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# JTAR

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## About the Journal

Founded in 2013, the Journal of Teacher Action Research (ISSN: 2332-2233) is a peer-reviewed online journal indexed with EBSCO that seeks practical research that can be implemented in Pre-Kindergarten through Post-Secondary classrooms. The primary function of this journal is to provide classroom teachers and researchers a means for sharing classroom practices.

The journal accepts articles for peer-review that describe classroom practice which positively impacts student learning. We define teacher action research as teachers (at all levels) studying their practice and/or their students' learning in a methodical way in order to inform classroom practice. Articles submitted to the journal should demonstrate an action research focus with intent to improve the author's practice.

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# COUPLING PHET SIMULATIONS AND POGIL: HIGH SCHOOL CHEMISTRY STUDENTS' LEARNING AND ENGAGEMENT IN ARGUMENTATION ON THE TOPIC OF ATOMIC THEORY

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**Abstract** POGIL – Process Oriented Guided Inquiry Learning – is a tested curriculum utilizing graphs, data tables, and illustrations presented in such a way as to prompt the students to discover the patterns and underlying rules of science. PhET is a group of internet-based simulations created by the University of Colorado that are used to teach select chemistry concepts. Guided inquiry worksheets prepared for use with these simulations allow students to discover the patterns and underlying rules of science. While these two platforms have been researched, the use of them in combination in a class has not been studied. This article examines the use of these two platforms in combination to teach the concept of atomic structure to high school chemistry students. Students completed a pre-test and post-test as well as several opinion surveys about the classroom activities. Observations of the students' actions by the teacher were also recorded. At the conclusion of the study, students showed a significant improvement on the post-test, and the number of times students were seen explaining multiple representations to their partner or team and arguing their position increased with each activity. The combination of POGIL and PhET guided-inquiry activities in this high school classroom was shown to successfully help students learn and use several science practices advocated by NGSS.

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**Keywords:** teacher action research, simulations, guided inquiry, multiple representations, high school chemistry, POGIL, PhET

## **Introduction**

When learning abstract concepts, a picture is truly 'worth a thousand words' (Barnard, 1921). Representations—tools for representing knowledge—help students understand

abstract science concepts (Treagust & Tsui, 2014). Representations in chemistry courses help students navigate the abstract understanding of atomic structure and the multiple perspectives (i.e. macroscopic, submicroscopic, and symbolic) from which chemists communicate knowledge about matter (De Jong & Taber, 2007; Williamson & José, 2009). Atomic structure is one of the first abstract concepts of the year in many high school chemistry curricula; and the abstract nature of the topic leads to student struggles. The Process Oriented Guided Inquiry Learning (POGIL) curriculum for high school chemistry (Trout, 2012) includes representations to help students learn about atomic structure through guided inquiry instruction. Several representations to help students understand atomic structure can also be found as simulations among the collections of PhET Interactive Simulations available freely online (PhET, 2018) and, like all the PhET simulations, are designed to be used as guided-inquiry activities (Moore et al., 2014). While each instructional strategy has been studied independently, the use of these two approaches together to help students learn has not been studied. The strategies together could provide students with multiple representations of the structure of atoms, ions and isotopes. Multiple representations give the students options when forming their own mental models to help them learn (Schwonke, 2009). In this article, we described the results of an action research study that combined POGIL activities and PhET simulations in guided inquiry activities to deliver instruction on atomic structure to high school chemistry students. It was hoped that by combining new representations of atoms, isotopes and ions in a guided inquiry, cooperative learning environment, high school students would help each other integrate the new representations into their knowledge base and learn about atomic structure while using science practices.

## Literature Review

*Multiple representations.* Many studies have been done on the efficacy of using multiple representations to learn chemistry. Common representations include text, images, graphs, equations, symbols, tables, diagrams, lists and animations. Students prefer pictures and animations when learning abstract concepts (Yesildag Hasancebi & Günel, 2013). When students endeavor to learn new concepts, providing multiple representations of the material can be beneficial to the process. According to Schwonke (2009) the benefits can be broken down into three categories:

Firstly, multiple representations may provide different information or stimulate different learning activities (complementary function). Secondly, known or easy-to-understand representations can facilitate the interpretation of others (constraining function). Finally, multiple representations can support deeper understanding, when information distributed over different representations is integrated (construction function) (p. 1227).

However, students have to make the connections between the representations themselves which can be challenging (Rau, 2015; Walldrip, Prain, & Carolan, 2010). Because not all students learn in the same manner, it is generally better to provide more than one representation of the material to be learned (Rose & Gravel, 2011). This gives the student options. They may relate to one type of representation more than another. Because knowledge is constructed in the mind of the learner, (Bodner, 1986) learners need to draw upon prior knowledge to build these connections. Learning to build bridges connecting

these different representations is also a significant challenge for some students, especially novice learners with low prior knowledge (Corradi, Elen, & Clarebout, 2012). Guided-inquiry in cooperative groups may hold the key to solving this conundrum.

*Guided Inquiry.* During guided-inquiry activities, which are sometimes referred to as teacher-initiated activities (Llewellyn, 2013), students explore teacher-generated questions or prompts. In experiments students might be guided by a single question, but it can be more. In guided inquiry, while students are given the questions, they are not given the procedures for answering the questions or the methods for analyzing data or communicating their results (Bell, Smetana, & Binns, 2005; Llewellyn, 2013). While the teacher facilitates the students' procedures and analysis, he/she does not provide the answers. As with other forms of inquiry instruction, guided-inquiry requires students to take ownership of their learning and is aligned with research on how students learn (Crawford, 2014; Llewellyn, 2013). Research into student learning has demonstrated that guided inquiry is an effective method for helping students learn (e.g. Crawford, 2014; Spencer, 2006)

*POGIL.* POGIL is a student-centered, guided learning experience where students work in small groups to complete specially designed activities. The activities promote active engagement and group learning following a learning cycle paradigm (Moog et al., 2006). The learning cycle used in POGIL activities is an inquiry strategy for teaching and learning that is based on constructivist principles (Moog et al., 2006). Initially, learners explore a model or some given piece of information that may encompass multiple representations of the information to be considered. Once the students have attempted to explain or understand the patterns in the given model, terms are introduced so that the students have a concept to which to tie them. The last step is the application phase where students apply their new learning using a series of deductive reasoning steps. The focus is on the process as much as the content (Moog et al., 2006). POGIL activities employ multiple representations of the material in a process that allows the students to draw connections between them.

POGIL are designed to be executed in cooperative groups that allow the students to interact in their assigned roles to achieve the goal. Cooperative learning structure allows students to use three important elements: (a) discussion among students, (b) problem solving, and (c) verbalization of methods and strategies (Cooper, 1995). Through the use of effective discourse, the students assist one another in the acquisition of the concepts. As students work in cooperative groups, instructors are facilitators not lecturers, listening to student discourse and providing guidance as needed.

Many studies have shown the effectiveness of POGIL, including higher course grade achievement as well as lowered attrition rate in college level chemistry courses (Moog et al., 2006). Additionally, when using POGIL, Spencer (2006) found that the greatest gains in course grade were seen in the lower half of the class. These increases may be attributed to greater student buy-in because the students are more actively involved in the learning process.

*PhET.* PhET is a multimodal tool that students can use to make concrete connections between the abstract and un-seeable, subatomic particles (Moore et al., 2014; also find simulations at <https://phet.colorado.edu/>). PhET simulations present content in an

interactive computer interface that allows the students to “play” with the content to try to draw their own conclusions as to how it works. These simulations use multiple representations ranging from the animation itself to supporting tables, graphs, and other visualizations of the data. The ease of use and the draw of a video game brings “even the most reluctant learners” (Sandoval, 2011, p. 46) into the game.

Developers of PhET simulations designed them to be performed by single students or in pairs (Moore et al., 2014). More than two students at a computer is not optimal for student learning due to space constraints. If the PhET is performed by a pair of students, the opportunity for student discourse is present, allowing for discussions that may lead to a deeper understanding of the activity and its goal. PhET simulations “provide a range of opportunities for conceptually rich, student centered activities and discussions” (Moore et al., 2014, p. 1194). PhET simulations were developed with implicit scaffolding to guide students through the use of the simulations for learning (Moore et al., 2013), making them good for guided inquiry activities with light guidance (Chamberlain et al., 2014). Most of the simulations found on the PhET website have teacher-generated guided-inquiry activities which could be used with the simulation (PhET, 2018).

The efficacy of PhET use in classrooms is well supported by several studies. Wickham (2016) found that, “The constructionist capability of the PhET microworld was a significant factor in the improvement of participants’ affective engagement” (p. 38). Ajredini (2014) found that when compared to real experiments, students working in the simulation group spent more time thinking, analyzing and discussing the concepts, while students working on the real experiment spent more time solving technical difficulties.

## Methodology

*Purpose of Study.* POGIL and PhET have both been found to be effective for helping students acquire difficult concepts, but their use has not been studied in combination. With their similar approaches they could be complementary. We wanted to know the efficacy of using POGIL activities along with guided-inquiry activities using PhET simulations to teach high school chemistry students about the structure of atoms, isotopes and ions. Not only did we want to know if students learned using the activities, but we wanted to know students’ opinions of the activities and how they engaged with the representations in the activities during class. The following questions guided this study:

1. Does students’ knowledge about basic atomic structure, including isotope and ion structure improve when coupling PhET simulations with POGIL?
2. How do students engage with each other and with the multiple representations of atomic structure that they encounter during each activity?
3. Do students’ preferences for guided inquiry process using a computer simulation (PhET) or guided inquiry process using POGIL result in a statistically significant difference in scores on the common post-test?

This classroom action research study sought to determine if combining guided inquiry learning through PhET and POGIL worksheets would increase students’ scores on a post-test. It was also designed to examine how students used multiple representations to build understanding of abstract concepts. Lastly, this research sought to draw connections

between the students' learning and their preferred guided inquiry format, either PhET or POGIL.

*Population and Environment.* This study was conducted at an eastern United States high school (MHS). MHS has a population of 1556 students who are 38.7% White, 25.4% Hispanic, 22.9% Black, 8.0% Asian, and 4.9% Other. Fifty one percent (51.4%) of students receive free or reduced meals, 12.0% are in the special education program, and 3.8% are in the ELL program.

Students from the first author's two honors chemistry courses (N =33) participated in this study. The majority of the students were in their junior year, but 2 sophomores in an accelerated science pathway were also enrolled in the study (representing 6% of students enrolled). Although two separate classes were used, all activities, surveys and tests were given on the same days for both classes. Groups for each activity were determined by alphabetical listing and did not change for the two types of activities. The groups of two for the PhET activities were the same, as were the groups of three for the POGIL activities.

*Atomic Structure Unit.* The students in honors chemistry completed a pre-test of their level of understanding of the concepts at the start of the unit. On Day 1, the students then completed the PhET Build an Atom Lab (PhET, 2018) with a partner. The next day, the POGIL Isotopes worksheet (Trout, 2012) was completed in teams of three. The second PhET activity, Isotopes and Atomic Mass Lab (PhET, 2018), was completed in pairs on Day 3. The last activity, POGIL Ions worksheet (Trout, 2012), was completed in teams of three on Day 4. Excluding Day 1, after each activity students completed a survey described below. After the four activities were completed (Day 5 of the unit), an unannounced post-test was administered to the students, and they completed one final survey. Three weeks later, the students took a unit test covering the topics in this study.

*Data Collection.* The nature of the three research questions above required a research plan, approved by the Institutional Review Board (IRB), that collected both qualitative and quantitative data to answer the different questions. After each activity (except the first PhET simulation) and at the end of the atomic structure unit, students self-reported on a survey their likes and dislikes and how they used the multiple representations presented in the two processes (POGIL and PhET) using Likert style and open-ended questions (See Appendix A and B for Survey Questions). The main question the students were asked was, "How did you use the different pictures, diagrams, symbols and tables to aid your understanding of the concepts covered in this activity?" In addition, the first author monitored the students' learning process, using descriptive notes and tally sheets. The tally sheet categories used were: Collaborating with Partner/Team, Explaining Multiple Representations to Partner/Team, and Arguing His/Her Position. Any time the first author saw a student doing one of the actions listed on the tally sheet, she marked next to a student's name. A pre-test and a post-test were designed to ascertain the effectiveness of each process using a two-tier multiple-choice instrument (Treagust, 1988). For each concept, students were asked

true/false questions and then were required to explain the reason(s) for their choice. For example, “T / F Neutrons have a negative charge. Reason(s)” (See Appendix C for the complete test). The test was designed by the first author and reviewed for accuracy and clarity by the second author and another experienced chemistry teacher. Students received a score for their answer to the true/false part of the question and for their reasons separately. They could get points for answering the true/false correctly even if they did not provide a reason.

*Data Analysis.* Several methods of analysis were used with the collected data to help answer the research questions. After grading the pre and post-tests, along with collecting descriptive statistics, *paired sample t-tests* were run (Creswell, 2012). In addition, qualitative data from the common survey question, “How did you use the different pictures, diagrams, symbols and tables to aid your understanding of the concepts covered in this activity?” (Survey 1 question 7, Survey 2 question 7, and Survey 3 question 6), was coded and students’ responses were placed into one of 7 categories. Table 1 provides the categories, a brief definition of the category, and a sample student response.

Table 1: Categories of Student Responses to How They Used the Representations in the Activities Question

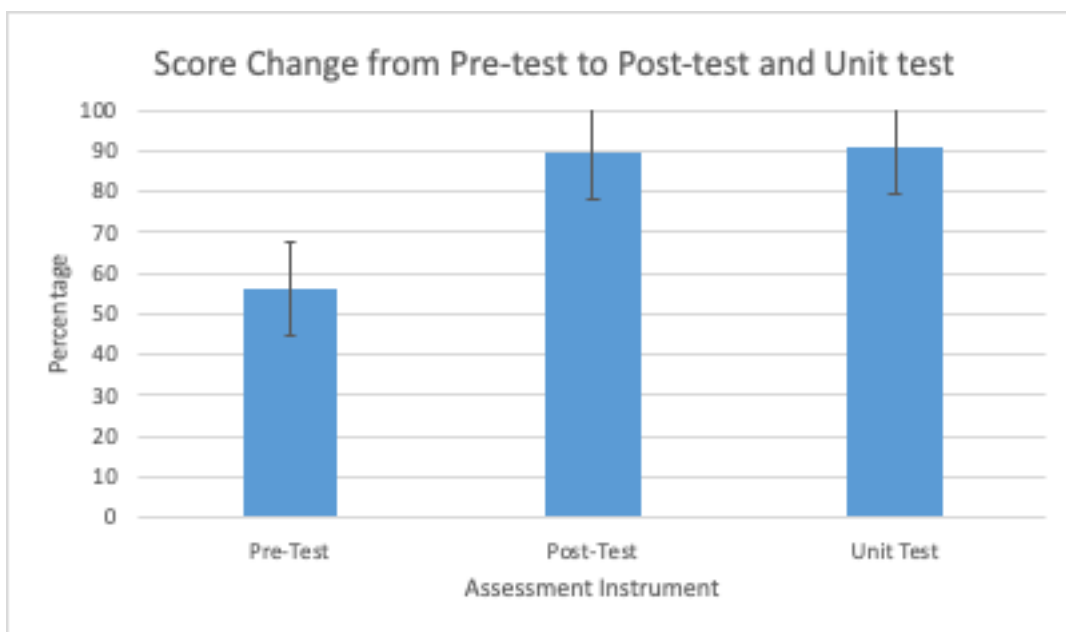
Response Category	Definition of Category Student’s Response Described....	Example Student Response
Pictures/Visuals	How the visuals aided their learning	“I took information from visual aids on the paper (POGIL) and interpreted them in a way so that I could comprehend them through comparison to other isotope sets.”
Place on the Periodic Table	Made reference to the periodic table	“The use of the periodic table helps me understand the concepts because this diagram shows all the info we learned throughout this process. It’s cool how it is all coordinated on a diagram.”
Comparisons/Patterns	Mentioned a pattern or made a comparison	“I was able to see what was going on and how it changes or stays the same.”
Didn’t Use/Not Helpful	Started with “No”	“No, I was still confused and did not know what to do.”
Used No Explanation	Started with “Yes” with no explanation provided	“Yes”

Used to Resolve Confusion	Using the representations to clear up a misunderstanding	"They helped me understand how many protons, neutrons and electrons are in an element."
No answer	Did not answer the question	

Data collected from the tally sheets was compiled by category (Collaborating with Partner/Team, Explaining Multiple Representations to Partner/Team, and Arguing His/Her Position) and compared across the four activities. Students' preferences for PhET or POGIL were determined based on their answer to the ranking questions on the final survey, higher number was preferred. Students' rankings for the PhET activities and POGIL activities were added together to determine which they preferred, and they were assigned to a preference group. Then *one-way ANOVA* was run to determine if there was a difference in performance on the post-test based on preference.

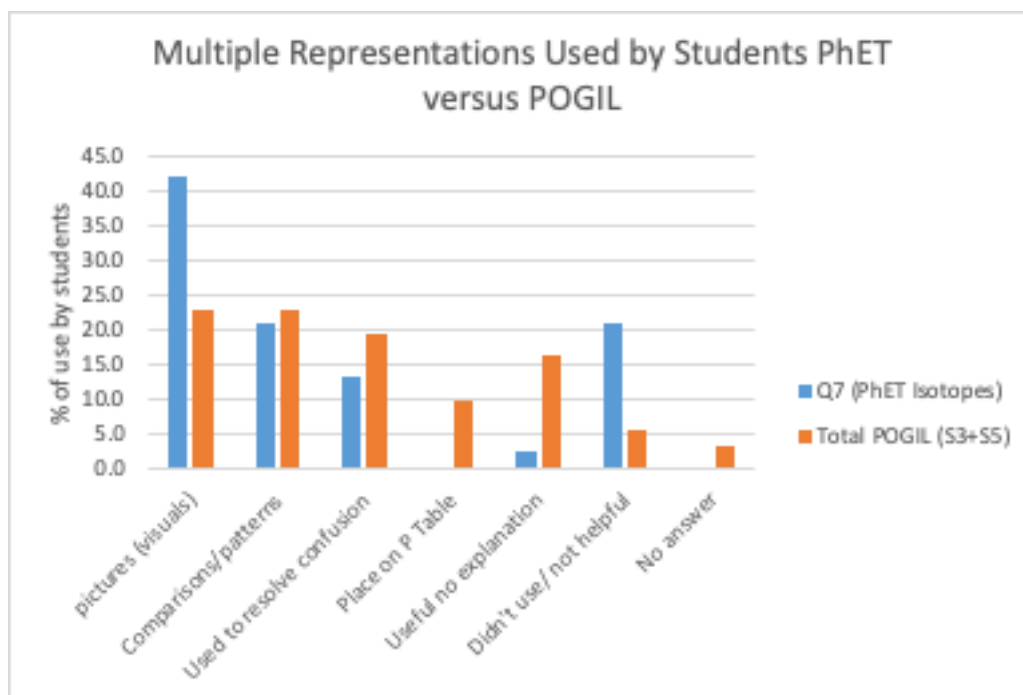
## Results

Statistical analyses were performed on the pre-test and post-test data, showing the percent improvement of each student and the entire set of students; the standard deviations were calculated as well. Based on the variety of student responses to questions 26, 29 and 30, these questions were not clear. The mean for the pre-test was 55.9% and the mean for the post-test was 89.7% (Figure 1). A paired sample t-test was run to determine if the four activities were effective at raising student scores on the post-test. The mean score improvement ( $M=33.75$ ,  $SD=11.91$ ,  $N=33$ ) was significantly greater than zero [ $t(32)=-16.28$ ,  $p < 0.01$ ] providing evidence that coupling PhET simulations with POGIL exercises helped students learn the topic of atomic theory. Three weeks after the post-test was administered, the students were given a unit test that included questions covering the topics in the study. Though a 1% improvement in the total score for the unit test from the post test, a t-test indicated no significant difference in students' post-test and unit test scores [ $t(32)=-0.503$ ,  $p = 0.618$ ], indicating that information had been retained.



*Figure 1: Student Scores on a Pretest, Post-test and Unit test 3 weeks later.*

Students were surveyed after each activity as to how they used multiple representations to aid their learning. The data in Figure 2 below were compiled by combining these data from the two POGIL activities (POGIL Isotopes and POGIL Ions) and from the survey administered after one PhET activity (PhET Isotopes).



*Figure 2: Multiple Representations Used by Students – PhET versus POGIL. This figure illustrates the side by side comparison of student reported use of multiple representations for both the POGIL (orange) and PhET (blue) activities.*

Students reported using more types of multiple representations while completing the POGIL activities, with only 5.4% reporting that they did not use the multiple representations, or they felt they were not helpful to their understanding. Students reported using fewer types of multiple representations for the PhET activity, with 21.1% reporting that they did not use any multiple representations, or they felt they were not helpful. During the PhET activity students' responses focused on the pictures or visuals.

The first author's observations through tally sheets showed that 100% of students participated in each of the four activities. With each activity, PhET or POGIL, students using multiple representations to explain concepts to their group or partner increased, but a dip was seen in the arguing position data for the PhET Isotopes activity (See Figure 3).

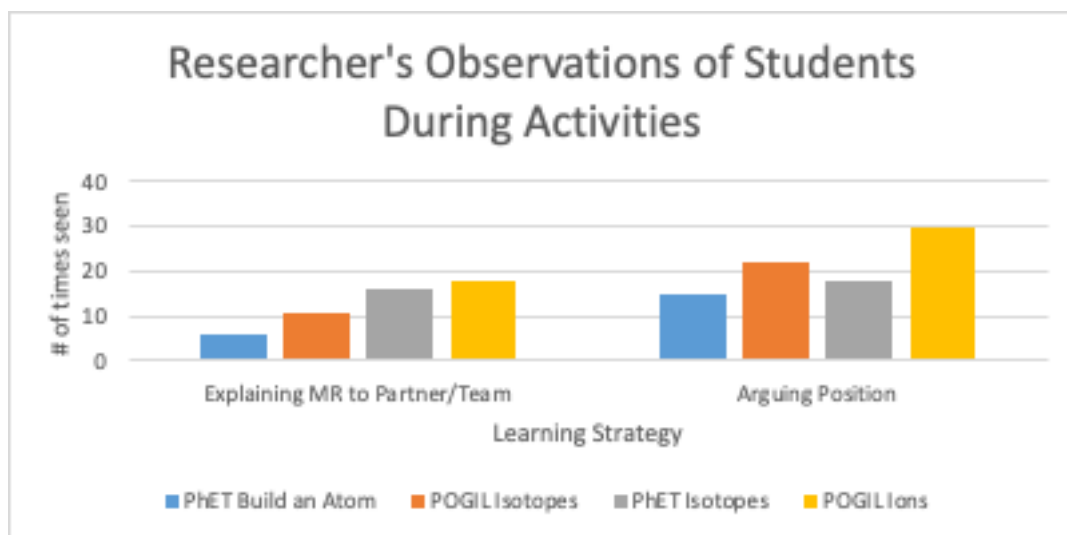


Figure 3: Researcher's Observations of Students During Activities. This graph shows that the number of times students were seen explaining multiple representations to their partner or team and arguing their position increased with each activity.

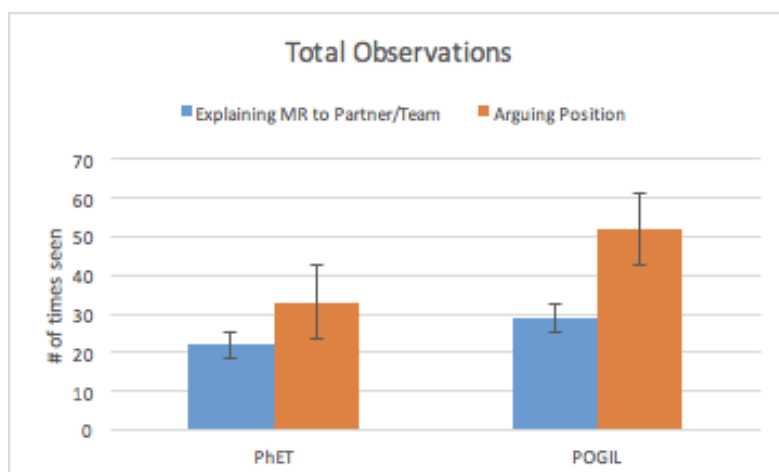
Along with tally marks, the observation sheets were also used to keep some field notes on students. In the first activity, PhET Build an Atom, the students quickly engaged each other in conversation about the activity. This topic was not new to them and they easily completed the task, helping each other recall the information they had seen two years prior. The active discussions helping each other understand the material continued for the second activity, POGIL Isotopes. One student described in her reflection on the activity what was observed for many students, "We used the periodic table to look for elements and atomic numbers, and we referenced the diagram on the POGIL to understand atomic number and how isotopes are written." She also commented that, "I like how we work in groups to complete these activities, and I think that they're challenging in a good way." Observations of students' behavior, on task, actively working with each other, suggest that many students agreed with her statement.

During the third activity, PhET Isotopes, the students seemed confused by the online simulation. Their conversations were more tentative, asking for confirmation of their ideas rather than stating them. One student said in class, "It always stays the same?" – referring to the number of protons in an isotope, but asking as a question rather than stating to his partner. The students appeared to lack confidence enough in their understanding to come out in favor of their ideas. Fewer instances of students arguing their position was seen with the PhET Isotopes activity than either of the POGIL activities.

From the observations sheets, as seen in Figure 3, students most effectively combined the use of multiple representations during the last activity, POGIL Ions. One student was observed explaining to his partner, using POGIL Ions Model 1 from the activity worksheet and the periodic table on the classroom wall, "You can predict charge because there's a pattern using the number of valence electrons." That same student wrote in his POGIL Ions reflection that, "I analyzed the pictures, diagrams and isotopic symbols to find the right

answer.” Another pair of students, completing the POGIL Ions activity, helped each other understand how to find the charge of an ion by using an algebraic equation. One student was explaining to her partner that “you subtract the electrons from the protons to get the charge.” Her partner responded by writing down “ $x - y = \text{charge}$ ” to which she said, “Yes, exactly!” The partner wrote in her POGIL Ions reflection that, “Filling in the table (question 7) helped me better understand because you have to use what you already know to fill it out.”

When combined together, the interactions between the students was higher when they were completing a POGIL activity than when they were completing a PhET activity. (Figure 4)



*Figure 4: Total Number of Observations of Student Behaviors seen during PhET activities versus POGIL activities*

The students were surveyed after each activity, soliciting their feelings about how much each activity aided their understanding of the concepts presented. The questions were specific to different concepts about atomic structure and their understanding (See Appendix A and B for survey questions). The students’ scores for all these understanding questions was averaged to give a score for how they rated the activity in aiding their understanding. Students reported gaining more understanding from the POGIL activities than the PhET activity (See Figure 5).

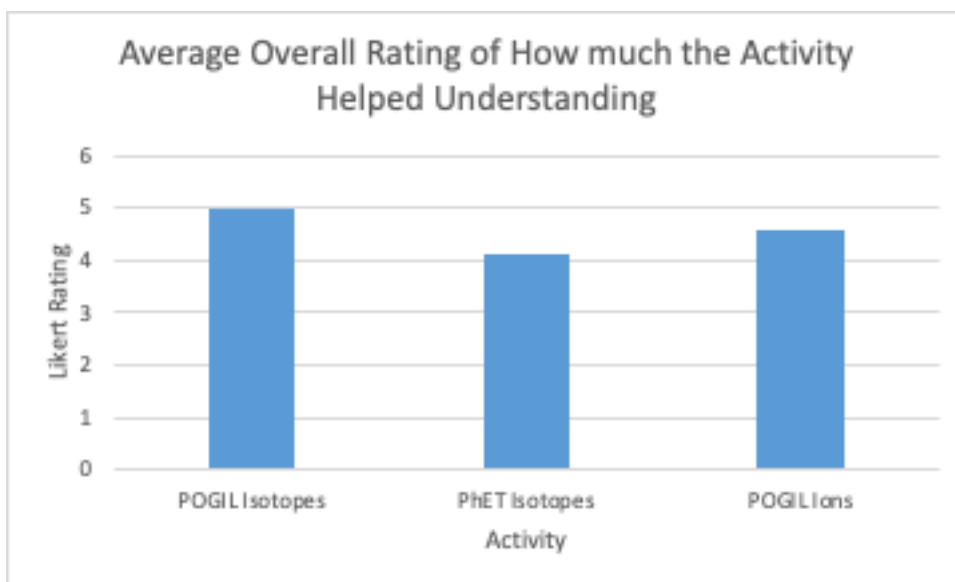


Figure 5: Students' average overall rating of how much each activity helped them understand, a 6 represents strongly agree with the statement.

At the conclusion of the study the students ranked the four activities with respect to their personal like or dislike of the activity, with a 4 being the activity they liked the best. By adding together students' scores for the PhET activities and for the POGIL activity, a total rating for each type of activity was created. Four students misunderstood the directions and ranked all four activities equally. This data was omitted. Of the 29 remaining students, 3 preferred POGIL, 2 liked PhET and POGIL equally, and 24 preferred the PhET simulation. The PhET Build an Atom activity was chosen as the favorite by 20 out of 29 students, making it overwhelmingly the favorite activity in the study. A paired sample t-test was run to determine if the student preference was significant. The mean preference score ( $M=2.76$ ,  $SD=2.73$ ,  $N=29$ ) was significantly greater than zero [ $t(28)=7.32$ ,  $p<0.01$ ], providing evidence that the students preferred PhET to POGIL to support their learning of atomic structure.

Individual student improvement was compared to reported student preference for PhET or POGIL using *one-way ANOVA* to see if their means are statistically different. The results showed that the groups were not different statistically ( $f=0.663$ ,  $p=.514$ ). There was not a statistical difference in student performance based on their preference for PhET or POGIL.

### Limitations

The validity of this study is limited by several factors. The sample size of 33 students from one high school is small and includes some level of bias. Although the students were sampled from a diverse high school, only students in the honors level were invited to participate. In addition, a survey was only given after one of the PhET simulations, not both. It was not given after the first PhET activity. While they ranked this activity in their final survey, they did not have the chance to give feedback on it directly. While the PhET and POGIL activities used covered similar topics on the concept of atomic structure, they were

not 100 percent aligned to each other, and did not present exactly the same material. There was no control group to compare, so students learned but it could just be a result of instruction of any type, not necessarily the guided-inquiry. Additionally, the survey results may have been affected by over use of the questions. Because the students saw the same question on each survey asking how they used the different pictures and diagrams, they may have inferred the purpose of the study and engaged with the representations differently than they would have without the study.

## Discussion

*Combining the Guided-Inquiry Platforms Increased Post-Test Scores.* The mean student performance on the post-test improved by 33.8 points from pre-test levels. This statistically significant result supports the hypothesis that students learned during this instructional sequence which combined PhET and POGIL activities in a unit on atomic structure. Student retention of the concepts was evident from the unit test scores as well. Students were tested three weeks after the post-test and improved 1% over the post-test levels showing retention of the material. The results also showed that the student's post-test score increased regardless of their preference for either PhET or POGIL. These results suggest that POGIL and PhET can be used together in classes to help students learn. They do not appear to confuse students or contradict each other when used in combination.

*Students Use of Multiple Representations and Reported Preference.* Students reported using multiple representations more often with the POGIL activities than with the PhET activity (Figure 2) and reported understanding the content better with the POGIL activities (Figure 5), yet they preferred the PhET activities to POGIL. Observations also showed that students were more active in explaining the multiple representations and arguing their position when completing the POGIL activities (Figure 4). These findings could be a result of students becoming more familiar with their groups over time or from the clarity of the activities themselves. However, the students reported a preference for the PhET activities. If they were confusing it would be unlikely that they liked them. In addition, even though they liked the PhET better, they were more actively engaged while completing the POGIL activities, even the first of the POGILs. Students stated that they liked the PhET activities better because they were “interactive” and “easier to understand”, while the POGIL activities were “a bit boring”. Comments taken from the student surveys suggest that the students liked the PhET activities and felt they were easier to understand because they were more visual. Student comments included:

- I think the online programs helped the best because we could play around with them and experiment on our own.
- I think that the activities where I could use the mousepad to move protons, neutrons, and electrons were most useful for me as a visual learner.
- Both of the PhET's were very helpful in visualizing the changes made from adding protons, neutrons and electrons. The POGIL's were good too, but didn't help as much to visualize everything.
- I liked the PhET's better than the POGIL's because it was more interactive than just seeing everything on paper. I like the step by step process (of POGIL) but still prefer the interactive interface (of PhET).

Given the design principles behind the PhET simulations (Moore et al., 2014), it is not surprising the students found the PhET simulations interactive and visual; they were designed to be. The use of this type of visualizations is important for student learning of the multiple levels of chemistry (De Jong & Taber, 2007; Williamson & José, 2009), and enthusiasm and active engagement in activities for learning also improves student learning (NRC, 2004). But while the students have a preference for the PhET activities, they did not hate the POGIL activities and, in fact, rated them higher in helping them understand the content. One student's comment sums up this idea: "I liked this activity (POGIL Isotopes) because it broke things down step by step which made it easier to understand. But I preferred PhET overall because they were more interactive." Thus, POGIL and PhET activities might be complementary in another way of improving the engagement and visualization while providing clarity to the content.

Three-dimensional learning emphasized in the Next Generation Science Standards (NGSS) asks teachers to engage students in scientific practices while learning core ideas (NGSS Lead States, 2013). The scientific practices (SEPs) K-12 students are expected to engage in while they learn science include, among other things, constructing explanations, engaging in argument from evidence, and evaluating and communication information (NGSS Lead States, 2013; NRC, 2012). In our study, overall, student use of multiple representations to explain concepts to their partners or argue their position increased with each activity; they were engaging in these SEPs with each other in their groups and showing greater use of the skill as they learned about atomic structure. The improvement over the course of the activities may be due to the students becoming more comfortable with their partners/group or the order in which the activities were presented. POGIL activities are designed for collaborative groups (Moog et al., 2006) and rely upon student discourse and interaction for successful completion. The students in this study had completed one previous POGIL activity in the class prior to the study, so were familiar with the process, which might explain the initially higher level of observed interactions between group members for the POGIL activities. Students were unfamiliar with the PhET platform prior to these activities and the PhET activity may have required less student-to-student discourse, but their discourse did increase with the two activities. Thus, the use of both activities gave them informal practice with SEPs. In addition, many students reported a preference for working in teams to accomplish goals. In the comments, students stated:

- I enjoyed the group project aspect as I learn better by asking questions of my peers and by comparing information.
- I liked it (cooperative group work) because I learned by finding stuff out with classmates.
- I like how we work in groups to complete the activities, and I think that they're challenging in a good way.

Not only were students engaged in scientific practices, but cooperative learning has also been shown to be effective in helping students learn (Cooper, 1995) and communication with others is an important part of learning according to the constructivist theory of learning (Bodner, 1986).

## Implications

Students in this study learned about basic atomic structure, used multiple representations of atoms to help them understand the content, and engaged in explanations and argumentations with their classmates when POGIL and guided-inquiry PhET simulation activities were used together. It is likely that the guided-inquiry design of these materials, along with the cooperative nature of the POGIL activity and the visual, interactive nature of the PhET simulation activities, supported students' learning. The alternating nature of the activities in this unit may be an effective way of obtaining the learning outcomes shown in prior research (e.g. Chamberlain et al., 2014; Spencer, 2006) of POGIL and PhET together and should be explored by other educators in their classrooms. Along with support from learning theory (e.g. Bodner, 1986) and the quantitative findings, the students' comments from the surveys also imply the cooperative nature (group aspects) of the activities were important parts of the successful learning for students and should be maintained by teachers if they implement these activities in their classes.

## Conclusion

This was a small initial study. More research is needed to support the findings that the activities support student learning on other topics, not just atomic structure. In addition, research into how the combination of POGIL and PhET might alter student understanding through a deeper look at student reasoning, needs to be examined. Finally, in light of NGSS, a closer look at the quality of students' arguments and scientific explanations, the SEPs they used in these activities, is needed to see how they can be leveraged to continue to improve students' skills in these areas. Nevertheless, this study provides evidence to encourage high school teachers to incorporate POGIL and PhET guided-inquiry activities in their classrooms regardless of student preference.

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### Appendix A: Survey Questions Following Each Activity

1. This worksheet helped me to better understand the role of a **proton** in atomic structure.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
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Why do you feel this way?

2. This worksheet helped me to better understand the role of a **neutron** in atomic structure.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
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Why do you feel this way?

3. This worksheet helped me to better understand the role of an **electron** in atomic structure.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
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Why do you feel this way?

4. This worksheet helped me to better understand what makes up the mass of an atom.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
-------------------	----------	-------------------	----------------	-------	----------------

Why do you feel this way?

5. This worksheet helped me to better understand what an isotope is.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
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Why do you feel this way?

6. This worksheet helped me to better understand how to write an isotopic symbol.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
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Why do you feel this way?

7. How did you use the different pictures, diagrams, symbols, and tables to aid your understanding of the concepts covered in this activity?
8. What are your thoughts and feelings about this activity? Likes? Dislikes?

**Appendix B: Final Survey Questions**

1. I feel confident that I understand the role of a proton in atomic structure.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
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Why do you feel this way?

2. I feel confident that I understand the role of a neutron in atomic structure.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
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Why do you feel this way?

3. I feel confident that I understand the role of an electron in atomic structure.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
-------------------	----------	-------------------	----------------	-------	----------------

Why do you feel this way?

4. I feel confident that I understand what makes up the mass of an atom.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
-------------------	----------	-------------------	----------------	-------	----------------

Why do you feel this way?

5. I feel confident that I understand what an isotope is.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
-------------------	----------	-------------------	----------------	-------	----------------

Why do you feel this way?

6. I feel confident that I understand what an ion is.

Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
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Why do you feel this way?

7. How did you use the different pictures, diagrams, symbols, and tables to aid your understanding of the concepts covered in this activity?

8. Were there any particular pictures, diagrams, symbols, and/or tables that you felt helped your learning? Which one(s)? Why do you think they were helpful?

9. Rank how much you liked the four class activities we did.

1=liked the best, 4=liked the least

\_\_\_\_\_ PhET Build an Atom

\_\_\_\_\_ POGIL Isotopes

\_\_\_\_\_ PhET Isotopes and Atomic Mass

\_\_\_\_\_ POGIL Ions

10. How do you feel about these four activities? Likes? Dislikes? Explain your reasons for the ranking you gave in question 9.

11. Do you feel that one particular activity helped you learn more than the others? If yes, name it.

**Appendix C: Atoms Pre and Post Test**

For each question, circle the letter for **True** or **False**. Then explain your reason(s) for your choice.

1	T / F	Protons are found in the nucleus of the atom.
	Reason(s)	

2	T / F	Protons are <b>NOT</b> found in the nucleus of the atom.
	Reason(s)	

3	T / F	Electrons are found in the nucleus of the atom.
	Reason(s)	

4	T / F	Electrons are <b>NOT</b> found in the nucleus of the atom.
	Reason(s)	

5	T / F	Neutrons are found in the nucleus of the atom.
	Reason(s)	

6	T / F	Neutrons are <b>NOT</b> found in the nucleus of the atom.
	Reason(s)	

7	T / F	Protons have a positive charge.
	Reason(s)	

8	T / F	Protons have a negative charge.
	Reason(s)	

9	T / F	Protons are neutral (they have no charge).
	Reason(s)	

10	T / F	Electrons have a positive charge.
	Reason(s)	

11	T / F	Electrons have a negative charge.
	Reason(s)	

12	T / F	Electrons are neutral (they have no charge).
	Reason(s)	

	T / F	Neutrons have a positive charge.
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13	Reason(s)	
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14	T / F	Neutrons have a negative charge.
	Reason(s)	

15	T / F	Neutrons are neutral (they have no charge).
	Reason(s)	

16	T / F	Protons have a mass of 1 amu.
	Reason(s)	

17	T / F	Protons have insignificant mass.
	Reason(s)	

18	T / F	Electrons have a mass of 1 amu.
	Reason(s)	

	T / F	Electrons have insignificant mass.
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19	Reason(s)	
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20	T / F	Neutrons have a mass of 1 amu.
	Reason(s)	

21	T / F	Neutrons have insignificant mass.
	Reason(s)	

22	T / F	You calculate atomic mass by adding the number of protons and the number of electrons.
	Reason(s)	

23	T / F	You calculate atomic mass by adding the number of protons and the number of neutrons.
	Reason(s)	

24	T / F	You calculate atomic mass by adding the number of electrons and the number of neutrons.
	Reason(s)	

25	T / F	Isotopes of an element have a different number of protons.
	Reason(s)	

26	T / F	Isotopes of an element have a different number of electrons.
	Reason(s)	

27	T / F	Isotopes of an element have a different number of neutrons.
	Reason(s)	

28	T / F	An ion has different numbers of protons and electrons.
	Reason(s)	

29	T / F	An ion has different numbers of protons and neutrons.
	Reason(s)	

30	T / F	An ion has different numbers of electrons and neutrons.
	Reason(s)	

