why are these important and why are they in that order?
Carrie:	Okay. Um, so, number one and number two are kind of, tied together for me. Um, I think it's important to, um, to tell kids what science is about and to, to, kind of, open their eyes to what all is out there and then, if we can do that in a positive way and if we can get them excited about what more there is to learn or what more there is to explore and discover in science, than I think that'll start, um, a snowball effect of them wanting to learn more and then as they learn more they learn more exciting things. Um, so, I think the ... So, so, exposing younger students to spark their interest in the sciences and helping them have fun are very much liked for me.
	And I think there's also because, um, when I was younger, science was never something I was obligated to learn. Um, but rather, I learned it because it was fun and if that hadn't been the case I, I don't think I would still be pursuing science. Like, if I were forced to learn science for the sake of a class or parental pressures or whatever, I don't think it would be nearly as enjoyable now. Um, and then number three, as a female in science, um, I've noticed throughout my career that I've often been one of the few or if not the only female around the science arena I'm in and part of the reason why I do outreach is to sh- ... to be a female role model for younger students.
	Um, so in high school one of the things that I did was, um, my friend and I started a, a group called STEMinism. Um, which was for girls who were interested in STEM at our school and it was mainly just to get everyone together and build a community that didn't exist at the time. Um, and while that group didn't do any outreach, um, when I was there it was ... I mean, it was a brand new club, so we didn't really have time to do too much. Um, but some of our members did things like, teach middle school students coding. Um, in conjunction with other clubs at our school, so, it was nice to pay it forward.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, for younger students and then I guess, that also, answers number four. Um, and then five (laughs) so, I remember instance last year, I was, um, our ... we had a team go to the [Festival Name] from [School Name] and we were preparing for that and, um, we were, I think, playing with Oobleck, figuring out throwing the ratio of corn starch to use for that demonstration and I just had a lot of fun doing that.
Interviewer:	Mm-hmm (affirmative).
Carrie:	And, um, I ... that was a, a, a nice break from work in the midst of a really stressful time in the semester. So, I think doing outreach, kind of, um, forces us to take a step back from all of our exams and studying and research and reminds

	us why we are doing science because it's, kind of, that, um, curious kid inside, well, for me at least, it's the curious kid inside me that makes me keep wanting to do this.
	Um, and then, six is the lowest priority. Um, like, I think it's, as I mentioned previously, I think it's nice if our audience learns something from our demonstrations, but I think that's less important than, um, making them want to learn more because there's only so much that we can do in a half hour or an hour. Um, and I think if we try to cram a lot of teaching things in there, that's not going to be a positive net experience.
Interviewer:	Mm-hmm (affirmative). Okay and so, you said, like, one and two are link and then, I guess, are three and four linked for you?
Carrie:	Um, yes.
Interviewer:	What about like the hierarchy? Like, is one higher than two even though they're connected?
Carrie:	Um, yes, yes. I do think the hierarchy is as it should be listed. Um, maybe it can be like, one and two are the top level, but one is higher than two and three and four are the next level, but three is still higher than four and then five and then six.
Interviewer:	Okay. So, kind of, like, the sections? Something like that?
Carrie:	Yes.
Interviewer:	Okay. Um, and so like, when you ... you have your event. How do you know like the event is going well or it's successful?
Carrie:	Um, audience reaction's mainly. Um, if we do an especially, exciting demo, usually, you'll get some sort of, "Oo" or "Ah" from the audience. Um, or if like, like, if kids are fidgety and like, looking away, that's usually a sign that they're disengaged. Um, I, I, I think, I'm pretty perspective of how my audience is reacting. Um, I obviously, can't speak for others, but, just if people look happy, I think it's going well.
Interviewer:	Mm-hmm (affirmative). How did you like, learn to like, gauge your audience?
Carrie:	Um, I think it's something I learned working at the Science Center in high school. Um, so, when I was going through the training there, uh, at first, I was mostly working with the mentor while ... So, I was doing the demos ... the, the physical parts of the demos, while my mentor talked through the, um, presentation and I would notice how my mentor would engage with certain audience members. Also, in those shows we asked for volunteers at certain points, um, of the

	presentation and I would just try to notice how my mentor was engaging with the volunteer that came up.
	Uh, and how my mentor called on different people in the audience to answer questions. I think the shows I did in high school were more interactive, um, because they could be because, because of the design of the show. Um, it was a smaller audience than most shows that we do for like, schools or [School Name] magic shows. Um, and the space was a very controlled ideal space, so ... and the demos were all performed in like, our safe, uh, little stage.
	So, we had to worry less about keeping our stuff away from the audience and more about how do we connect with the audience given how they're reacting to what we're doing right now.
Interviewer:	Mm-hmm (affirmative) and so, now you have to worry more about that 'cause the setting's very different?
Carrie:	Yeah.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, because with every new venue that we go to, we have to plan out, "Okay, what- what space do we have here? Um, how much distance can we keep between us and the audience?" Especially, if we have things ... Especially, if we have kids that want to get up really close, but obviously, it's not safe for them to do so, because we have chemicals. Um, so that adds a layer of difficulty. It's nice to be able to travel with our stuff, um, and to be able to reach more, more people, but there's a balance between that and keeping track of everything.
Interviewer:	Yeah and so you said like, the audience being fidgety or disengaged is a, a way you tell they're like, not ... it's not going well. Is there any other ways you know like, the events not going so great?
Carrie:	Mm, for magic shows we tend to work ... there's usually two or three, um, presenters at a time and if we, ourselves, are well coordinated, I think that also, shows in how, how smoothly we transition between things. Um, how smoothly the demonstration, itself goes, so that's something from our end and that's probably easier to notice than judging audience reactions. Um, that- that's probably what I can think of at the moment.
Interviewer:	Okay and so, I've done like, a lot of these interviews and everyone has like, a different idea for like, how you know your events are going good 'cause, you know, you do them with different uh...schools, you do them with different like, ages of kids.
Carrie:	Mm-hmm (affirmative).

Interviewer:	And so, what I have is a list that other people have said for what they say makes like, a good successful event and I want you to basically, look at the list and tell me which ones you agree with and why? Which ones you don't agree with and why?
Carrie:	Okay.
Interviewer:	Um, so it's in survey format, so, uh, that way you don't ... I don't have to write anything down. Um, so you can just ... it will ask for your name. So, I make sure I know that it was yours. Um-
Carrie:	Okay.
Interviewer:	... but just basically, walk me through each one. Like, do you agree with it or not and why?
Carrie:	Um, okay. So, so, the audience had fun. Yes, I think that's important. That ties back to what I said previously about, uh, wanting kids to ... making kids want to learn more science after the event. Um, the audience learn chemistry and science content, I feel like that's really hard to gauge unless you specifically ask them questions throughout the presentation. Um, which could be fun, but it could also, select four ... a few kids who are more willing to answer questions. Um, and is not a good general indicator of whether the show went well.
Interviewer:	Mm-hmm (affirmative). So, would you select it or not?
Carrie:	I think ... I, I think not.
Interviewer:	Okay.
Carrie:	Um, yeah. Okay, the audience learned that Chemistry/Science is fun. Yes. Um, you know, I feel like this is gonna ... that my answers to these, these indicators will, will align very closely with my priorities-
Interviewer:	Mm-hmm (affirmative).
Carrie:	... that I've said previously, um, which I guess informs my, my outreach presentation more than I realized, but-
Interviewer:	(laughs)
Carrie:	Yeah. So, learn that Chemistry and Science is fun, um ... Oh, so, it's, kind of, interesting to distinguish between the audience had fun and the audience learned that Chemistry and Science is fun. Um, I think both are important. Um, the audience, the audience should have fun, in terms of ... like, just within the context of the presentation itself, but then the ideal takeaway would be that the audience learns that chemistry is fun, so they want to do it later.

Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, and then the next one, the audience learned that Chemistry or Science is not scary, could be a consequence of seeing that Chemistry or Science is fun or, or it could be ... yeah, I think that's important, to show them that they shouldn't be afraid to try things and then ... So, I think it should be like, the audience learns that Chemistry and Science is not scary, so that they can then see that it is fun because if the think it's scary, there's no way they're gonna think it's fun, whether or not, they see that we're having fun.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, yeah. The audience had high attendance. Um, I think that's, that's also a hard indicators. Like, difficult to tell because that there's too many compounding factors and then, like, the audience schedule or there might be something going on at the same times that is more interesting or relevant to them. Um, and then high attendance also depends on the context of, is it a school show? Is it a public show? Like, how many people was it advertised to? Do they have to come? Do they not have to come? I think that, that's not a clear indication of success.
Interviewer:	Okay.
Carrie:	Um, okay. The audience left smiling. Sure. Um, if they had ... if they enjoyed the show, then I presume that they would leave smiling. I don't have much of an explanation for that one.
Interviewer:	Okay.
Carrie:	Um, the audience had ... So, so, the next five seem like audience reaction type things, uh, mostly after the show. Also ... but also, during the show. Um, I think these ... the next five, audience love smiling, had a good time, was engaged, think presenters with excited. I think those are all indicators of success. Well, question, are these supposed to be like ... is this supposed to be treated as, um, if this happened then bonus ... Like, add positive thing or if this didn't happen, that's not good?
Interviewer:	Um, it's, kind of, however, you think about it. It's just like, at a successful event, blank happens.
Carrie:	Okay. Um ...
Interviewer:	So, like, it would lead to the event being successful.
Carrie:	Yeah. Um, so, I think, of the, the, the last five audience related things, thanking the presenters is probably the least necessary or the least good indicators of success in my opinion. Um, so, if the audience takes the time to thank the

	presenter, that could be an indication of a really good show. If they're willing to put in the extra effort to come up and say hi and say thank you, um, but, I think it's not a big deal if they don't thank the presenters because thanking the presenters takes extra effort from the audience and if the audience is shy then they're not gonna want to put in that extra effort.
Interviewer:	Okay, so-
Carrie:	Um.
Interviewer:	... would you not select it? Maybe think about it like, it's that base level of success. Like, if it doesn't happen the event's not successful.
Carrie:	Yeah. Um, I don't think that-
Interviewer:	So, the thanking is like a, a bonus on top of already being successful?
Carrie:	Yeah, I don't think it's a necessary thing to have a successful event. I think it's a bonus-
Interviewer:	Okay, that makes sense. What about the other four?
Carrie:	Um, so the audience being excited, um, I would probably be more concerned with the audience becomes more excited throughout the show because they might not be excited to begin with, but, um, as the show goes on, they might be more excited about what we're doing and if they see what we're doing and they ... and as they see that it's interesting.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Uh, so just a blanket, the audience was excited, I don't think I would consider that a criterion-
Interviewer:	Okay.
Carrie:	... um, by itself, but maybe if the wording were changed a bit.
Interviewer:	So, if, if the audience wasn't ever excited during the show, is that bad?
Carrie:	Right.
Interviewer:	So, you want them to be exited at some point during the show?
Carrie:	Mm-hmm (affirmative).
Interviewer:	Okay.

Carrie:	Yeah.
Interviewer:	Then I would, I would say go ahead and pick it.
Carrie:	Okay.
Interviewer:	Just so it's on the list.
Carrie:	Yeah and I think ... I'll, I'll keep all five of these checked just so they're there.
Interviewer:	Okay.
Carrie:	With the caveat of what I just told you.
Interviewer:	Okay. So, is it the same with the, the smiling that like-
Carrie:	Uh.
Interviewer:	... you want them to be smiling as the show goes on?
Carrie:	Yeah.
Interviewer:	Okay.
Carrie:	Yeah. I think all five of those or like, at some point during the show or as the show goes on, I would like them to show more of those kinds of things.
Interviewer:	Okay.
Carrie:	Um, yeah. Okay, then, the presenters side, the presenters had high attendance, but that's kind of, a given. Um, well, high attendance is a weird thing for presenters. Um ...
Interviewer:	I think the person that wrote it was like, um, they can't have a good event if only like, one person shows up to do it.
Carrie:	Yeah.
Interviewer:	I think that's what they were thinking when they wrote it.
Carrie:	Okay. Um, so the way that our [School Name] magic shows work is that we have a pool of presenters and we get everybody's availability and then we usually, just have two ... uh, assign two, preferably three presenters per show. Um, so, almost ... there's almost never only one person doing a show, which is why it's kind of, a weird questions for me and I, I don't know that it's really applicable for me.

Interviewer:	Okay.
Carrie:	Um-
Interviewer:	So, for you guys, it's not really a concern because you have like, people assigned and stuff like that?
Carrie:	Yeah.
Interviewer:	Okay.
Carrie:	Yeah.
Interviewer:	So then, you don't have, you don't have to check it then.
Carrie:	Okay. Um, the presenter had no safety concerns. Yes, that is important. Um, because if you're concerned about safety than that takes away from the rest of your presentation. Um, and that takes away from how well you're able to present the information and engage with the audience.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, so, actually, I think that ties into the presenter's demonstrations worked. Well, it, it's slightly different because safety is not the same thing as something not working. Um, I think you can still have a successful show if one of x number of demonstrations fails. Um, as long as you put it in a context and say, "What happened? Why didn't it work? Or Why do you think it didn't work? And how you might change it in the future?"
	For example, um, in one of our recent shows, we were doing the synthesis of nylon from the two monomers and one of our things ran out, so we couldn't make nylon 'cause we only had one of the two components and we explained that and I think it was fine. It wasn't, it wasn't ideal, obviously.
Interviewer:	Mm-hmm (affirmative).
Carrie:	But the rest of the show made up for it.
Interviewer:	Okay. Do you think the audience can still get something from it if it doesn't work?
Carrie:	Yes. Yes. Um, in our case, we explained what would happen if we had both components and we actually had access to a chalkboard right behind us, so we kind of, drew the, um, the ... how, how the polymer would form, um, on blackboard and I think that, kind of, got the point across. Even though it wasn't as exciting as actually seeing the nylon thread.

Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, so, I'm actually going to uncheck the presenter's demonstrations worked for that reason.
Interviewer:	Okay.
Carrie:	Um, the presenters enjoyed themselves, I think is important. Um, I think it is necessary for the presenters to enjoy themselves, in order to transfer that enjoyment to the audience.
Interviewer:	Okay.
Carrie:	Um, and on the last two, presenters used good presentation skills and gave good explanations, um, those are necessary for the audience to get the most out of what you're trying to, to show them. Um, I would arguably value the, for the presenter's side, I would value the good presentation skills and good explanations above all the other ones.
Interviewer:	Okay. Well, if you hit the next button, it's actually going to ask you to rank order the ones you picked.
Carrie:	Okay.
Interviewer:	So, you've, kind of, mentioned a little bit like, this is more important than this. So, go ahead and rank order them, but talk out loud as you do it, so I know like, what you're thinking and what you're doing.
Carrie:	Okay. So, rank order everything regardless of whether it's audience or presenter?
Interviewer:	However, you would rank order it.
Carrie:	Okay.
Interviewer:	From most important to least important.
Carrie:	Hmm. Okay, well, just from a, a basic baseline show success perspectives, you can't have safety concerns because that, that leaves a negative impression on the audience. So, I'm putting that as first.
Interviewer:	Okay.
Carrie:	Um, and then second, I'm putting that the audience learned that chemistry and science is not scary and anyone can do it. Um, because I think, it's most important to remove the, the barrier between, um, every day person and scientists because scientists are everyday people. I think that, that, that, uh,

	barrier is the first thing that should be removed and then on top of that, you can show science is fun and everything else.
	Um, and then, I would put the presenters used good presentation skills. Um, so to me, presentation skills includes, um, showing clearly what you're doing. Showing why you're doing in, um, and, just making it very easy for the audience to, to understand what you're trying to do. Um, that, I think is next most important, so that the audience ... I think that's, kind of, a baseline necessity for the audience to get what you want out of the show. Um-
Interviewer:	But it's lower than them learning that it's not scary?
Carrie:	Yeah. Right, because if they think it's scary they're not even going to p- p- pay attention to your presentation, no matter how good it is.
Interviewer:	Okay.
Carrie:	Um.
Interviewer:	What about the, uh, the learning that it's fun one? Did you already put that one in there?
Carrie:	No, I was thinking of doing that next. Um, okay, so if the presentation ... the presenters use good presentation skills, um, even if the audience doesn't think that science is fun, they can still appreciate that it exists and it is a positive thing, whether or not it is fun to them.
Interviewer:	Okay.
Carrie:	Which is why I think the good presentation skills are more important, um, to, to, to show science, show science, um, respectfully is not really the right word, but like, give science it's due.
Interviewer:	Okay.
Carrie:	Um, okay, so, so, so far there's presenters that know safety concerns. Um, two is audience learn that chemistry/science is not scary and anyone can do it. Three is the presenters use good presentation skills. Four is the audience learn that chemistry and science is fun and then, and then, five, the audience was engaged because you have to be engaged to, kind of, get what's going on.
Interviewer:	Okay.
Carrie:	And then, six, the audience ... Oh, hmm. Uh, I'm trying to distinguish between the audience had fun and the audience had a good time or enjoyed themselves.
Interviewer:	Can you have a good time without having fun?

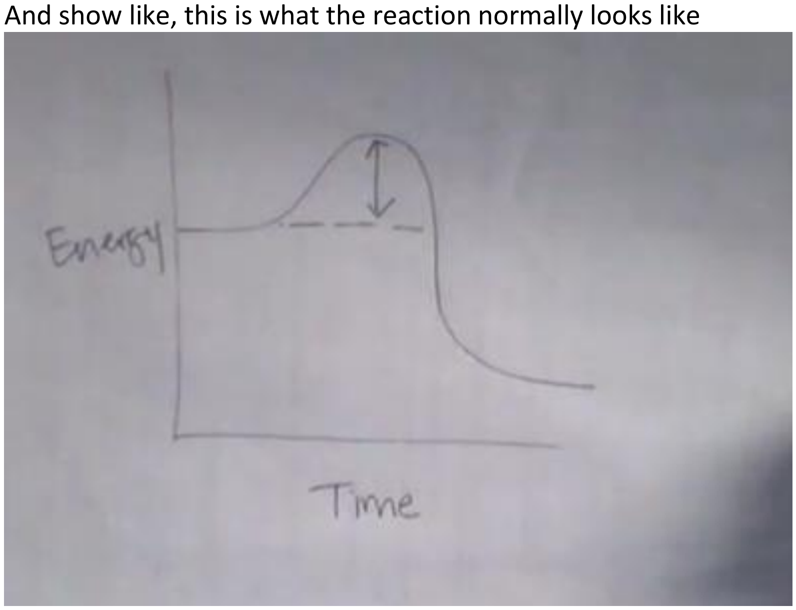
Carrie:	I'm, I'm having trouble imagining that, having a good time without having fun. Maybe fun can be more superlative than having a good time.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Okay. If fun is more superlative, than I would rank having a good time before having fun because than you, you should ... the audience should at least have a, a, a good experience, if not a really fun one.
Interviewer:	Okay.
Carrie:	Uh, yeah and then after the audience having a good time and having fun, then I think the presenters should also enjoy themselves, um, because ... So, I, I am placing more emphasis on the audience having a good experience, um, but then I think, because teaching is a two-way street, then the presenters should also have a good experience. Um, yeah.
Interviewer:	Okay.
Carrie:	Then ... and then the audience was excited. Followed by the audience left smiling. I think it's easy for the audience to be excited than, uh ... So, when I say the audience was excited, I mean, was excited as the show went on. Um, I think that's more important than, at the end of the show they leave all like, giddy and smiling and happy. I mean, I- I- I- I would hope that they don't immediately become sad after the show ends.
Interviewer:	(laughs)
Carrie:	(laughs) Um, but, I think if you get the audience to be exited at some point or at the end of the show, then that's fine. Um, so then that leaves, the presenters gave a good explanation. For me, audience engagement is more important than clearly explaining ... Well, it- it- it's ties together. Um, so I was saying that, audience engagement is more important than the presenter explaining the science clearly. Um, maybe I'll move this up. Let's see.
	I think, I'm going to put the presenters gave good explanations between the audience was engaged and the audience had a good time. Um, so, so, this, this places the scale now from, basic things you need to have to ensure a show goes okay to subsequent things are like ... the subsequent things make the show better.
Interviewer:	Okay.
Carrie:	Or that's how I'm ranking it. So then, the audience was engaged. So, let's see, I would say that, no safety concerns is a must. Learning that chemistry and science is not scary is a must. Good presentation skills is a must and then, learning that

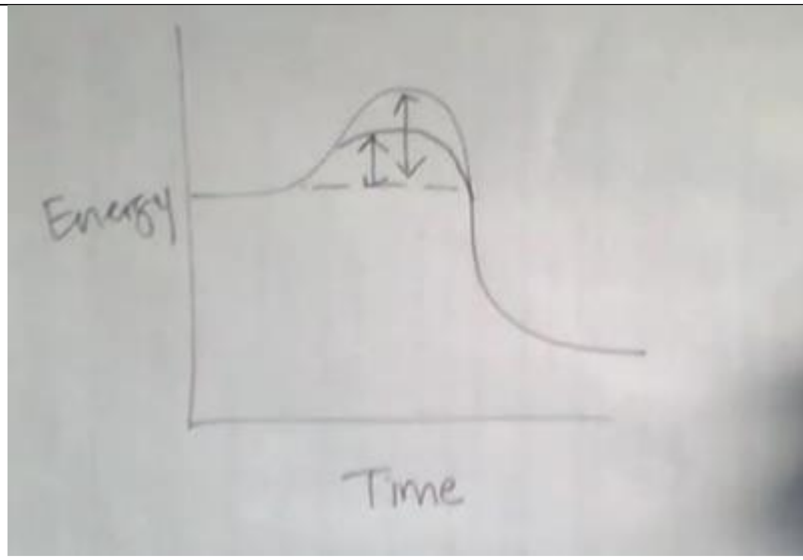
	chemistry is fun is, is kind of, must and the audience is engaged is kind of, a must and the present- presenters gave good explanations, um, would be then next thing on top of engaging the audience. To have ... to, to create a good experience for everyone and then on top of that the audience having a good time, having fun and the presenters having a good time is all cherry on top for me.
Interviewer:	Okay and then if you hit the next button it should, uh, give you like, a confirmation screen.
Carrie:	Yes.
Interviewer:	Okay, cool and so, like-
Carrie:	Can I close this window?
Interviewer:	Yeah, sure. So, like, when you think about your events, is there anything that you think you need to learn more about to have more successful events?
Carrie:	Um, I think, the presenters being more familiar with the, um, with the science and why they're doing it, would help. I feel like ... So, we have scripts that we give the presenters as a, kind of, guideline to how to do each demo, which is nice as a starting point, but I think it, um, is easier to make it come alive if you have more context as to why you're doing something or, um, if you're able to place more context around each demo, which I think is only possible if the presenters know more about what they're doing.
Interviewer:	Mm-hmm (affirmative). Okay and then like, you personally, what would say is something like, it's a strength or you're really good at with outreach?
Carrie:	I think my presentation is the strongest aspect of my outreach. Um, I think, no matter what's happening with the demos or like, whether the demos are going well or the explanation ... Like, the scientific part of the presentation is going well, I can still manage to put on a good face and, um, act in such a way that my audience sees that I'm comfortable on stage.
Interviewer:	Mm-hmm (affirmative).
Carrie:	So, yeah.
Interviewer:	Okay and I guess, like, the, the opposite to that is like, is there anything that you're weak at or could improve at?
Carrie:	Um, so, so, I think I should learn more about the demos that I do, actually.
Interviewer:	Okay. (laughs)

Carrie:	That also comes from, I think, not having had a lot of research experience. Um, although, it's not even research experience. So, I feel that when I'm doing, for example, my undergrad chem lab, I tend to struggle more than my peers who have had more experience doing research and, just doing the techniques. Um, so, being more fluent with that, I think, would help make when I do outreach demos, would help make those more fluid as well.
Interviewer:	Mm-hmm (affirmative). So, what do you ... why do you think like, research specifically helps with that?
Carrie:	Um, that's mainly because I don't know how else to get experience besides physically practicing the demos that we're doing. Although, practicing the demos would probably be better for outreach specific fluency.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, but in the context of what I've seen with my peers and myself at [School Name], it's much easier to get ... much easier and much more common to get experience through research, than it is for everyone to get together and actually practice our outreach demos.
Interviewer:	Mm-hmm (affirmative). And so, was it fluency like, doing the motions or is it like, thinking about the chemistry behind it?
Carrie:	Both of those.
Interviewer:	Both of those?
Carrie:	Mm-hmm (affirmative).
Interviewer:	So, you think it- it's easier for you to get research experience where you can practice the techniques and think about the chemistry than it is to get a group together to practice your demos?
Carrie:	Yes, mainly, because of scheduling issues.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, and also, because we have limited hours where we can have access to, um, lab space to practice demos.
Interviewer:	Mm-hmm (affirmative).
Carrie:	So, I think the scheduling of practice session is more difficult than people go about doing their own research and getting familiar with the techniques that they're doing in, in lab. Um, which are, at least, partially transferable to outreach demos.

Interviewer:	Mm-hmm (affirmative). Okay and I wanna move and talk about some of the specific activities you've done before.
Carrie:	Mm-hmm (affirmative).
Interviewer:	And so, have you done, uh, elephant toothpaste before?
Carrie:	Yes.
Interviewer:	Yeah? What's like, the, the typical age group you do that with?
Carrie:	Uh, it's really whatever age group we ... I, I don't think we differentiate too much between age groups for specific demos. It's more the show as a whole. Although, we, we do somewhat. Okay, so, elephant tooth paste, we can probably do with K through whatever.
Interviewer:	Okay.
Carrie:	Um, the only thing is we would change how we explain things depending on the audience and that goes for all of our demos, not just elephant toothpaste.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Uh, yeah.
Interviewer:	So, like, how do you normally do elephant toothpaste? Is it like a demo? Do the kids get to touch anything?
Carrie:	No. Uh, we use 30% peroxide, so only we do it.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, and we preface with, um, we preface with this is 30% hydrogen peroxide. It's 10 times as concentrated as what you find in a drug store. So, don't try this on your own, but here's what happens.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, but, so like, hydrogen peroxide breaks down in to water and oxygen and oxygen forms bubbles, um, and we do it in a two-liter flask. So, we, uh, we usually are talking as we put everything together. So, what we do is, we have a two liter flask. We put, um, a little bit of dish soap in the bottom and a few drops of food coloring, um, and about 50 milliliters of ... I think it's 50 milliliters. I would have to check that, but it's either 40 or 50 milliliters of peroxide. Um, and we put all of that in the bottom of the flask as we're explaining the water reach down into or peroxide reach down into water and bubbles, the bubbles will form.

	And then, as we're ... we use, um, potassium iodide as our catalyst, about two grams and, um, just before we put the KI into the two-liter flask we ... So, by that point, we've explained what the break down is and we've explained ... So, like, we're putting a little bit of dish soap to enhance the bubbles. We put food coloring to make it look pretty and then just before we put the KI in, we explain the role of a catalyst, depending on ... So, depending on the age. If it's younger, we'll say, "This stuff helps the peroxide form bubbles." If it's older, we'll probably actually say, "This is the catalyst, um, and the catalyst helps the reaction go." Um, and then we put the KI in and stand back and everybody's just like, "Yay." And that's usually the end of our show.
Interviewer:	Like, the ... you do elephant toothpaste last?
Carrie:	Yes.
Interviewer:	Okay and so, like, with like, explaining the catalyst like, what all do you say with like, those older kids?
Carrie:	Um, so we haven't actually done a demo for older kids that I've been to in a while.
Interviewer:	Okay.
Carrie:	Um ...
Interviewer:	What's like, the oldest group you've done it with?
Carrie:	Um, probably up to middle school.
Interviewer:	Okay.
Carrie:	Um, so, the last show that I've done was for our [School Name] family weekend. Um, where I think there were some older kids who were siblings of [School Name] students.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Potentially, even high schoolers, but we were gearing it ... We were, we were assuming audience, basically, no audience knowledge. So, I think we explained it as, um ... I don't think we mentioned anything specific about activation of energy or anything, just a catalyst is something that, um, helps the reaction go faster. It's still the same reaction, but it just helps it go faster and that's about it.
Interviewer:	Mm-hmm (affirmative). So, if like, what if you had like, a really inquisitive kid that's like, "How does it make the reaction go faster?" What would you say to them?

Carrie:	Um, I would probably explain that, so it takes some energy to break apart hydrogen peroxide and, um, the catalyst lowers the energy that you need to put in to, um, get the peroxide to break down. So, it makes it easier by making it take less energy to break the peroxide down.
Interviewer:	Mm-hmm (affirmative). So, I've had like, those really, kind of, annoying kids that like, want to know everything.
Carrie:	Mm-hmm (affirmative).
Interviewer:	And so that's what I ... I'm like, pretending to be like. So, what if the kid was like, so, it lowers the, the energy required, but like, how?
Carrie:	Oh, um, it depends on my space then. If, if I can draw on the board, I'll probably just draw an energy diagram.
Interviewer:	Mm-hmm (affirmative).
Carrie:	And show like, this is what the reaction normally looks like  and then this is what the reaction looks like with the catalyst.

	 Um, if I don't have a board, I would probably get some ... get my fellow presenters help and be like, this is ... show, show with hands or something. This is how much it usually takes or ... I do think about how I would do that. I've never had anyone that inquisitive.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, it might also be that our audience is ... are less willing to ask questions because they tend to be on the bigger side. Um ...
Interviewer:	Do you have something like, to write on that you could pretend you have like, the chalkboard or something?
Carrie:	Um, yeah. So, you mean right now?
Interviewer:	Mm-hmm (affirmative).
Carrie:	So, if I have a chalkboard, um, I'd probably draw a standard ... So, this is not labeled yet.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, but, reaction diagram with energy and then, I would flash the reaction coordinate and just call it time. Um, and then, draw something like this. Can you see that?
Interviewer:	Oh yeah, there we go. Okay.
Carrie:	Okay. So, I would draw that arrow and show ... say, "This is what the reaction normally looks like."
Interviewer:	Mm-hmm (affirmative).

Carrie:	And draw the ... now this is what the reaction looks like with the catalyst. You can see that the little bump is lower, um, after you add the catalyst in.
Interviewer:	Mm-hmm (affirmative).
Carrie:	And the catalyst does this by somehow, um, making the conditions for the molecule to react in a certain way the best it can be, um, and in doing that, it takes away some of the energy that the molecule needs to get in its specific ready to react form. Um, and, and by lowering that energy of the molecule getting ready to react, then you make the reaction go faster.
Interviewer:	Mm-hmm (affirmative). And so like, you said like, somehow makes the conditions the best they can be, how, how does the catalyst do that?
Carrie:	Um, well, I'm thinking ... Uh, when I was saying that, I was thinking of a biological enzyme in which, uh, it literally allows the, um ... your sub-straights to bind to your active site and orient them in the perfect way and adjust the PH in everything. I guess it's a bit different for breakdown of peroxide. So, I'm not really sure how I would answer that question. Um, and generally, when I get questions that I'm not sure how to answer, I'll just say, um, so, I'll, I'll just tell them what I can and then say, "You know, I, I'm not sure how to answer that more, but I'm sure if you look up this and this, then you can get more information on it."
Interviewer:	Mm-hmm (affirmative).
Carrie:	So, I, I try to give them, um, a way to go forward if I can't help them myself.
Interviewer:	Okay. Have you also done, um, making slime before?
Carrie:	Yes.
Interviewer:	How do you normally do that one? Is that one a demo or do the kids get to, to touch stuff?
Carrie:	Yeah. Um, that one is something we did at one of our interactive, um, activities at the USA Science and Engineering Fair. So, we had a, a booth at a table, um, and a table at that booth. So, slime is not something that we normally do for shows.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, it's something we usually reserve for when we have more like, festival fair type people walking in and out, kind of-
Interviewer:	Mm-hmm (affirmative).

Carrie:	Um, so we poured the glue and the laundry detergent for the kids, but we allowed them to add in food coloring and to mix the things themselves. Um, we had little ... I think they were Tupperware containers. Just small containers that we poured, um, the glue and detergent into and then we allowed them to play within that container and to do whatever they wanted with it.
Interviewer:	Mm-hmm (affirmative). What did you like ... How did you explain it to them as they were doing it?
Carrie:	Um, I think the audience was ... tended to be very young, like elementary school age. So, we just said, "Okay, so these two things, um ... " I think we told them what the name of each thing was. So- so, glue has something called polyvinyl acetates and laundry detergent has this thing that help polyvinyl acetate link together to form this, this network and I think, I showed fingers or something like that.
Interviewer:	Mm-hmm (affirmative).
Carrie:	And as the laundry detergent helps the glue link together, then you get slime as things start to link together and form one big blob.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, and in that setting, there was not a lot of time to do a full explanation. So, that's really all we had time for and the kids were usually more interested in playing with the slime than hearing the explanation any way.
Interviewer:	Yeah.
Carrie:	So, so that's where my philosophy of show them what it can be, get them to have fun and kind of, be interested in, well, what's behind the fun comes in, um, because we didn't really have time to give them a full lesson. So, we just told them, "This is science, if you think this is cool then learn more science."
Interviewer:	Mm-hmm (affirmative).
Carrie:	And that's about it.
Interviewer:	Okay. If you had to like, teach another like, undergrad about slime, how would you explain it to them?
Carrie:	Um, uh, I would probably ask them if they've had Organic Chemistry or if they've seen any polymer chemistry. (laughs) Um, I don't know. What, what are we assuming here?

Interviewer:	Um, maybe assume they've only had like, gen chem. Like, they finished freshman chemistry.
Carrie:	Okay, um ...
Interviewer:	So, they might be in Organic-
Carrie:	Right.
Interviewer:	... but they've at least finished freshman chem.
Carrie:	Right. Okay. Um, I think I would start off by giving that same, very basic cross-thinking explanation and then, if they're interested go through and show them the structure of PVA and how it forms the bonds that it forms. Um, I tend to be a very visual person, so I like to draw a lot.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, and show arrow pushing and all of that and if they haven't seen line angles or arrow pushing I would say ... So, I would either, either draw out the structure more fully. Like, include all the hydrogen and carbons and show, um ... and then when I'm doing arrow pushing, say if these are electrons moving, um, yeah.
Interviewer:	So with, uh, the like, cross-links. What bonds are being formed?
Carrie:	Uh, I forget. (laughs)
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, so, I did this last in April. So, I, I would have to refresh myself if I were actually to do this demo again.
Interviewer:	Mm-hmm (affirmative).
Carrie:	And that's actually, generally true. Like, I have to refresh myself on the chemistry of the demo. If it's something that I don't do on a regular basis before the show and I try to send out information for our, um, presenters to do that also, the week before the show. So, that they have some time to familiarize themselves with what they'll be doing.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um.
Interviewer:	That makes sense 'cause you're only doing it like, one time and stuff like that.
Carrie:	Yeah.

Interviewer:	Um, and so, with all the interviews I've done, uh, everyone like, explains these activities differently 'cause, like you said, you change it based on your audience and if you're doing it like, at a fair versus a big show and so, I have some explanations that other students have given me.
Carrie:	Okay.
Interviewer:	And I want you to like, read them and, kind of, like, critique them, um, and like, if they said it's for like, a second grader, do you think the words in the explanation's appropriate for a second grader.
Carrie:	Okay.
Interviewer:	Um, as well as the science behind it, um, because we've received, kind of, like a mixture of like, some accurate and inaccurate stuff, but we just really want to understand like, what makes a good explanation and what people like when they explain these activities.
Carrie:	Okay.
Interviewer:	So, I'm gonna, um, message you some of the explanations other people have given me and if you could just, kind of, like, go line by line through it and tell me what you're thinking, if it's appropriate, if it's accurate. Um, just so we, kind of, know what like, makes a good explanation.
Carrie:	Okay.
Interviewer:	So, this one is like, a ... I think it- it's a second grader one for elephant toothpaste.
Carrie:	Okay. So, we're changing the liquid into multiple gases. Uh, okay. When the particles become ... Uh, can I just read through this and then go back and ...
Interviewer:	Yeah, sure. Yeah.
Carrie:	Okay.
	Okay, um, hmm. Um, in this reaction we are changing a liquid into multiple gases. That seems fine, not particularly exciting to start off with. I'm still questioning is it actually water vapor or water liquid? I thought it was water liquid and oxygen gas, but I guess, that's not super important if you're talking to second graders. Um, also, questioning whether second graders know what the difference between liquids and gases are.
	Um, it seems like a thing that if you have time it would be nice to explain. For, uh, for one of my shows in high school, it was a liquid nitrogen demo, um, it was

	a liquid nitrogen show and the first thing we did was to explain the, the states of matter using what we call a molecule dance and we just like, show molecules moving in a solid liquid gas phase with our hand, because we didn't assume that they knew what phases were.
Interviewer:	Mm-hmm (affirmative).
Carrie:	But that takes time. So, okay. When the particles become gas, they grow and become larger taking up more space, which is why gas is spread out. Um, I think you can make that shorter. You can just say, when the particles become gas ... Wait, particles don't actually become larger, right? They just get more spread out.
Interviewer:	I don't know. (laughs)
Carrie:	(laughs) Okay, well, anyway, when then particles become gas, they ... I would just say, when the particles become gas, they take up more space and show that with my hands.
Interviewer:	Okay.
Carrie:	Um, however, most gases are invisible. A very ... Okay, I'm going to really rip this apart.
Interviewer:	(laughs) Go for it.
Carrie:	Um, however can just be but because it's second grade, right? So like, you don't have to be all, however. Anyway (laughs) um, most gases are invisible. So, in order to see this reaction, we have to, we have to find a way to see the gas. Um, I- I don't think it's very clear what they're ... what they mean when they say, we need to capture the gas. Why do you need to capture it if it's invisible? I ... 'Cause you captured invisible stuff, it's still invisible.
	Um, so then, just like blowing bubbles in ... just like blowing bubbles or bubbles ... Okay, just like blowing bubbles in the bathtub, we use soap here to capture the gas and give us evidence that the gas was produced. I like the, just like blowing bubbles in the bathtub, we use soap. I like that. That is very clear and relatable. Um, so, now, we see why we need to cap- ... how, how capturing the gas is relevant. Um, though for second grade, I might just say, "We use soap here to help us see the gas that's made." Instead of going through the entire capture the gas.
Interviewer:	Okay.
Carrie:	As the reaction progresses, you can see the foam grow and expand, as the particles grow and become gas. So, progresses as the reaction grows-

Interviewer:	Okay.
Carrie:	... you can see the soap bubbles get bigger as the particles take up more space because previously, you said, when the particles take up more space. So then, you can tie it back and say, "As the reaction goes forward, you can see the soap bubble get bigger as the particles ..." Yeah, exactly what you said before.
Interviewer:	Okay. Okay. So, what do you think about ... So, the, the language is a little too much, you think and that's why you like, changed like, the however to a, a but and that kind of stuff?
Carrie:	Mm-hmm (affirmative). I- I do tend to basis toward the simplest language possible, whether it's for second grade or 12th grade.
Interviewer:	Okay.
Carrie:	Like, in any si- situation, I prefer to remove fluff or high-end language-
Interviewer:	Mm-hmm (affirmative).
Carrie:	... if it's not adding to the discussion because then you can focus more on the science and not on the language.
Interviewer:	Mm-hmm (affirmative). Okay. I have a- another one that's like, I think they said it was for eight grade.
Carrie:	Okay.
Interviewer:	So like, late middle school.
Carrie:	Yep.
Interviewer:	Um, and so, just, kind of, the same thing. Read through it and walk me through what you're thinking.
Carrie:	Okay.
	Um, am I supposed to be critiquing the science in this as well?
Interviewer:	Uh, the level and the science.
Carrie:	Okay. Uh, my first problem is that they say hydrogen is produced and they keep saying that hydrogen is produced throughout the dem- ... throughout the explanation, which is horribly inaccurate. Um, and, if you teach that to eight graders they'll probably remember it.
Interviewer:	Mm-hmm (affirmative).

Carrie:	And that's probably not good. Um, and then ... So, okay, hydrogen peroxide changes into water and hydrogen using a catalyst. I think that's fine, just replace hydrogen with oxygen. Um, a catalyst speeds up the rate of reactions, that's also good. And then, the water on the stove example, I guess, heat is a catalyst, but I tend to think of heat separately from when I think of a catalyst such as KI for the purposes of elephant toothpaste because heat actually changes the activation energy.
	It's, uh ... or sorry, heat ... I think of it on a different axis, um, as actually changing how the reaction ... changes the reaction diagram or changes the energy landscape as opposed to just the activation energy. Like, changing more than just the energy hump. Although, I don't know if my explanation is very accurate either. So, um ... Well, anyway.
Interviewer:	So, would you leave that analogy or would you put something different?
Carrie:	I would probably put something different, um, to avoid confusion. Although, I doubt that eighth graders will think into it that much.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um.
Interviewer:	Do you have like, an example that you would use?
Carrie:	Um, off the top of my head, no, but I think it would not be that difficult to come up with one. Let me, um, not at the moment.
Interviewer:	Okay. Okay.
Carrie:	Um, but I do think the explanation that they give is very clear. Um, if, if heat is used as the catalyst, um, the, the thing about water to the stove acts as a catalyst is meant to be the reaction, I think that's all very clear.
Interviewer:	Okay.
Carrie:	Um, my only problem with that is the actual example that they used. Um, okay. We use the soap to break down the molecules of hydrogen peroxide. They're implying that the soap is the catalyst, which I don't think is true. Um, so, if it's true than that's very clear, but if it's not then they risk again, teaching incorrect science to eight graders.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, the water and not hydrogen, but oxygen produced are gases, which want to be as far apart from each other as possible. So, they expand, which is why the

	bubbles get bigger. The latter part of that sentence is a bit unclear to me from, as far apart to the end of the sentence.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, the water and oxygen produced are gases, which ... Hmm. Okay, maybe, the water and oxygen produced are gases, which want to be as far apart from each other as possible, so ... Okay, wait. The water and oxygen produced are gases, which want to be as far as possible ... as far apart from each other as possible, period. Um, so, the, the ... I'm just like ... either a period or comma or some like, break. Um, so, as they ... as, um ... So, we see the bubbles get bigger as the molecules move further apart.
Interviewer:	Okay.
Carrie:	Something like that.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, the heat produced is because when we broke apart hydrogen peroxide, we released energy that was being stored in the molecule. Um, the heat produced, kind of, comes out of nowhere, which ... Okay. Um, it kind of, comes out of nowhere. So, I would probably say ... because, well, I feel like it's kind of, hard for eight graders or anyone to see heat. Um, so, maybe some, sort of, preface that by saying, "The beaker is hot. This is because when we broke apart hydrogen peroxide, we released energy." Um, just a little bit of context, but otherwise, I think this explanation is very clear.
Interviewer:	Mm-hmm (affirmative). So, just the, the hydrogen oxygen thing.
Carrie:	Mm-hmm (affirmative).
Interviewer:	And the ... Maybe a different analogy, but other than that, you think it's pretty good?
Carrie:	Yeah and then the gases being far apart, just a little bit more concise.
Interviewer:	Mm-hmm (affirmative).
Carrie:	But otherwise, it's pretty good. Yeah.
Interviewer:	Okay and then, I've got one more, uh, so some people like do it for college students.
Carrie:	Mm-hmm (affirmative).
Interviewer:	Um, and so this is like, if they've had that general chemistry, uh, level.

Carrie:	Okay.
	I think the language is fine.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, okay. This reaction involved the catalytic decomposition of hydrogen peroxide into water and hydrogen gas. Okay, I, I don't know if it's me, but I feel like it should be oxygen and I, I'm almost like, trying to balance it in my head. Um, well, okay, whichever the correct one is betw- ... should be between water and ... or hydrogen and oxygen.
	Um, this acid base reaction is an exothermic reaction because bonds are broken and heat is released. Um, I feel like bond breaking is not necessarily exothermic.
Interviewer:	What do you mean no necessarily?
Carrie:	Is it? Is it always exothermic? Uh, I might be overthinking it. Like, I'm trying to think of if there is a situation in which bonds could be broken and ... Well, wait, bonds breaking takes energy. Wait, bon- bonds breaking takes energy, so it should never be exothermic. I- I- I'm, I'm having trouble remembering how they thermodynamics of that works, but ... Like, I would just explain it as ... Oh, also, I-I don't know that it's as a base.
	Um, I would just explain it as, this reaction is an exothermic reaction because heat is released and, um ... because I was actually confused by the bonds are broken, uh, part of that sentence and I was trying to think through, "Wait, are bonds actually broken and release heat? Is that necessarily a thing that goes together?" Um, and for me, that causes confusion, so, yeah.
	A catalyst is used because the decomposition is not spontaneous. That's not true. Um, the decomposition is spontaneous, but it's just very slow. They catalyst allows the reaction rate to increase. Yes, because the mechanistic pathway changes. No, no, no way, that's not what a catalyst is. That's horribly wrong. I have a horrible problem with that.
Interviewer:	(laughs)
Carrie:	Um, okay. So, um, I would actually just get rid of the sentence saying, the catalyst is used because ... or if you're going to keep that sentence, say instead, the catalyst is used because the decomposition is not ... is, is, is slow, instead of not spontaneous.
Interviewer:	Mm-hmm (affirmative).

Carrie:	But, if you're gonna say that, I feel like it's kind of, redundant. You can say, the catalyst allows the reaction rate to increase. So, maybe just condense all of that and say, "The catalyst allows the reaction rate to increase." Um, but, not because the mechanistic pathway changes, but because it lowers the activation energy. So, the next part about the catalysis mechanism has two-step with higher activation energies and overall the catalyst decreases the overall, enthalpy change.
	I would just nix all of that because it's just not right. Um, and instead, just replace that with, the catalyst allows reaction to increase because it lowers the activation energy of the reaction.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um.
Interviewer:	Can you walk me through like, you have that like, really adverse reaction to the mechanistic pathway changes?
Carrie:	Mm-hmm (affirmative).
Interviewer:	Can you like, walk me through like, why and what you were thinking?
Carrie:	Um, because a catalyst, as I was taught, a catalyst never changes the reaction, whether it's ... Uh, so, a catalyst never changes what actually reacts with what. It only changes the energy ... the activation energy needed for the reaction, which comes from, um, the orientation and collision energy of the molecules, at least that's what I was taught. So, for a catalyst to fundamentally, change the reaction mechanism is to change the energetics in a way that's changing the reaction itself, not just how the reaction proceeds.
Interviewer:	Okay.
Carrie:	Um, so they're confusing ... Like, to me, that's confusing kinetics with like, the actual equilibrium.
Interviewer:	Mm-hmm (affirmative). Okay. I think you're on the, the reaction starts off slow part.
Carrie:	Yeah. Um, so the reaction starts off slow because the first step is the rate limiting step. I'm, I'm thinking about whether that's true. If it's true, than that makes sense, but I don't think we see ... Like, we the audience see, um, the actual steps ... the elementary steps like, physically, on a microscopic scale. So, that's why it's confusing to me.
Interviewer:	Okay.

Carrie:	Soap is used to help break down the hydrogen peroxide. Again, I'm not sure that soap is actually the catalyst. If it is, if that's actually what they're using than okay, but, I, I've never personally used soap as a catalyst. Um, once all of the catalyst is converted to the intermediate ... Wait, the catalyst doesn't participate in the reaction. Um, well, it can if it's reproduced at the end of the reaction.
	Well, okay, let me keep reading. Once all of the catalyst is converted through the intro mediate, the reaction dramatically speeds up as noted by the increase in foam being produced. Okay, so, taken together with the reaction starting off slow, with the rate limiting and stuff to here, that all makes sense taken together.
Interviewer:	Mm-hmm (affirmative).
Carrie:	I'm just not sure that, that's actually what's happening scientifically.
Interviewer:	Okay.
Carrie:	Um, but I think the explanation is good.
Interviewer:	Okay.
Carrie:	Since the products are gas, the foam expands as the gas molecules in the foam spreads out. Um, I think that's okay, but I would add that the expansion is due to liquid becoming gas and gas expanding as a liquid ... or gas as it is, as it is produced from the liquid, instead of just gas spontaneously expanding.
Interviewer:	Mm-hmm (affirmative). Okay. So, we're like at the end of time that I told you.
Carrie:	Okay.
Interviewer:	Um, I have some more questions. Um, and I have the ... more explanations for the slime. I just want to know like, how much time do you have? Do we need to stop?
Carrie:	Um, I have some time, but not much more time. So, we can probably go ... So, you have some more questions and explanations, you said?
Interviewer:	Yeah. Uh, the questions I have left are like ... There's like five or six of them and then there's those explanations. We could skip the explanations and just do the questions if you want?
Carrie:	That would be preferable, yeah.
Interviewer:	Okay, cool. So, the questions I have are about like, the training and the learning that you did in order to be able to like, go lead these events.

Carrie:	Yes.
Interviewer:	So, like, you mentioned there's like, scripts. How did you like, I guess, like, learn how to elephant toothpaste?
Carrie:	Uh, so at the beginning of each year, there's a training session in the undergrad lab, where, um, one or a few experienced magic show people, usually, the magic show coordinators, um, which there ... each year there's some number of magic show coordinators. Last year, there were two. This year there's four, but the magic show, experienced magic show people, um, just gather all the new people and physically ... So, I think we had the scripts, um, printed out and then the more experienced people breakup into ... breakup the, the new people into small groups and each small group will walk through ... take turns walking through each demo, um, with supervision from the more experienced person.
	And that happens at the beginning of the year. Um, so, in that training session everyone gets to see how each demo is done or practice doing each demo at least once or at least see it once, so they had some idea of what it's supposed to look like. Um, and then afterwards, um, the script and the instructions for the demos are sent out for reference for the rest of the year and then I usually ... Um, so, since I'm coordinating this year, I usually send out the scripts relevant to the demos that we're doing for each show sometime ahead of that show so the, the presenters can re-familiarize themselves with the script and the demos.
Interviewer:	Okay and so, is that same for like, all the demos you do? Is that ... there's this one day-
Carrie:	Yes.
Interviewer:	... where they see them and do them-
Carrie:	Yeah.
Interviewer:	... and then other than that, they just show up to the events that they're assigned to?
Carrie:	Um, yeah, basically.
Interviewer:	Mm-hmm (affirmative). And so, you mentioned like, practicing. You, you guys don't like, practice them before your event?
Carrie:	Right. So, that's mainly a limitation of our facilities and the time that we have and coordinating with our lab managers. So, something that we would like to do is to host more practice sessions before people actually do shows, but, um, what we have been doing, given the limitations that we have is for each show ... Especially, at the beginning of the year, um, so we have two to three, preferably three presenters for each show.

	We tend to pair, um, at least one experienced presenter with one or two less experienced presenters for each show. So, that for each show there's someone who's done everything before, who's able to, kind of, take over if something goes wrong, but then during, um ... But then the less experience people have the chance to practice the- the demos in front of an audience.
Interviewer:	Mm-hmm (affirmative). Okay and so, like, what about your faculty advisor? What is their role with your outreach events?
Carrie:	Um, they're mainly, a contact person. Our outreach is mainly organized and performed all by students. Um, so, our faculty advisor gives us suggestions on ... Especially, if we're trying to prepare new demonstrations or optimize old ones. Um, we had a meeting with him before we went to D.C. to, kind of, discuss what we were gonna do with the, um, all of the interactive things with kids up close and he gave us some suggestions on how to improve our presentation and everything. But throughout most of the year, it's the magic show coordinator, um, handles everything.
Interviewer:	Mm-hmm (affirmative). And what about like, how do you learn to adjust your explanations based on your audience? Is that talked about during that training day?
Carrie:	Um, not explicitly. Although, I think, so, the way I've been running things is, um ... I mean, our scripts, our OK for most audiences that we have, I think the only time that we really need to adjust or if we have an especially, young audience or an especially, different audience from what we normally have and then in that case we'll, we'll probably have met to discuss in more detail what we're doing anyway.
	Um, so, like, for the D.C. trip, we met ... We had several meetings with our advisor and just with, uh, the group of us to discuss what we were doing, who's doing what, how we're doing the explanations, um, because it was very different from a normal magic show. But otherwise, for a normal magic show, if I notice that it's like, a really young audience like, K to one or K to three or something, then I'll make note of that when I send out the information prior to the show, um, and let the presenters know. Otherwise, I- I don't really talk about it. Um, it's something that, I think we all learn from with experience.
Interviewer:	Mm-hmm (affirmative).
Carrie:	And that, that's why it helps to have a more experienced presenter, along with the less experienced presenter. Um, so-
Interviewer:	Mm-hmm (affirmative).
Carrie:	... yeah.

Interviewer:	Okay and then like, if the American Chemical Society were to like, come out with a handbook for like brand new, uh, chem clubs on like, how to do outreach. What do you think should be in that?
Carrie:	Hmm.
Interviewer:	Like, if it's a, it's a chapter who's just- ... getting ready to start outreach for the first time.
Carrie:	Uh, something that I've been emphasized in my training is safety. For someone who's just starting out, it can be, uh, difficult to manage adjusting demos from a lab that is well ventilated and has all of the resources that you could ever need for chemical things to a classroom, where, um, you might not know where ... Well, when you go to a demo, you're supposed to figure out where the bathrooms are and stuff, but adjusting from the lab to a classroom setting, where there might not be as good ventilation and you might be in a smaller space with limited resources and just handling your space is an important thing to know.
	Um, so, handling your space, handling your audience, um, knowing how to deal with rowdy kids and inquisitive kids. Um, and probably just being very comfortable doing what you're doing are the most important things I would include. Um, I mean, I guess there could be multiple sess- sections about, here's what you want to be aware of for safety. Here's what you want to be aware of when you're trying to plan your demos. Um, what kind of demos should you do? How should you, um ... yeah. How should you adjust them, so that they're safe for classrooms?
	Um, so, like a section about the demos themselves and then a section about presentation skills. How do you deal with different audiences? How do you present science in a way that's understandable to people who are not familiar with it? Um, those are three big sections and then, maybe miscellanea. Um, how do you transport chemicals from point A to point B. Um, oh so, I guess some of that could be tied into safety. The safety of the demonstrations and safety of transport and safety of your venue. Yeah, all of that is safety.
Interviewer:	Mm-hmm (affirmative). With, uh ... Like, knowing how to handle those rowdy kids or the inquisitive kids, is that like, something that they have to learn just by doing?
Carrie:	Hmm, no. I think there's some tips that can just be transferred ... just like tips that can be given. Um, as in, if you're asking for a volunteer, don't call on the kids who's been jumping out of his seat for, for a while because he might be too ... he might not be careful with whatever you're doing.
Interviewer:	Mm-hmm (affirmative).

Carrie:	Um, I think there are certain tips that can be transferred, but I would also emphasize that you need to be very flexible and need ... you need to be very aware of the situation as it is, as you're doing the show because there's things that you can't predict. And so, you can prepare all you want, but in the end you need to be able to handle situations that are unexpected.
Interviewer:	Mm-hmm (affirmative). Okay. So, that's, uh, really all the questions I have. Oh, um, so the scripts that you guys have, how do you ... who made those? Where did they come from?
Carrie:	Um, so there's one year, somebody wrote up scripts for our demos and they've, kind of, been passed down, edited as needed, but passed down. I actually don't think they existed before a few years ago.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um-
Interviewer:	So one like, student sat down and wrote them out and they've just, kind of, been handed down?
Carrie:	Yeah. Previously, there were just the safety proposals that were sent to our EHS, um, that were sent on to the presenters and they had like, a little blurb of what the demo is, but there was no script for how to present the demo. How to explain the science, that kind of thing.
Interviewer:	Mm-hmm (affirmative).
Carrie:	So that was written up, in addition to the safety proposal, um, either last year. I think last year, um, and then that's just been passed down.
Interviewer:	Okay. Okay. So, yeah, that's all I have. Is there anything that like, you want to add that I didn't ask you about with your experiences with outreach?
Carrie:	Um, it's always a learning experience for everyone involved, both audiences and presenters.
Interviewer:	Mm-hmm (affirmative).
Carrie:	Um, and you'll always be iterating and improving on your shows as you go along. Um, I think that's about it though.
Interviewer:	Yeah.
Carrie:	You covered ... You were pretty comprehensive.

Interviewer:	(laughs) Do you have any, uh, questions or anything for me?
Carrie:	Um, not that I can think of at the moment.
Interviewer:	Okay. Um, so all I have left is, kind of, like, some book keeping stuff.
Carrie:	Okay.
Interviewer:	Um, so we do have a, a second phase to our study, where like, we can talk in this interview, but it's really different when you have like, kids in front of you.
Carrie:	Mm-hmm (affirmative).
Interviewer:	Um, and so, we're interested in trying to see what that looks like.
Carrie:	Okay.
Interviewer:	And so, we're offering an extra 10 dollars if you'd be willing to like, have someone video tape you with an iPhone doing, uh, like, elephant toothpaste and sending it to us.
Carrie:	Mm-hmm (affirmative).
Interviewer:	Does that sound like something you'd be interested in doing?
Carrie:	Um, what's the timeline on that?
Interviewer:	Whenever. (laughs)
Carrie:	(laughs)
Interviewer:	Next semester, I assume since it's so late.
Carrie:	Yeah.
Interviewer:	Um-
Carrie:	Sure.
Interviewer:	I don't know if you have like ... if you plan on doing events in the spring.
Carrie:	Mm-hmm (affirmative). Um, actually, we have a large event happening in March that I'm sure we would be able to get video of.
Interviewer:	Okay.
Carrie:	Um, yeah.

Interviewer:	'Cause it, it would have to be like, you doing like elephant toothpaste, so we can like, compare like, what we talked about here, with what it looks like when those kids are there.
Carrie:	Okay.
Interviewer:	Um, but I can send you more information about it. There is like, another consent form you have to sign 'cause it's like a-
Carrie:	Yeah.
Interviewer:	... video of of your face.
Carrie:	Mm-hmm (affirmative).
Interviewer:	Um, and if like, it's a show and there's multiple college students there, if they're on the video, there's something they have to sign.
Carrie:	Mm-hmm (affirmative).
Interviewer:	Um, but it can really be like a two minute of just like, you doing elephant toothpaste and that's all it is.
Carrie:	Okay. Um, so, maybe it would be helpful if I had more information about it before I say for sure yes or no.
Interviewer:	Okay.
Carrie:	Um-
Interviewer:	I can send you ... So, the consent form we have is like, a pretty lengthy one that describes like, what we're looking for, everything like that. So, I can send you that and you can read about it.
Carrie:	Okay.
Interviewer:	Um and it, it can definitely be in the spring. Like, it's not anything we need to do like, right now.
Carrie:	Yeah.
Interviewer:	Um, but you can just keep me posted on it.
Carrie:	Sure.
Interviewer:	And we can see how it goes.

Carrie:	Okay.
Interviewer:	Uh, for the $15 you get for doing the interview, um, there's a paper work you have to sign because my University pays it.
Carrie:	Okay.
Interviewer:	And so, they have to make sure that I didn't steal the money or something.
Carrie:	Mm-hmm (affirmative).
Interviewer:	Um, and so, I'm gonna send you a form that you just have to put your name and your address and you sign and once you send that back to me, I email you the gift card.
Carrie:	Okay.
Interviewer:	So, it's pretty easy. Um, there's some phone apps you can use to like, scan the form, so you don't have to use an actual scanner. Um, but basically, it will just be a bunch of emails from me with forms in it.
Carrie:	Yep. Okay. Sounds good.
Interviewer:	Cool. Well, if you have any other questions or anything, you have my email.
Carrie:	Yep.
Interviewer:	Otherwise, thank you, uh, and just look out for those emails from me.
Carrie:	Okay.
Interviewer:	Great. Thanks. Bye.
Carrie:	Bye.