Virtual Research Group Modules: Scalable Simulations of STEM Research

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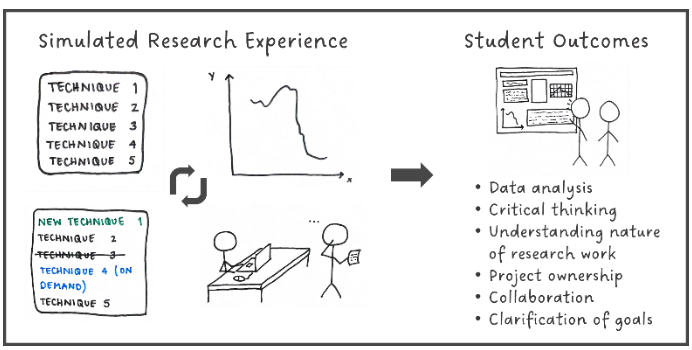
ABSTRACT

Laboratory research experiences can be an important part of the training process for STEM professionals, but barriers exist that can prevent broad access to these opportunities. Virtual Research Group (VRG) modules, which use data curated from the scientific literature to simulate aspects of the research process, provide a scalable alternative to traditional in-lab research experiences. Here we describe the general concept of VRG modules and the implementation of a VRG module focused on block copolymers in both a high school outreach program and an undergraduate materials science course. Through qualitative and quantitative data analysis of student post-survey responses, we demonstrate that VRG modules effectively simulate many of the attributes of traditional research experiences. We also compare student experiences when VRG modules are offered in three different formats: (*i*) competitive in-person, (*ii*) competitive virtual, and (*iii*) collaborative virtual. Finally, we demonstrate that VRGs can be applied to topics other than block copolymers through implementation of a VRG module on bulk metallic glass.

GRAPHICAL ABSTRACT



KEYWORDS

General public, curriculum, public understanding/outreach, inquiry-based/discovery learning, problem solving/decision making, materials science, undergraduate research, polymer chemistry

INTRODUCTION

Undergraduate research experiences (UREs) are considered high-impact educational opportunities that can help increase retention and persistence of students in science, technology, engineering, and mathematics (STEM), build disciplinary knowledge and practices, and integrate students into STEM culture.[1] A body of literature demonstrates the benefits of research experiences, including the role they can play in helping students increase self-efficacy, develop a science identity, and refine career goals.[2] UREs have also been an integral part of efforts to broaden diversity, inclusion, and belonging in STEM, with numerous studies demonstrating the positive impacts UREs can have on underrepresented minorities in particular.[3]

Despite the benefits of UREs, barriers exist that hinder widespread and equitable access to these opportunities. These barriers include limited faculty time/resources, lack of knowledge of opportunities, socioeconomic barriers, and low student confidence in being able to meaningfully contribute to research.[4] Course-based undergraduate research experiences (CUREs) have been explored as one approach for overcoming some these barriers[4b], particularly in the chemical sciences.[5] These courses, which are centered around inquiry-based learning, try to recreate aspects of UREs by emphasizing exploration of a question with an unknown answer, collaboration, iteration, and engagement in scientific practices.[6] CUREs are more scalable than traditional UREs since they serve all students enrolled in a course rather than relying on the apprenticeship model typical of other research experiences. They also offer more authentic experiences than traditional laboratory courses because they revolve around inquiry rather than a “cookbook” list of tasks.[7] CUREs are often implemented in introductory courses, including general chemistry,[7-8] which has made it possible to expose students to research early in their STEM careers without them necessarily seeking out such opportunities independently.

While CUREs help address many of the barriers to accessing research experiences, they still require physical laboratory space and resources, and can require substantial faculty and technician time. These factors can impact scalability (*e.g.*, a 100 person lecture). To address this challenge, we have developed Virtual Research Group (VRG) modules (VRGs) focused on block copolymers and metals. These modules are designed to simulate the investigative, discovery, and peer learning aspects of the research process that are present in both UREs and CUREs, without requiring any physical laboratory space or intensive computational resources. We hope that the VRG model can serve as a scalable pathway for broad student access to research experiences, including for students in the chemical sciences, and provide students with this exposure early in their careers.

VIRTUAL RESEARCH GROUP MODULE CONCEPT

VRGs utilize datasets curated from the literature to simulate research experiences. The general flow of a VRG is illustrated in Figure 1. Students are provided with background information and/or instructional scaffolding (*e.g.*, introductory lectures/course material, recommended resources) to introduce them to foundational concepts and common analysis tools relevant to the topical focus of the VRG. They are then given a problem statement, such as "identify the unknown material" and a list of experimental tools they can use to investigate the problem. Students work in teams to select an initial experimental technique to use in their investigation and are then provided with the corresponding data which has been curated by the instructor in advance of the module. Students analyze the data, choose a next step, and continue through an iterative process until they have either addressed the problem statement given at the beginning of the module, or they run out of the allotted time. In some cases, the data provided for an experiment is inconclusive, suboptimal, or of limited use for the study. Students must "modify" their technique to get usable data as a part of their iterative problem-solving process. The experience is then culminated with a final presentation or report, a final reveal, and (if available) an expert interview (*e.g.*, a short video from a scientist involved in the original investigation). The purpose of the interview is to incorporate a role model aspect into the experience. Regardless of topical focus, by going through this workflow VRG participants will ideally achieve the learning outcomes detailed in Box 1.

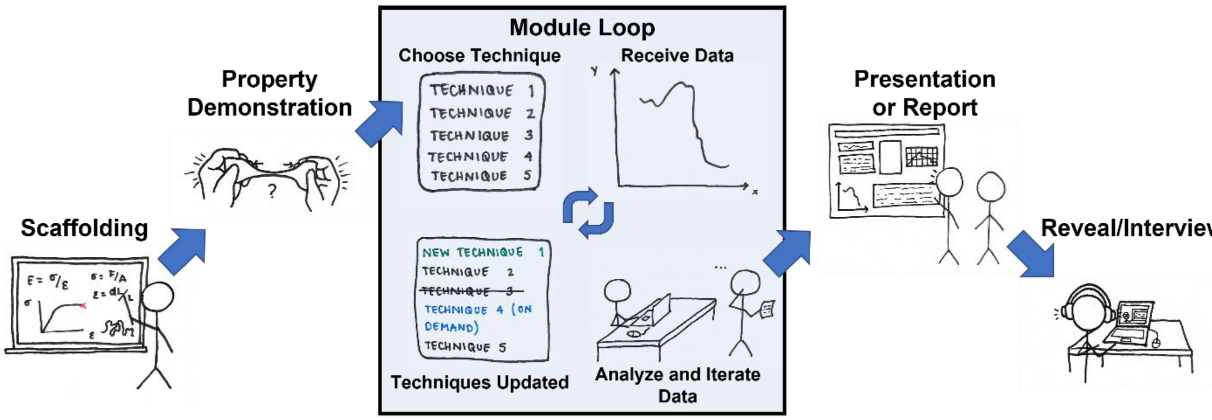


Figure 1: Workflow of Virtual Research Group modules.

Box 1. VRG Module Learning Outcomes

By the end of the VRG, participants should be able to:

- Identify and describe the experimental tools commonly used in a specific field.
- Analyze and interpret experimental data.
- Debate and discuss potential next steps in a problem-solving approach with a group of peers.
- Choose an experimental tool to explore a hypothesis and justify the tool's selection based on background knowledge and/or previously obtained data from other experimental tools.
- Modify an experimental approach in instances when unexpected and/or unusable experimental data was obtained.
- Discuss conclusions from an investigation involving multiple experimental tools via written or oral communication.
- Identify a scientist or engineer related to the VRG topic.

VRGs can, in principle, be developed for a variety of different topics and fields. Box 2 outlines the general criteria for a VRG module. The focus of our preliminary VRG module was on block copolymers (BCPs), an important class of material in the field of materials science that is used in everyday applications, such as tennis shoe soles, safety glasses, and chewing gum.[9] BCPs were selected because of their ubiquity, both in common life and research over decades, while still remaining relatively obscure in popular science. This combined with the beauty of the self-assembly that leads to their unique properties made them an excellent topic for investigation. Students were tasked with identifying this material, which at the start of the VRG module was unknown to them. Specifically, students worked to identify samples of styrene-butadiene-styrene (SBS) triblock copolymer, commercially sold as Kraton resin. SBS was first synthesized by the Shell corporation in 1961 with the goal of enhancing the properties of butadiene rubber.[10] An unintentional feature of the newly synthesized SBS copolymer was its thermoplastic elastomer properties. It could be reformed and remolded at moderate temperatures, which opened new possibilities for recyclability and rapid processing via injection molding.

Box 2. General Criteria for a VRG Module

- Availability of data
- Multi-technique requirement
- Commercial/real-world impact
- Ease of understanding
- Aesthetic appeal/ease of demonstration

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Technique	Cost	Difficulty	Notes
Differential Scanning Calorimetry	$$	+	Can be requested for specific samples
Extensometry	$	+	In-lab. No heat stage.
Rheology	$	+	In-lab. Heating only.
Dynamic Mechanical Analysis	$$	+++	Heating only.
Optical Microscopy	$	+	In-lab. Fluorescent and polarized.
Scanning Electron Microscopy	$$	++	5 nm maximum resolution.
Transmission Electron Microscopy	$$$	++++	Sub-nm resolution.
Optical Scattering	$	+	Can be requested for specific samples
X-ray Diffraction	$	+++	In-lab. 20° to 90° 2θ detector. λ=0.154 nm.
UV-Vis Reflectometry/Spectroscopy	$	+	Visible light (200~700 nm) absorption.
Nuclear Magnetic Resonance	$$$$	+	Big magnets are costly but effective.
Fourier Transform Infrared Spectroscopy	$$	+	Can be requested for specific samples
Gel Permeation Chromatography	$$$	++++	Would be easier if you knew the right solvents to use.
Other General Properties (Density, Index of Refraction, Solubility)	$	+	Might do anyway if you have extra time.

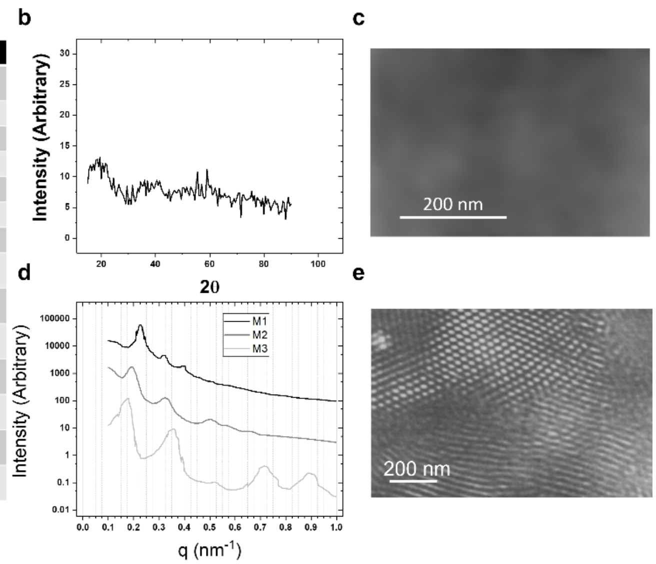

Figure 2: (a) Example list of experimental techniques provided to VRG participants. Data from a "failed" (b) x-ray diffraction and (c) transmission electron microscopy experiments. Data from iterated (d, e) X-ray diffraction and transmission electron microscopy experiments, where small angle X-ray scattering and staining were introduced, respectively, to overcome previous experimental barriers. Diffraction data was made by hand, scattering data was assembled from multiple sources (M1,[11] M2,[12] and M3[13]), and the microscopy data was adapted from Pedemonte et al.[14] and is reused here with permission from Elsevier.

The participants of the BCP VRG were provided with the list of experimental techniques shown in Figure 2a. Each of these techniques is a common tool used in materials characterization; however, some of the tools, such as scanning electron microscopy, are not particularly useful for SBS copolymers. Other tools, such as X-ray diffraction (Figure 2b) and transmission electron microscopy,

(Figure 2c) initially did not provide useful data. With some modification, however, such as moving the detector position to change the scattering angles probed ("inventing" small-angle X-ray scattering, Figure 2d) or staining the sample (Figure 2e), these techniques were able to yield meaningful and useful results that the students could use in their investigation after additional data analysis and interpretation. Upon utilizing several experimental techniques, students had enough information to identify the unknowns: three SBS samples with structural variations. As a culminating experience of the BCP VRG module, students either participated in or were played an interview with Dr. Geoffrey Holden, who worked on the Shell research team responsible for the material's discovery.

IMPLEMENTATION

We deployed the VRG modules in two highly different environments: (*i*) as an elective in the New Jersey Governor's School for Engineering and Technology (NJGSET), a program for gifted high school rising seniors and (*ii*) in a required junior-level Chemical Engineering course, *Materials Science and Engineering*, at Rose-Hulman Institute of Technology (RHIT). The delivery also took on two distinct modalities, respectively: (*i*) a 16-hour elective course and (*ii*) a required final project. A more detailed discussion of VRG implementation in each environment can be found in the Supplemental Discussion section of the Supporting Information. It should be noted that while the structure of the RHIT VRG remained relatively unchanged (a project completed outside of class), the NJGSET implementation evolved slightly from year to year, which most notably included a transition from a competitive in-person structure in Summer 2019 to competitive (Summer 2020) and collaborative (Summer 2021) virtual structures following the COVID-19 pandemic.

As a part of the modules, VRG participants completed pre- and post- surveys containing short response and Likert-type questions about their previous research experiences, professional goals, and takeaways from the experience. Short answer responses were analyzed using qualitative coding and Likert-type responses were compared between groups using a Mann-Whitney U Test. All data was collected in accordance with Rutgers' IRB approval process (Pro2018001132) and Rose-Hulman's Human Research Protection Policy (RHS0314). Approval for the studies at both institutions were granted under "exempt" status, according to 45 CFR 46 exempt categories 1 and 2 and only the survey responses from participants who gave informed consent were analyzed. Additional information on survey design and data analysis approach can be in the Methodology section of Supplemental Information.

RESULTS AND DISCUSSION

Student Experience and Overlap with Traditional Research Experiences

VRG participants were asked to complete a series of post-survey questions upon completing the modules to help us gain insight into their experience. As can be seen in Figure 3, both NJGSET and RHIT students indicated that VRG modules positively impacted their interest in doing research and in materials science. We found these responses promising given that one of the goals of UREs is to increase interest in STEM fields.[1b] Post-survey responses also indicated that most VRG participants enjoyed the research simulation more than previous in-lab research experiences and traditional laboratory classes, and most students were interested in completing a project (RHIT) or course (NJGSET) of a similar format in the future. One reason why some students may have enjoyed the simulation more than other in-lab experiences is the faster pace afforded by not running the experiments themselves, as evidenced by post-survey comments such as *"the experiment portion wasn't actually in a lab so it didn't take extra time to do"*. It should be noted, however, that other student comments lamented not getting hands-on experience with the various experimental techniques.

A major goal of VRG modules is to simulate aspects of traditional research experiences. Only 31% of NJGSET and 39.6% of RHIT VRG participants had some type of previous research experience, so these modules were the first exposure to research for the majority of the participants. While the effect of previous research experience on students' perception of the VRGs is discussed in-depth in the Supplemental Information, it should be noted here that previous research experience did not have a statistically significant effect on responses to most of the questions in Figure 3.

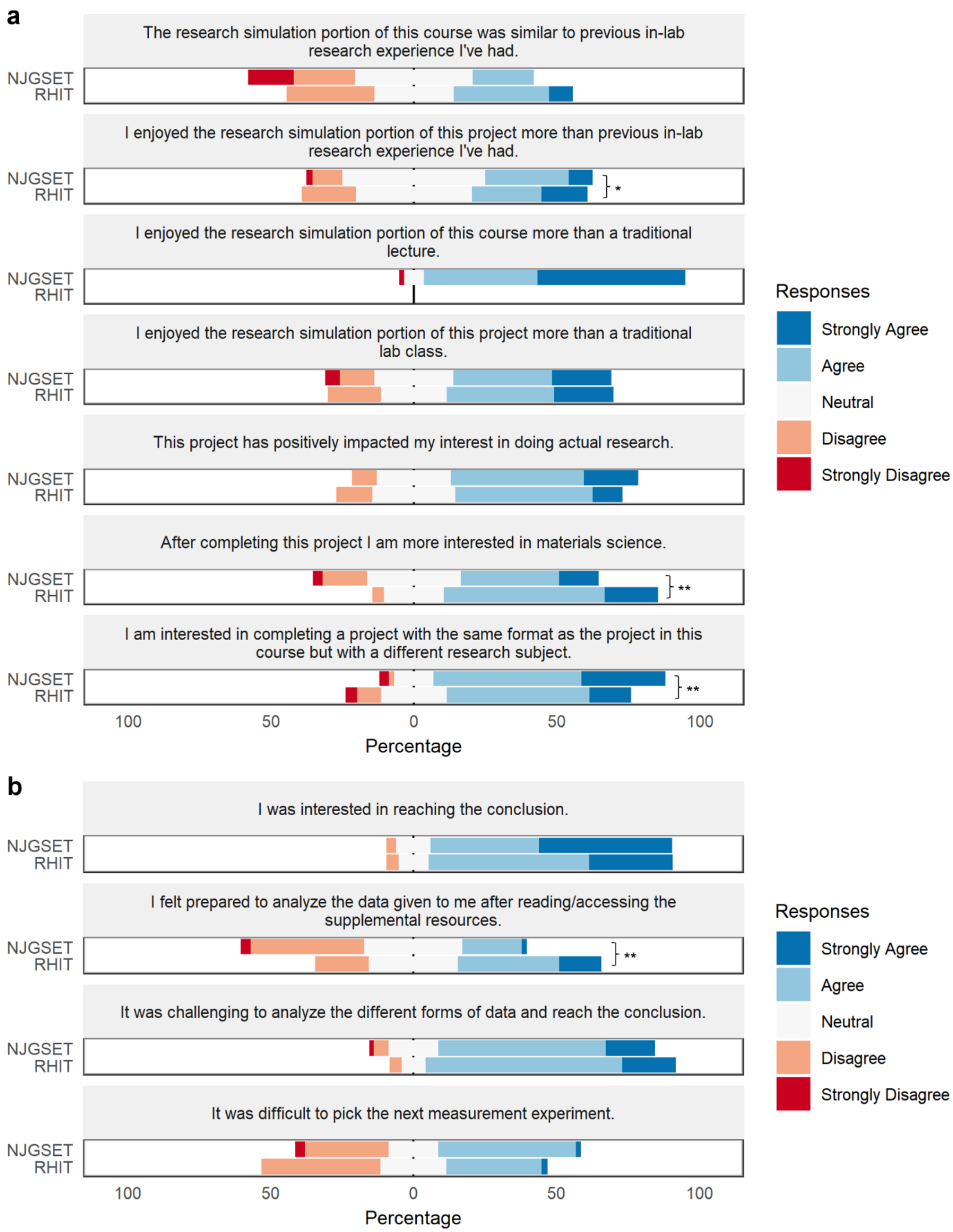

Figure 3: Post-survey responses of block copolymer VRG participants. (a) Questions gauging student interest and comparing VRGs to other educational experiences. The RHIT post-survey did not include the Likert-type question "I have enjoyed the research simulation portion of this course more than a traditional lecture". (b) Questions gauging student engagement and preparation during the VRG module. Statistically significant differences between NJGSET (N =68) and RHIT responses (N = 35 for the two questions related to previous research experiences; N = 48 for all other questions) are indicated by an asterisk (*, $p < 0.1$; **, $p < 0.05$). A medium effect size (0.3 < r > 0.5) was observed for the question "I felt prepared…". Small effect sizes (r < 0.3) were observed for all other questions. Two notes for the questions related to previous in-lab research experiences: (1) All NJGSET students participated in either an in-person or guided virtual research project as a component of the program. (2) Some RHIT students who indicated that in their pre-survey they had no prior research experience may have acquired research experience during the quarter, which is common for students in their junior year.

To better understand how the student VRG experience compared to traditional UREs, we coded post-survey responses to short answer questions according to common gains associated with UREs.[2a, 15] We considered gains in four categories:

(i) gains in students' practical understanding of the research process and scientific knowledge (categorized as "thinking and working like a scientist")

(ii) gains in/presence of attitudes and behaviors associated with being a researcher (categorized as "becoming a scientist")

(iii) gains in science identity and collegiality (categorized as "personal-professional")

(iv) gains in understanding of career and education goals (categorized as "clarification, confirmation, and refinement of career/education paths")

These categories were modeled after an ethnographic study by Hunter et al.,[2a] which found that more than 75% of all gains-related statements made during interviews with faculty, staff, and undergraduate researchers belonged to one of these four categories. Other studies have documented gains in similar categories.[1e, 2d, 16] The percentage of VRG participants with coded post-survey responses and representative comments for each category are shown in Table 1 and Table S3, respectively. 95.5% of all VRG participants had at least one coded post-survey response.

The most common gain for VRG participants was in the category of "thinking and working like a scientist". Within this category, 67.1 % of NJGSET and 74.0% of RHIT participants made statements in their post-survey responses that indicated gains related to hands-on experience analyzing and interpreting results, critical thinking, and/or problem solving. This finding is consistent with the design of the VRG modules, as modules were structured to emphasize choosing experiments and analyzing and interpreting data. Additionally, 12.2% of NJGSET and 24.0% of RHIT participants made comments indicating gains in their understanding of the open-ended and constantly constructed nature of science. Iteration and "failed" experiments were intentionally incorporated into the VRG module design, so it was promising to find that some students reported growth resulting from these elements. The higher percentage of RHIT students who gained understanding in the nature of science compared to NJGSET students may be due to difference in VRG format and duration. RHIT students completed the VRG module over several weeks, outside of class, which meant they had more time than

NJGSET students to reflect as they progressed through the module. Finally, 17.1% and 18.8% of NJGSET and RHIT participants, respectively, made comments indicating gains in their understanding of theory/concepts and connections within science, indicating that VRG modules may be able to serve as a tool to expand students' general scientific knowledge.

Table 1. Percent of BCP Unknown Participants with Post-Survey Comments Related to Traditional Attributes of Research Experiences

	Percent (%) of Participants	
Common Research Experience Attributes	NJGSET	RHIT
*Thinking and working like a scientist**	*76.8 (18.3)*	*87.5 (32.3)*
• Understanding science and research through hands-on experience (analyzing and interpreting results, critical thinking, problem solving)	67.1	74.0
• Understanding the nature of scientific knowledge (open-ended, constantly constructed)	12.2	24.0
• Increased knowledge of theory/concepts and connections within science	17.1	18.8
• Transfer between research and courses/coursework	2.4	7.3
• Understanding how to approach research problems/design	0.0	3.1
*Becoming a scientist**	*68.3 (31.7)*	*68.8 (13.5)*
• Greater understanding of the nature of research work	62.2	35.4
• Project ownership	37.8	47.9
*Personal Professional**	*47.6 (1.2)*	*20.8 (1.0)*
• Establishing collegial working relationships with peers and/or faculty.	*40.2*	*18.8*
• Gains in confidence to do science.	*8.5*	*3.1*
*Clarification, Confirmation, and Refinement of Career/Education Paths**	*54.9 (-)*	*41.7 (-)*

**Values for main categories (shaded grey) include the percent of participants who had a response coded for at least one attributes. The percent of participants with coded responses for at least two attributes are indicated by the number surrounded by parenthesis. The attributes considered are listed in the table directly below the main category title.*

The relative prevalence of gains in the different subcategories of "thinking and working like a scientist" for VRG participants (Table 1) was consistent with the findings of Hunter et al.[2a] In Hunter's study, the highest number of faculty and student observations in the "thinking and working like a scientist" category were related to understanding science and research through hands-on experience (67% of faculty observations, 46% of student observations), whereas only a small percentage of observations (2% of faculty observations, 9% of student observations) were related to gains in understanding how to approach research problems and designs. Similar findings were observed in a study by Thiry, et al. of undergraduate students conducting research in the biosciences.[16b] An intermediate number of our observations were related to gains in understanding of theory and concepts, which is also consistent with the findings of Hunter et al.[2a] These similarities indicate that VRG modules may realistically replicate aspects of a traditional, in-lab research experience.

Our findings are further reinforced by student responses to Likert-type questions from the Undergraduate Research Student Self-Assessment (URSSA) survey (Figures S3 and S5), a validated survey instrument designed to evaluate URE outcomes.[16a] RHIT participants predominantly reported "a fair amount" or "a great deal" of gain in post-survey responses for several of the questions related to "thinking and working like a scientist", such as those related to gains in analyzing data, problem solving, and understanding the relevance of research to coursework. NJGSET students answered URSSA questions in this category on both the pre- and post-surveys and statistically significant shifts in responses were observed for all questions. It should be noted, however, that these changes were also likely influenced by the research component of NJGSET outside of the VRG course. Other studies that have used URSSA to assess undergraduate research experiences, as well as C.U.R.E.s, have reported high self-reported gains similar to our findings in "thinking and working like a scientist",.[16b, 17] Studies on a Group-Led Undergraduate Research Program (GURP) at University California Berkeley, a program similar in concept to VRGs that was designed to introduce early career students to nanomaterials, have also shown that research experiences focused on discovery and the analysis of pre-collected data lead to gains in research skills and scientific knowledge.[18]

Coding of post-survey response also revealed that a large percentage of students had gains related to "becoming a scientist". Most prevalent for NJGSET students (62.2%) were comments indicating the development of a deeper understanding of the nature of research work, such as developing an understanding that research can require iteration, requires planning, and connects to real-life applications. Most prevalent for RHIT students (47.9%) were comments demonstrating project ownership, such as expressions of excitement toward scientific inquiry and expressions of a sense of personal scientific achievement.[2a, 19] VRG participant comments, such as:

> *"Often different tests yielded unhelpful results, making progress somewhat frustrating or slow."* (coded as understanding nature of research work)

"It was gratifying to be able to select a material based on our own interpretations of the data given. I enjoyed being able to choose which experiments to run as it gave us more freedom for how we could approach finding a solution." (coded as project ownership)

are consistent with those documented in the study by Thiry, et. al, in which interview responses from undergraduate researchers were coded according to the "becoming a scientist" category.[16b] In our study, we suspect the difference in emphasis in post-survey comments of NJGSET and RHIT participants may be due to differences in background experiences and VRG implementation format. NJGSET students were rising high school seniors, whereas RHIT students were predominantly sophomore, junior, and senior chemical engineering majors. As such, RHIT students may have had more previous educational experiences that had already shaped their understanding of the nature of research work. Additionally, NJGSET students completed the VRG module synchronously and had more frequent group discussions and interactions with the module facilitator. These interactions may have led to greater emphasis in the NJGSET VRG on the nuances of what research entails. Regardless of the reasoning for the high prevalence of NJGSET comments related to understanding the nature of research work, perceived gains in this area are important as they have been linked to increases in student self-efficacy and are considered an attribute of an authentic research experience.[20]

The greater prevalence of coded responses indicating project ownership for RHIT participants compared to NJGSET participants (47.9% vs. 37.8%) may have been related to: (i) the independence student groups had while completing the project outside of class, (ii) the longer project duration, leading to more time for emotional investment, and (iii) a greater exposure to STEM experiences than NJGSET students. Two dimensions of project ownership, emotional investment and overcoming challenging moments, were also hinted at in responses to Likert-type questions.[19] The majority of NJGSET and RHIT students agreed or strongly agreed that (i) they were interested in reaching a conclusion and (ii) it was challenging to analyze the data (Figure 3b). A larger proportion of RHIT students compared to NJGSET students, however, tended to agree or strongly agree that they felt prepared to analyze the data given to them. This increased feeling of preparation, may indicate that RHIT students felt more prepared to actually overcome challenging moments associated with identifying the unknown material as a part of the VRG module. In a study by Thiry, et al., it was observed that as undergraduate students gained more research experience, they tended to demonstrate more ownership over their work, in part due to their stronger foundational knowledge of scientific concepts and the research process.[16b] The hands-on intensive nature of the engineering curriculum at RHIT, in addition to knowledge and experiences students acquired through internships, research projects, the materials science course itself, may have allowed students to come into the VRG feeling prepared to take ownership over their project. The prevalence of responses demonstrating project ownership for RHIT and NJGSET students alike is given that ownership is typically observed in both UREs and CUREs[2a, 19] and has been shown to help promote interest and persistence in STEM.[21]

The strong emphasis on collaboration in the instructional scaffolding for the NJGSET VRG module implementation was apparent in the analysis of student responses related to “personal-professional” gains. 40.2% of NJGSET participants mentioned collaboration and other aspects of establishing collegial working relationships in their post-survey responses. This frequent mention of collaboration is promising given that high school students in a study by Burgin, et al. who experienced high degrees of collaboration in research apprenticeships tended to express an interest in pursuing additional research experiences in the future.[22] While group collaboration was less strongly emphasized in the scaffolding provided for the RHIT VRG modules, the students did work together in groups and 18.8% of RHIT participants had coded responses relating to collegial working relationships. The majority of RHIT students also reported “a fair amount” or “a great deal” of gain in URSSA survey questions related to working collaboratively with others and discussing scientific concepts (Figure S4). These results are consistent with a survey of 212 undergraduate researchers at University of Texas El Paso, where students also largely reported “a fair amount” or “a great deal of gain” in their responses to the same URSSA survey.[17a] Given that collaboration and mentorship are important aspects of undergraduate research experiences, it is promising to see VRG participants from both populations commenting on this aspect of their VRG experience.[23]

Finally, 54.9% NJGSET and 41.7% RHIT had post-survey comments indicating “clarification, confirmation, and refinement of career/education paths”. Some students discovered a newfound enthusiasm for materials science and/or research, whereas others discovered or confirmed that their interests may lie elsewhere. Undergraduate research experiences have previously been shown to help students gain clarity on their future goals, so it is promising to see the VRG modules may have similar effects.[2a, 24]

Effect of Delivery and Environment in Course Setting

The NJGSET course setting, being fully focused on the VRG module, has been adjusted in mode of delivery several times. These adjustments have been made in response to student feedback or changes to the program itself (Table S5). Figure 4 shows the student ratings collected by the NJGSET program for each year of the NJGSET VRG course, including the 2017 course that was offered before the data collection protocol was implemented. These ratings were a single value of 1-10 and a box for student comments, which were combined with an informal “focus group” session held after the post surveys to obtain student feedback for the purposes of improving the course. In addition to the adjustments discussed below, more subtle improvements were also made to the material, such as drop-in teleconferencing with research group members to “show off” select machines in 2021. For the 2018 course, student feedback suggested that instructional scaffolding was too intensive, so the Experts system was added. For 2019, additional Experts’ activities were added since students found that the videos and brief in class discussion was not sufficient for them to feel prepared. This format was retained in 2020; however, the 2020 program was moved to remote instruction due to the COVID-19 pandemic. Students found the remote format eliminated the feeling of competition and, instead, left them feeling isolated in their teams. To combat this, the most recent 2021 remote cohort was switched from a competitive to a cooperative format, where students would start each day as a large group to recap the previous day’s results and then be assigned to 2-4 smaller breakout groups to pursue investigations defined through group discussion. Here, the breakout membership was shuffled and composed of relevant Experts for each task, such that any two students had a chance to work in the same group at least once. This resulted in a rise in student reviews. Interestingly, the 2021 cohort’s selection of experiments lead them to arguably make less progress towards the solution of the BCP structure than individual teams in past years (Table S5).

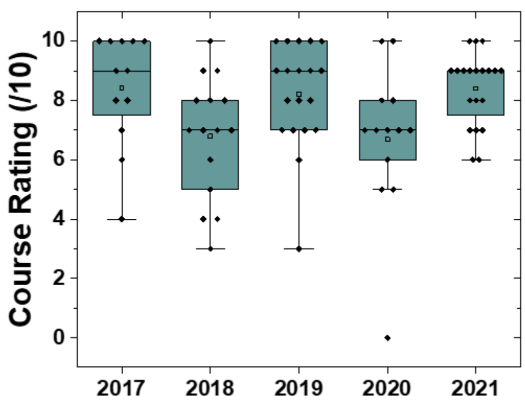

Figure 4: Box plot of student course evaluations, where black dots represent an individual rating, the open dot represents the mean, the black line in the median, the green region is the first through third quartiles, and the lined region is the second standard deviation.

To evaluate the effects of (1) the change to remote instruction and (2) the change from competitive to cooperative formats in remote learning environments, it is instructive to compare the 2019, 2020, and 2021 student survey responses (Figure 5). Interestingly, student interest in doing research and in materials science was similarly affected in all formats. Where differences become more apparent is in comparison to other educational experiences. Students in the 2021 cohort were more likely to find their past research experience to be similar to the VRG, which is not surprising since high school students conducting research in advance of the 2021 program were much more likely to have conducted this research in a remote format. The results of short/long term remote transition can also be seen in comparisons to lab courses, which were the most favorable in 2019 when the class was in person, making the experience more social, if simultaneously more “hands-off,” than labs they had experienced. In 2020, students were not yet accustomed to the remote environment, and had a greater chance of having participated in an in-person lab class. More favorable comparisons in 2021 are therefore likely affected both by (1) lab classes shifting remote during the 2020-2021 academic year and (2) students adapting to remote learning. This is echoed in student interest in conducting a similar activity, which had no disagreeing answers in either 2019 or 2021 and an overall higher mean. A combined “what you know” and “what you are used to” effect may impact the overall student view of the quality of the experience and should be kept in mind when considering student responses to engagement and preparation questions (Figure 6).

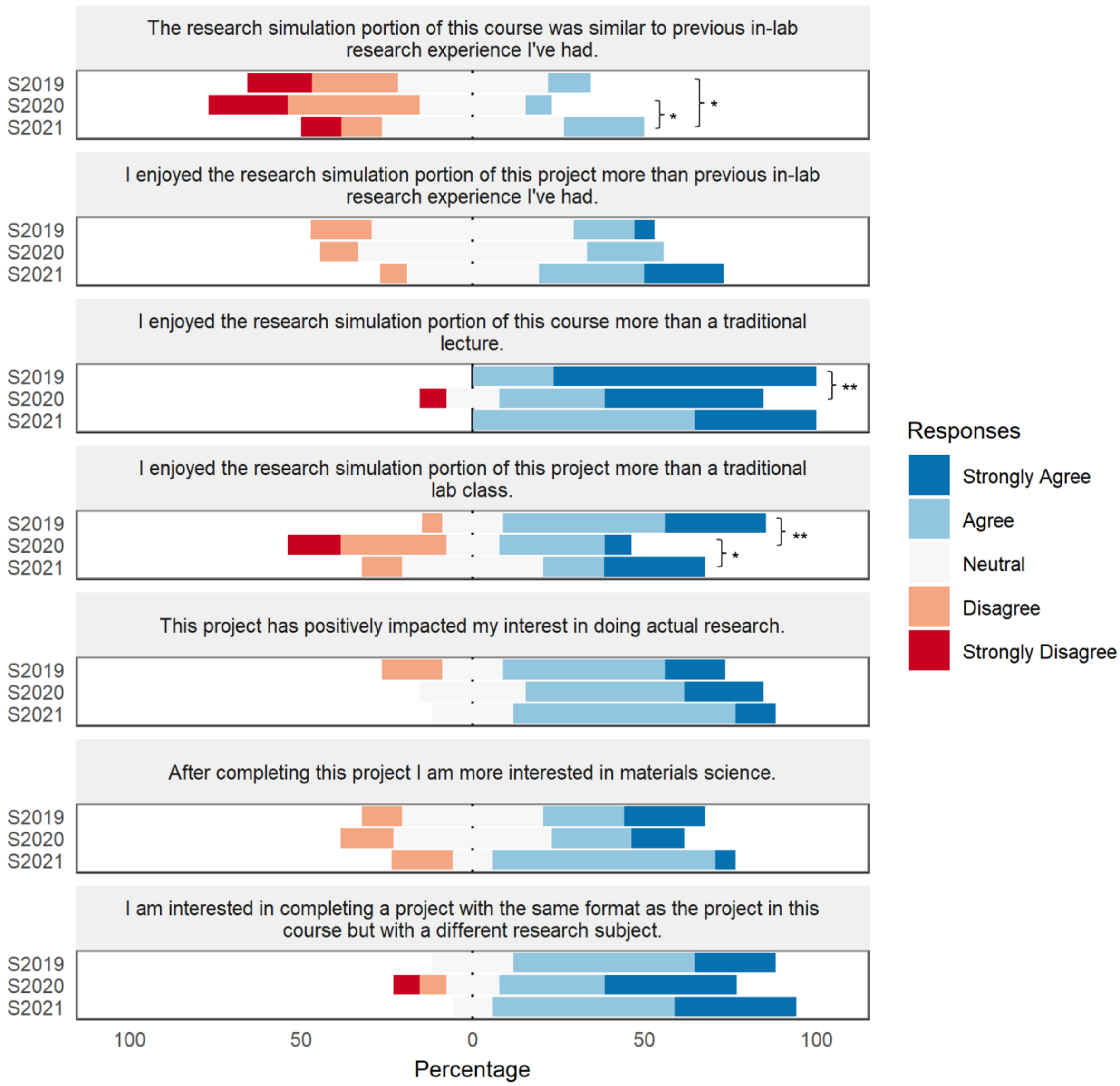

Figure 5: Post-survey responses of NJGSET VRG participants to questions gauging student interest and comparing VRGs to other educational experiences. The Summer 2019 VRG (N = 17) was offered in-person and had a competitive focus, Summer 2020 (N = 13) was virtual and had a competitive focus, and Summer 2021 (N = 17) was virtual and had a collaborative focus. Statistically significant differences between cohort responses are indicated by an asterisk (*, $p < 0.1$; **, $p < 0.05$). A medium effect size (0.3 < r > 0.5) was observed the comparison of the S2020 and S2021 responses to the question "The research simulation…" and for comparisons of responses to the questions "I enjoyed …research experience I've had" (S2020 vs. S2021, S2019 vs. S2021), "I enjoyed … lecture" (S2019 vs. S2020, S2019 vs. S2021), and "I enjoyed … lab class" (S2019 vs. S2020, S2020 vs. S2021). A small effect size (r < 0.3) was observed for all other questions.

Comparing the in-person (2019) and remote (2020) competitive formats, the only significant difference is that the in-person group had a greater difficulty in choosing their next measurement/experiment (Figure 6). This is echoed in their perception of the challenge being greater, with the 2019 cohort all agreeing or strongly agreeing that it was challenging to analyze the data and reach a conclusion. While this result may seem counterintuitive considering that both the course reviews and the overall interest in reaching a conclusion were higher in 2019 than in 2020, it most likely speaks to a reduction in competition caused by the remote environment. Anxiety is a natural result of competition, as has been shown in studies of college-level students.[25] It is therefore not surprising that students competing in the same room might be more concerned about their choices and feel both less prepared and more motivated. Mulvey and Ribbens demonstrated that intergroup competition leads to better goal setting and higher performance,[26] having a greater effect than students having clearly defined goals set. Conversely, students who mainly see the same team in a breakout room and, due to the competitive structure, have very little interaction with other teams, can easily self-evaluate their progress as being satisfactory while feeling isolated from actual competition.

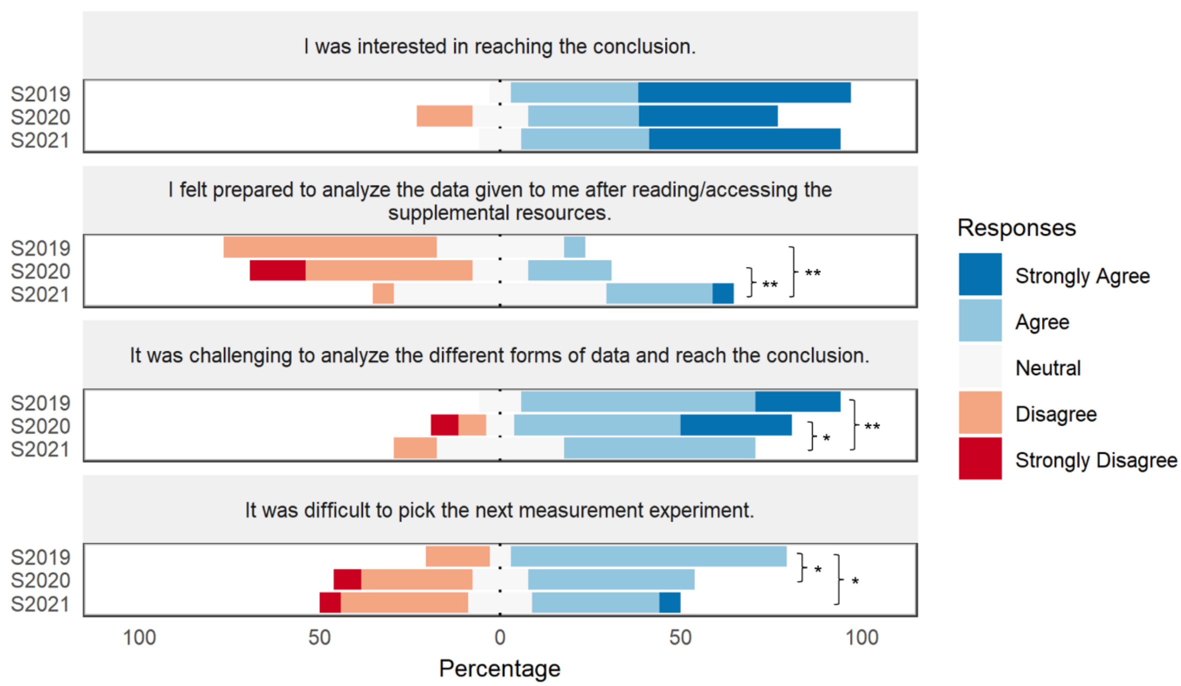

Figure 6: Post-survey responses of different cohorts of NJGSET participants to questions gauging student engagement and preparation during the VRG module. The Summer 2019 VRG (N = 17) was offered in-person and had a competitive focus, Summer 2020 (N = 13) was virtual and had a competitive focus, and Summer 2021 (N = 17) was virtual and had a collaborative focus. Statistically significant differences between cohort responses are indicated by an asterisk (*, $p < 0.1$; **, $p < 0.05$). A large effect size (r > 0.5) was observed for the comparison of S2019 and S2021 responses to “I felt prepared…” and medium effect sizes (0.3 < r > 0.5) were observed for “I felt prepared…” (S2020 vs. S2021), “It was challenging…” (S2020 vs. S2021, S2019 vs. S2021), and “It was difficult…” (S2019 vs. 2020). Small effect sizes (r < 0.3) were observed for all other questions.

In light of this, the changes that occurred when shifting from remote competitive (2020) to remote cooperative (2021) become quite intuitive. In general, cooperative approaches have been shown in a meta-analysis by Qin, Johnson, and Johnson to increase quality of problem solving in both children and adults, especially with nonlinguistic problems.[27] In the remote cooperative VRG, difficulty in experiment selection remained similar to the remote competitive format, while the perceived challenge of analyzing data and reaching a conclusion in the remote cooperative format was significantly reduced compared to both competitive formats. This supports that while competition may not have been perceived in the remote format, collaboration can enhance problem solving. Interest in 2021 returned to almost the same as 2019. Most significant, however, is student feelings of preparation, which became much greater in the collaborative format than in either of the previous years. This shift was likely the result of meeting together as a whole class at the beginning of each analysis round to discuss what tasks were needed for the day, leveraging collective understanding to define what each student needed to be working on. However, returning to the conclusions of Mulvey and Ribbens, the lack of competition may explain the fact that these students made less progress overall,[26] since they may have not taken the selection of measurements as seriously as past years.

Effect of Unknown

At RHIT a second VRG module focused on metals and BMGs was implemented in Fall 2019 and Fall 2020, with student groups being randomly assigned either the BCP or BMG module for their final project. BMGs were selected for the second VRG module topic, in part, because they satisfy all of the criteria outlined in Box 2, but also because their amorphous structure provides an opportunity to challenge students' expectations surrounding metals. The design of this new module mirrored that of the BCP module, in that it contained multiple unknowns, an identical list of experimental techniques (Table S6), curated data from the literature, and inconclusive results.

Our analysis of post-survey responses reveals that the BCP and metal/BMG modules provide students with a similar experience. Participants in both VRG modules were very interested in reaching a conclusion (Figure 7), reported similar levels of enjoyment and interest in doing future research (Figure S6), and provided similar response distributions to URSSA questions probing students' perceived gains in skills relevant to UREs (Figures S7 and S8). The two areas where student response distributions differed with a high degree of statistical significance were in how prepared students felt to analyze the data and how challenging it was to analyze data and reach a conclusion. Specifically, students with the metal/BMG unknown felt more prepared and less challenged than students with the BCP unknown (Figure 7). These differences are likely attributed to aspects of the materials science course itself, where metals are much more strongly emphasized than polymers when introducing students to structure-property relationships. The BCP module may also have been inherently more difficult, as slightly more nuance is required to distinguish between the three BCP unknowns (samples with lamellar, hexagonal, and cubic structures) than the two unknowns in the metal/BMG VRG (a crystalline and an amorphous metal).

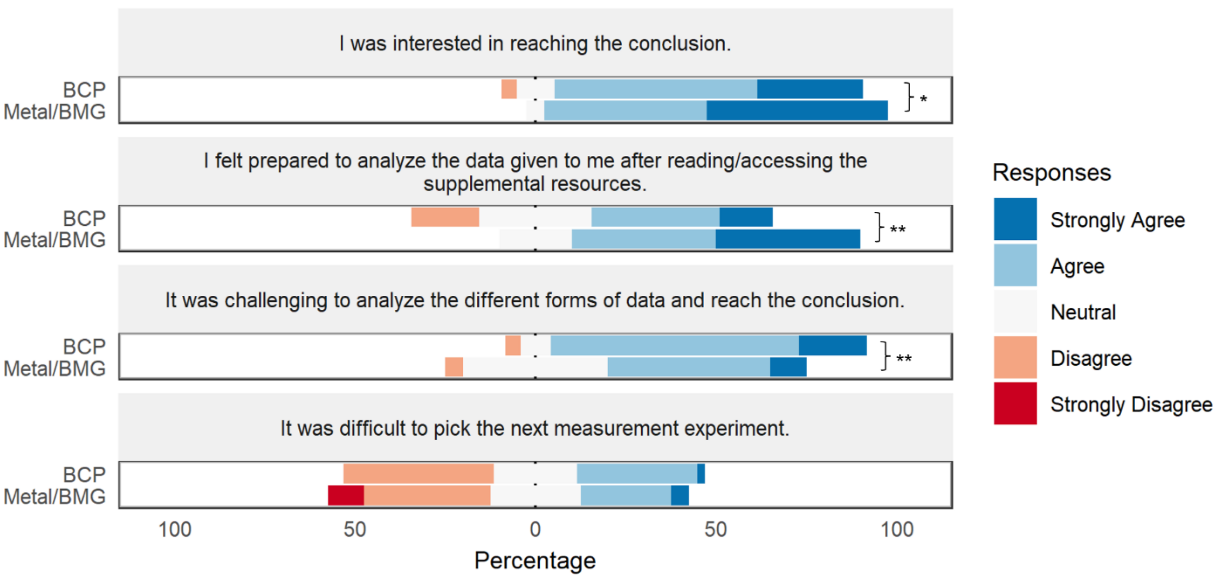

Figure 7: Post-survey responses of RHIT participants with block copolymer (BCP) and metal/bulk metallic glass (BMG) unknowns. Questions gauged student engagement and preparation during the VRG module. Statistically significant differences between responses for the BCP unknown (N = 47) and the metal/BMG (N = 19) are indicated by an asterisk (*, $p < 0.1$; **, $p < 0.05$). A medium effect size (0.3 < r > 0.5) was observed for “I felt prepared…”. Small effect sizes (r < 0.3) were observed for all other questions.

CONCLUSIONS

VRG modules provide a scalable approach for simulating research experiences that overcome some of the barriers to access present for traditional UREs and CUREs. Our results demonstrate that VRGs replicate several attributes of traditional UREs known to promote interest and persistence in STEM. The implementation of VRGs in distinct environments and several modalities demonstrates that these modules are flexible and can be adapted to fit various educational settings. Furthermore, implementation in the NJGSET setting demonstrates the potential of VRGs for providing early-stage STEM students exposure to research. These students often have fewer opportunities to engage in research than their later-stage peers and may benefit from research experiences as they explore their interests and make decisions about the next steps in their educational and professional trajectories.

While the two VRG modules presented here are centered around materials science, VRGs have the potential to be developed and applied to other STEM disciplines. These modules can be designed and developed by educators using the learning outcomes and design criteria highlighted in this report. An initial time investment and access to scientific literature is required to create a VRG module; however, VRG modules have the potential to be assembled into educational kits that can be shared with educators in environments including K-12 classrooms, community colleges, and university settings. With this goal of developing educational kits, one key aspect that will need to be evaluated in the future is the ability for a VRG to be run by an instructor who (1) did not assemble the materials and/or (2) is not familiar with the VRG topic beyond the included materials.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. [ACS will fill this in.]

Methodology and supplemental tables, figures, and discussion (PDF)

Sample NJGSET instructional scaffolding lecture. Borrowed images have been blurred out. Hosted at https://rutgers.mediaspace.kaltura.com/media/t/1_axq0h579.

Sample datasheet provided to RHIT students (PDF)

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DEDICATION

J. P. S. would like to dedicate this manuscript to the memory of Prof. Max Mintz as it is expected that the two of them would have greatly enjoyed discussing these results over iced espresso.

REFERENCES

(1) (a) Kuh, G. D.; Schneider, C. G. Association of American Colleges and Universities (2008) High-impact Educational Practices: What They Are, Who Has Access to Them, and Why They Matter. *Report, Washington, DC: Association of American Colleges and Universities*. (b) National Academies of Sciences, E. a. M. Undergraduate Research Experiences for STEM Students: Successes, Challenges, and Opportunities. **2017**. (c) Zydney, A. L.; Bennett, J. S.; Shahid, A.; Bauer, K. W. Impact of Undergraduate Research Experience in Engineering. *Journal of Engineering Education* **2002**, *91* (2), 151-157. (d) Kilgo, C. A.; Pascarella, E. T. Does Independent Research with a Faculty Member Enhance Four-Year Graduation and Graduate/Professional Degree Plans? Convergent Results with Different Analytical Methods. *Higher Education* **2016**, *71* (4), 575-592. (e) Lopatto, D. Survey of Undergraduate Research Experiences (SURE): First Findings. *Cell biology education* **2004**, *3* (4), 270-277.

(2) (a) Hunter, A.-B.; Laursen, S. L.; Seymour, E. Becoming a Scientist: The Role of Undergraduate Research in Students' Cognitive, Personal, and Professional Development. *Science Education* **2007**, *91* (1), 36-74. DOI: https://doi.org/10.1002/sce.20173. (b) Estrada, M.; Hernandez, P. R.; Schultz, P. W. A Longitudinal Study of How Quality Mentorship and Research Experience Integrate Underrepresented Minorities into STEM Careers. *CBE—Life Sciences Education* **2018**, *17* (1), ar9. DOI: 10.1187/cbe.17-04-0066. (c) Russell, S. H.; Hancock, M. P.; McCullough, J. Benefits of Undergraduate Research Experiences. *Science* **2007**, *316* (5824), 548-549. (d) Seymour, E.; Hunter, A. B.; Laursen, S. L.; DeAntoni, T. Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings from a Three-Year Study. *Science education* **2004**, *88* (4), 493-534.

(3) (a) Hernandez, P. R.; Woodcock, A.; Estrada, M.; Schultz, P. W. Undergraduate Research Experiences Broaden Diversity in the Scientific Workforce. *BioScience* **2018**, *68* (3), 204-211. DOI: 10.1093/biosci/bix163 (acccessed 10/7/2021). (b) Espinosa, L. Pipelines and Pathways: Women of Color in Undergraduate STEM Majors and the College Experiences that Contribute to Persistence. *Harvard Educational Review* **2011**, *81* (2), 209-241. (c) Jones, M. T.; Barlow, A. E. L.; Villarejo, M. Importance of Undergraduate Research for Minority Persistence and Achievement in Biology. *The Journal of Higher Education* **2010**, *81* (1), 82-115. (d) Slovacek, S.; Whittinghill, J.; Flenoury, L.; Wiseman, D. Promoting Minority Success in the Sciences: The Minority Opportunities in Research Programs at CSULA. *Journal of Research in Science Teaching* **2012**, *49* (2), 199-217. (e) Pender, M.; Marcotte, D. E.; Sto Domingo, M. R.; Maton, K. I. The STEM Pipeline: The Role of Summer Research Experience in Minority Students' Ph.D. Aspirations. *Education policy analysis archives* **2010**, *18* (30), 1-36. PubMed.

(4) (a) Pierszalowski, S.; Bouwma-Gearhart, J.; Marlow, L. A Systematic Review of Barriers to Accessing Undergraduate Research for STEM Students: Problematizing Under-Researched Factors for Students of Color. *Social Sciences* **2021**, *10* (9), 328. (b) Bangera, G.; Brownell, S. E. Course-Based Undergraduate Research Experiences Can Make Scientific Research More Inclusive. *CBE—Life Sciences Education* **2014**, *13* (4), 602-606.

(5) (a) Wilczek, L. A.; Clarke, A. J.; Guerrero Martinez, M. d. C.; Morin, J. B. Catalyzing the Development of Self-Efficacy and Science Identity: A Green Organic Chemistry CURE. *Journal of Chemical Education* **2022**. DOI: 10.1021/acs.jchemed.2c00352. (b) Lau, J. K.; Paterniti, M.; Stefaniak, K. R. Crossing Floors: Developing an Interdisciplinary CURE between an Environmental Toxicology Course and an Analytical Chemistry Course. *Journal of Chemical Education* **2019**, *96* (11), 2432-2440. DOI: 10.1021/acs.jchemed.9b00289. (c) Pagano, J. K.; Jaworski, L.; Lopatto, D.; Waterman, R. An Inorganic Chemistry Laboratory Course as Research. *Journal of Chemical Education* **2018**, *95* (9), 1520-1525. DOI: 10.1021/acs.jchemed.7b00812. (d) Williams, L. C.; Reddish, M. J. Integrating Primary Research into the Teaching Lab: Benefits and Impacts of a One-Semester CURE for Physical Chemistry. *Journal of Chemical Education* **2018**, *95* (6), 928-938. DOI: 10.1021/acs.jchemed.7b00855. (e) Heemstra, J. M.; Waterman, R.; Antos, J. M.; Beuning, P. J.; Bur, S. K.; Columbus, L.; Feig, A. L.; Fuller, A. A.; Gillmore, J. G.; Leconte, A. M.; Londergan, C. H.; Pomerantz, W. C. K.; Prescher, J. A.; Stanley, L. M. Throwing Away the Cookbook: Implementing Course-Based Undergraduate Research Experiences (CUREs) in Chemistry. In *Educational and Outreach Projects from the Cottrell Scholars Collaborative Undergraduate and Graduate Education Volume 1*, ACS Symposium Series, Vol. 1248; American Chemical Society, 2017; pp 33-63.

(6) Auchincloss, L. C.; Laursen, S. L.; Branchaw, J. L.; Eagan, K.; Graham, M.; Hanauer, D. I.; Lawrie, G.; McLinn, C. M.; Pelaez, N.; Rowland, S. Assessment of Course-Based Undergraduate Research Experiences: A Meeting Report. Am Soc Cell Biol: 2014.
(7) Dolan, E. L. Course-Based Undergraduate Research Experiences: Current Knowledge and Future Directions. *Natl Res Counc Comm Pap* **2016**, *1*, 1-34.
(8) (a) Ward, A. M.; Wyllie, G. R. A. Bioplastics in the General Chemistry Laboratory: Building a Semester-Long Research Experience. *Journal of Chemical Education* **2019**, *96* (4), 668-676. DOI: 10.1021/acs.jchemed.8b00666. (b) Silsby, C.; McCormack, R.; Roll, M. F.; Moberly, J. G.; Waynant, K. V. Implementing the Elements of Course-Based Undergraduate Research Experiences (CUREs) in a First-Year Undergraduate Chemistry Laboratory with Bioremediation Relevance. *Journal of Chemical Education* **2022**. DOI: 10.1021/acs.jchemed.2c00360. (c) May, N. W.; McNamara, S. M.; Wang, S.; Kolesar, K. R.; Vernon, J.; Wolfe, J. P.; Goldberg, D.; Pratt, K. A. Polar Plunge: Semester-Long Snow Chemistry Research in the General Chemistry Laboratory. *Journal of Chemical Education* **2018**, *95* (4), 543-552. DOI: 10.1021/acs.jchemed.7b00823.
(9) Noshay, A.; McGrath, J. E. Block copolymers: overview and critical survey. **2013**.
(10) Holden, G.; Bishop, E.; Legge, N. R. Thermoplastic elastomers. In *Journal of Polymer Science Part C: Polymer Symposia*, 1969; Wiley Online Library: Vol. 26, pp 37-57.
(11) Saijo, K.; Shin, G.; Hashimoto, T.; Amemiya, Y.; Ito, K. Strain-Phase-Resolved Dynamic SAXS Studies of BCC-Spherical Domains in Block Copolymers under LAOS: Creation of Twinned BCC-Sphere and Their Dynamic Response. *Macromolecules* **2013**, *46* (4), 1549-1562. DOI: 10.1021/ma302559w.
(12) Noda, I.; Ozaki, Y. *Two-dimensional correlation spectroscopy: applications in vibrational and optical spectroscopy*; John Wiley & Sons, 2005.
(13) Okamoto, S.; Saijo, K.; Hashimoto, T. Real-time SAXS observations of lamella-forming block copolymers under large oscillatory shear deformation. *Macromolecules* **1994**, *27* (20), 5547-5555.
(14) Pedemonte, E.; Dondero, G.; Alfonso, G. C.; Candia, F. d. Three-block copolymers: morphologies and stress - strain properties of samples prepared under various experimental conditions. *Polymer* **1975**, *16* (7), 531-538. DOI: https://doi.org/10.1016/0032-3861(75)90013-0.
(15) Laursen, S.; Hunter, A. B.; Seymour, E.; Thiry, H.; Melton, G. *Undergraduate Research in the Sciences: Engaging Students in Real Science*; Wiley, 2010.
(16) (a) Weston, T. J.; Laursen, S. L. The Undergraduate Research Student Self-Assessment (URSSA): Validation for Use in Program Evaluation. *CBE—Life Sciences Education* **2015**, *14* (3), ar33. DOI: 10.1187/cbe.14-11-0206. (b) Thiry, H.; Weston, T. J.; Laursen, S. L.; Hunter, A.-B. The Benefits of Multi-Year Research Experiences: Differences in Novice and Experienced Students' Reported Gains from Undergraduate Research. *CBE—Life Sciences Education* **2012**, *11* (3), 260-272. DOI: 10.1187/cbe.11-11-0098.
(17) (a) Daniels, H.; Grineski, S. E.; Collins, T. W.; Morales, D. X.; Morera, O.; Echegoyen, L. Factors Influencing Student Gains from Undergraduate Research Experiences at a Hispanic-Serving Institution. *CBE—Life Sciences Education* **2016**, *15* (3), ar30. DOI: 10.1187/cbe.15-07-0163. (b) Kinner, D.; Lord, M. Student-Perceived Gains in Collaborative, Course-Based Undergraduate Research Experiences in the Geosciences. *Journal of College Science Teaching* **2018**, *48* (2), 48-58. Jstor.
(18) Calvin, J. J.; Ondry, J. C.; Dahl, J. C.; Sedlak, A. B.; McKeown-Green, A.; Wang, X.; Crook, M. F.; Gleason, S. P.; Hauwiller, M. R.; Baranger, A. M.; Alivisatos, A. P. Research Group-Led Undergraduate Research Program: Analyzing and Improving a Versatile Springboard for First-Year Undergraduates. *Journal of Chemical Education* **2022**, *99* (2), 799-809. DOI: 10.1021/acs.jchemed.1c01065.
(19) (a) Hanauer, D. I.; Frederick, J.; Fotinakes, B.; Strobel, S. A. Linguistic Analysis of Project Ownership for Undergraduate Research Experiences. *CBE—Life Sciences Education* **2012**, *11* (4), 378-385. DOI: 10.1187/cbe.12-04-0043. (b) Hanauer, D. I.; Dolan, E. L. The Project Ownership Survey: Measuring Differences in Scientific Inquiry Experiences. *CBE—Life Sciences Education* **2014**, *13* (1), 149-158. DOI: 10.1187/cbe.13-06-0123.
(20) (a) Quan, G. M.; Elby, A. Connecting Self-Efficacy and Views About the Nature of Science in Undergraduate Research Experiences. *Physical Review Physics Education Research* **2016**, *12* (2), 020140. DOI: 10.1103/PhysRevPhysEducRes.12.020140. (b) Burgin, S. R.; Sadler, T. D. Learning Nature of Science Concepts Through a Research Apprenticeship Program: A Comparative Study of

Three Approaches. *Journal of Research in Science Teaching* **2016**, *53* (1), 31-59. DOI: https://doi.org/10.1002/tea.21296.
(21) Hernandez, P. R.; Hopkins, P. D.; Masters, K.; Holland, L.; Mei, B. M.; Richards-Babb, M.; Quedado, K.; Shook, N. J. Student Integration into STEM Careers and Culture: A Longitudinal Examination of Summer Faculty Mentors and Project Ownership. *CBE—Life Sciences Education* **2018**, *17* (3), ar50.
(22) Burgin, S. R.; Sadler, T. D.; Koroly, M. J. High School Student Participation in Scientific Research Apprenticeships: Variation in and Relationships Among Student Experiences and Outcomes. *Research in Science Education* **2012**, *42* (3), 439-467. DOI: 10.1007/s11165-010-9205-2.
(23) (a) Linn, M. C.; Palmer, E.; Baranger, A.; Gerard, E.; Stone, E. Undergraduate Research Experiences: Impacts and Opportunities. *Science* **2015**, *347* (6222), 1261757. DOI: 10.1126/science.1261757. (b) Haeger, H.; Fresquez, C. Mentoring for Inclusion: The Impact of Mentoring on Undergraduate Researchers in the Sciences. *CBE—Life Sciences Education* **2016**, *15* (3), ar36. DOI: 10.1187/cbe.16-01-0016. (c) Corwin, L. A.; Runyon, C. R.; Ghanem, E.; Sandy, M.; Clark, G.; Palmer, G. C.; Reichler, S.; Rodenbusch, S. E.; Dolan, E. L. Effects of Discovery, Iteration, and Collaboration in Laboratory Courses on Undergraduates' Research Career Intentions Fully Mediated by Student Ownership. *CBE—Life Sciences Education* **2018**, *17* (2), ar20. DOI: 10.1187/cbe.17-07-0141.
(24) Adedokun, O. A.; Zhang, D.; Parker, L. C.; Bessenbacher, A.; Childress, A.; Burgess, W. D. Understanding How Undergraduate Research Experiences Influence Student Aspirations for Research Careers and Graduate Education. *Journal of College Science Teaching* **2012**, *42* (1), 82.
(25) (a) Posselt, J. R.; Lipson, S. K. Competition, anxiety, and depression in the college classroom: Variations by student identity and field of study. *Journal of College Student Development* **2016**, *57* (8), 973-989. (b) Johnson, R. T.; Johnson, D. W.; Bryant, B. Cooperation and Competition in the Classroom. *The Elementary School Journal* **1973**, *74* (3), 172-181. (acccessed 2022/05/30/).JSTOR.
(26) Mulvey, P. W.; Ribbens, B. A. The effects of intergroup competition and assigned group goals on group efficacy and group effectiveness. *Small Group Research* **1999**, *30* (6), 651-677. DOI: 10.1177/104649649903000601.
(27) Qin, Z.; Johnson, D. W.; Johnson, R. T. Cooperative Versus Competitive Efforts and Problem Solving. *Review of Educational Research* **1995**, *65* (2), 129-143. DOI: 10.3102/00346543065002129.