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Employing Context-Based Learning to Bolster Conceptual Understanding of Gas Law Relationships in General Chemistry

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Abstract

The subject of gas laws is regularly taught as part of the general chemistry curriculum in college. In this study, there is an examination of the effectiveness of a 45-minute in-class based intervention using a series of four short vignettes of contexts students are likely to be familiar with to help improve students' conceptual understanding of the relationships between different properties of gases. The study was completed over a 3-year period involving a total of 352 students. In each year, there was one intervention class and one control class in which performance on identical gas law assessment items was compared. In particular, this intervention was designed such that it could fit smoothly into a traditionally lecture based general chemistry course without requiring major shifts in overall course design in order to make it more attractive to faculty who might be resistant to a major overhaul of their general chemistry course. When compared with the control class not containing the intervention, students in the intervention course were found to have performed significantly better on assessment items related to how gases behaved when not supplied with numerical data ($p < .001$).

Keywords

Post-Secondary Education, Science Education, Chemical Education, Gas Laws

1. Introduction

This study explores an intervention using context-based learning to improve student understanding of the conceptual trends of gas law relationships. Gas laws are generally taught towards the end of the first semester of general chemistry when taught as a two-semester sequence at the college level. The course tends to cover both conceptual ideas, such as how heating up a balloon will cause it to expand, as well as numerical relationships, such as using the ideal gas law to numerically calculate how many moles of gas are present at a set temperature, pressure, and volume of a gas. It is a concept that includes both significant conceptual understanding of relationships as well as calculation-based ones. For some students though, it is much easier for them to turn problem solving into an algorithm in which they apply equations and get out answers. Problems related to those same concepts in which they apply equations though can prove quite challenging for students once their algorithmic approach cannot solve the problem with the information, and they have available.

Even after completing a unit on gases in a chemistry course, students often do not have a strong understanding of how gases work that is consistent with correct scientific interpretations (Lin, Cheng, & Lawrenz, 2000; Chen, Wilson, & Lin, 2019). Students often have difficulty with using consistent interpretations and may apply different models in different situations without a scientifically sound reason for changing the model they are using. For example, students may attempt to utilize an equation they learned such as $PV = nRT$ or $P_1V_1 = P_2V_2$ but incorrectly apply them by not being able to correctly identify what parts of the system they are examining are constant or represented by particular variables therefore incorrectly modeling the behavior of the system they are attempting to explain. Students can also often complete calculations that provide correct values for arithmetic relationships between different properties of a gas but cannot provide a correct explanation for what causes those changes. Challenges in learning gas laws highlight a common challenge when teaching general chemistry of difficulty in integrating models at the macro and submicro levels together into a single coherent understanding (Saritas, Ozcan, & Aduriz-Bravo, 2021).

One reason for this choice of topic is that textbook materials do focus on teaching the conceptual part of gas laws whereas some concepts are almost entirely computational in their focus in general chemistry. However, when looking at assessment items from previous years, it was clear that a fair number of students were still not having much success with doing the more conceptually focused questions on exams even when they were doing quite well on quantitative focused questions such as ones requiring them to solve problems using the ideal gas law. The textbook materials with which they engage tend to focus primarily on algorithmic questions that rely on mathematical manipulation as the way of demonstrating understanding in chemistry (Davila & Talanquer, 2010; Niaz, 2005) meaning students do not have as much focus on conceptual understandings when compared to numeric manipulation when engaging with their material outside of the classroom. This relationship has been explicitly studied in examining what types of questions students are given when taught about gas laws and it has been identified that textbooks regularly contain over twice as many quantitative focused questions as compared to qualitative questions (Gillette & Sanger, 2014). In other studies of students' understanding of gas laws in chemistry classrooms, it has been found that students have the most difficulty with concept application style questions and are much more likely to have trouble with them compared to algebraic manipulation questions (Robins, Villagomez, Dockter, Christopher, Ortiz, Passmore, & Smith, 2009).

In the intervention, the faculty member provided time for students to work together including having them discuss with their neighbor about their answer. Having explicit prompts to encourage students to use metacognitive skills are critical to get students to think about why they are coming up with the answers that they are and how they are engaging with the material (Overman, Vermunt, Meijer, Bulte, & Brekelmans, 2013). When answering student questions or engaging with them about the intervention, examples were used that focused on objects or phenomenon that students have engaged with in everyday life to focus on contexts with which the students would be familiar.

Finally, another consideration in the design was in creating something that could be easily adopted by faculty members with minimal friction in implementing into their current classroom design. While there are multitudes of innovative teaching strategies, these can be difficult to get faculty to implement consistently for a variety of reasons (Brownell & Tanner, 2012). In particular, aligning with existing resources and expanding on current practices have been cited as positive drivers for faculty adoption of reforms (Shadle, Marker, & Earl, 2017). In addition, from previous experience with interventions with our student body, students in introductory chemistry courses have been resistant to significant change away from the lecture model and have reported dissatisfaction with large scale changes such as flipped classroom models. This intervention is designed to be able to be included into a lecture classroom model to increase student engagement within a lecture-based teaching style. Increasing the amount of reform-based teaching styles that are used in the classroom has been shown to improve student understanding of gas laws (Roehrig & Garrow, 2007) and as such finding ways to encourage faculty adjustments in this area is critical to improving student understanding.

2. Context-Based Learning

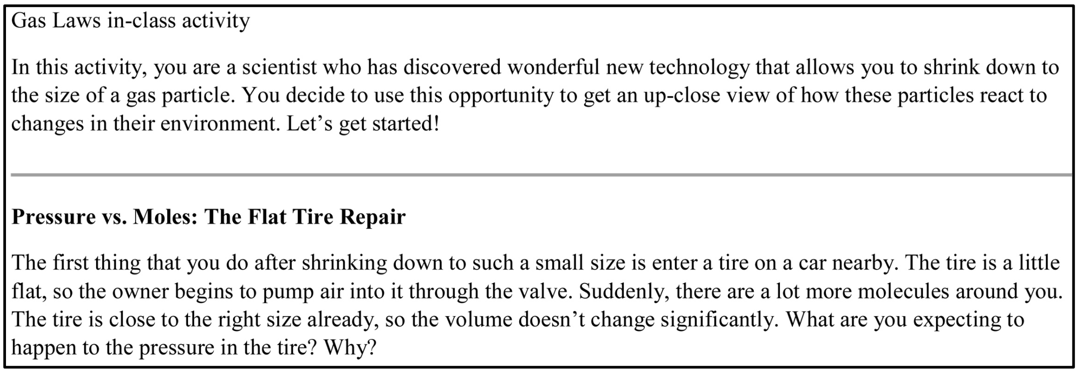
Context based learning uses examples in teaching that are relatable to students to help them improve their understanding of materials with which they are engaged. There is support for the idea that context-based learning is an effective pedagogical method (Khumas, 2022; Sevian, Hugi-Cleary, Ngai, Wanjiku, & Baldoria, 2018; Sevian, Dori, & Pachmann, 2018) and has been used to explore different concepts in chemistry effectively (Bromen, Bernholdt, & Christtensson, 2022; Giammatteo & Valdivia, 2021). Context based learning has been shown to be effective in secondary school chemistry for improving student science process skills (Ngozi, 2021) as well as generally improving student achievement (Avargil & Piorko, 2022). It has also been noted that when using CBT to improve student chemistry knowledge it is critical for student motivation that assessment items appropriately align with context based learning strategies (Sadi-Yilmax, Yildirim, & Ilhan, 2022).

This study serves to explore a specific example in the field of chemistry. It is reasonable to assume that not all methods will be equally effective in all contexts, so exploring specific examples is critical to determine the usefulness of these frameworks in particular cases. Specific examples also serve as evidence to teachers and professors of the effectiveness of these methods within their own disciplines and provide examples they can use as starting points for using these methods in their own classrooms. It has also been demonstrated in college chemistry classrooms that different forms of context-based learning have had different impacts on the areas in which students demonstrate improvement for a topic (Sevian, Hugi-Cleary, Ngai, Wanjiku, & Baldoria, 2018).

3. Methodology

The study took place at a comprehensive university in the southeastern United States. The study included a total of 352 students who were taking a first semester general chemistry course. The students were part of six total classes offered across three different fall semesters. 174 of the students who participated in the study were part of the control classes which received lectures and homework about gas laws that matched with standard practice for the department for teaching introductory lecture classes. 178 of the students participated in an intervention class which included an in-class intervention described in this study as well lecture material and homework problems on gas laws similar to the control classes although with less time on lecture to make time for the intervention. Approximately 45 minutes of class time were scheduled for the intervention in which students were encouraged to work in small groups to complete the assignment together. The professor was also available to answer questions and would go between groups and check on their progress and offer just in time assistance when appropriate. Any work not completed in class could be finished at home and students submitted a copy of their work to an online submission portal.

A student who previously had taken the course and tutored students in the subject did the initial design on the scenarios for the intervention for this course. By being someone who had recently taken the course, the student had relevant insights into what the students were going through and could choose examples that were likely to be topical for other students. After the initial design, the intervention scenarios were iterated on multiple times to improve readability and clarity based on feedback from both chemistry faculty that taught the course as well as student feedback on the initial draft. An example scenario can be seen in **Figure 1**. The goal of the scenarios was to create relatable events for students to help them connect the concepts they were learning to concepts the students have built up on their own about their understanding of how the world functions. In the end four scenarios were developed in which students answered free response



Gas Laws in-class activity

In this activity, you are a scientist who has discovered wonderful new technology that allows you to shrink down to the size of a gas particle. You decide to use this opportunity to get an up-close view of how these particles react to changes in their environment. Let's get started!

Pressure vs. Moles: The Flat Tire Repair

The first thing that you do after shrinking down to such a small size is enter a tire on a car nearby. The tire is a little flat, so the owner begins to pump air into it through the valve. Suddenly, there are a lot more molecules around you. The tire is close to the right size already, so the volume doesn't change significantly. What are you expecting to happen to the pressure in the tire? Why?

Figure 1. Example scenario that students engaged with in the in-class intervention. Students were provided 45 minutes to answer questions about four scenarios involving changes in gases. They were allowed to and encouraged to work with their neighbors. In addition, the instructor was also available to answer questions and to help get groups going if they were stuck. After completing their answers, they were able to look at scientifically accurate responses and compare them to their own responses.

style questions about trends involving: blowing up a flat tire, balloons at a birthday party, hiking up a mountain, and a can of hairspray heating up.

To assess the effectiveness of these scenarios, students were given three multiple choice questions (Figure 2) on their exam which included gas laws that were conceptually focused questions. These exam questions were given to both a class that was being taught using the intervention and a course using a standard lecture style that did not include the intervention. Both courses used a similar amount of time to cover the material so that the comparison was on the effectiveness of replacing some lecture time with the intervention. The intervention class still had lecture material about gas laws as well but had less in class time devoted to lecture. The questions were designed to be similar to questions that would normally be given by the faculty teaching the class about gas law conceptual relationships in order to make for a fair comparison between the intervention and control course.

The multiple-choice assessment items were designed to ask questions that were directed towards explanations of why phenomenon occur, but simultaneously be easy to implement which was an important consideration for both the long-term viability of the assessment tool and to improve the chance of widespread adoption by all faculty in the program. The students were also generally assessed using multiple choice items, so it was appropriate to maintain a similar form of assessment to evaluate the effectiveness of the intervention instead of student comfort level with a different type of assessment. The choice of three exam items was made so that they did not make up a disproportionate portion of the exam compared to the amount of time spent in class on the topic.

In addition to evaluating the assessment items, the researcher talked to students to get feedback about the assessment. These discussions were informal such as talking to the students before/after class. The goal of these discussions was to get as authentic of a response as possible based on continued rapport building with students throughout the semester before the gas law's unit (which

1. A balloon contains an ideal gas. The balloon is placed in a heated sauna. The air pressure in the sauna is no different from the initial air pressure of the balloon. Does the balloon expand or shrink? Why?

(a) The balloon will expand, because volume and temperature are directly proportional.
(b) The balloon will expand, because volume and temperature are inversely proportional.
(c) The balloon will shrink, because volume and temperature are inversely proportional.
(d) The balloon will shrink, because volume and temperature are directly proportional.

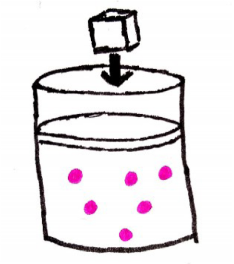
2. A grocery store clerk uses a helium tank to fill up 15 balloons. After the balloons have been filled with helium, how does the pressure change in the tank?

(a) The pressure inside the tank increases, because there are more moles of helium in the tank after the balloons are filled.

(b) The pressure inside the tank increases, because there are less moles of helium in the tank after the balloons are filled.

(c) The pressure inside the tank decreases, because there are less moles of helium in the tank after the balloons are filled.

(d) The pressure inside the tank decreases, because there are more moles of helium in the tank after the balloons are filled.



3.

The piston above is filled with gas. When the mass in the picture is added to the top of this piston, what happens to the pressure and volume of the molecules inside if the temperature remains constant?

(a) The pressure decreases and the volume decreases.
(b) The pressure decreases and the volume increases
(c) The pressure increases and the volume increases.
(d) The pressure increases and the volume decreases.

Figure 2. These are the assessment items common to exams in the control and intervention course that were compared.

is in the last one-fourth of the semester). Both the treatment and control classes used a workshop model in which, in addition to twice a week lecture, students met once a week in small groups with a student leader to work on problems related to the current class topic. The researcher was able to speak to the student leaders as well to get ideas of how students felt about the intervention and the test on gas laws.

After the exams were completed but before they were graded, copies were made of the page of the assessment that included the questions being evaluated. When evaluating student correctness for the questions, the evaluator was unaware of which papers were from control class and which were from intervention classes. For each student who agreed to participate in the study, each question was evaluated and added to an overall tally of correct or incorrect responses. This was done for three years and all data was compiled and the results between the intervention and control classes were compared.

4. Results and Discussion

Student answers to the assessment items were compared between the control classes (n = 174) and the treatment classes (n = 178) over a three-year period. Each year had one fall control class and one fall treatment class. As can be seen in Table 1 on all assessment items, the treatment class performed better than the control class. A chi-square test of the results shows a statistically significant result ($p < .001$). The results show evidence of a moderate effect size with a Cohen's V = 0.33 and a Cohen's w = 0.47. All data was tracked and statistics calculated by putting equations into Microsoft Excel to do the calculations. When examining each question, all questions show signs of significant improvement. The third question on evaluating a mass being added to a piston was the most missed both before and after the intervention but still showed significant improvement.

Looking at the results of the assessment, there was a clear improvement in student performance when comparing the classes for each assessment item suggesting improvement in the ability for students to correctly identify trends in gas properties without having to have numbers available to plug into equations to do so. The first assessment item showed that more students in the intervention class were able to correctly identify what would happen to the gas molecules in a balloon when it was placed into a hotter environment. The second assessment item showed that more students in the intervention class were able to correctly identify that when gas molecules left a container, in this case due to being used to fill up balloons, that the container would have a decrease in pressure inside due to the reduced number of molecules present. In the third assessment item, students were able to correctly interpret a pictorial representation of a pressure change and describe what would happen to the volume of a container upon a pressure change occurring.

The improvement on the third assessment question is especially interesting. This question presents the students with a scenario of placing a block on top of a piston and asks what would happen to the pressure of the air inside. While this is a common general chemistry question to ask about pressure and volume changes, the intervention brought up the concept of pressure and volume with a different type of scenario involving air pressure on top of a mountain when compared with sea level. This item demonstrates that working through the scenarios helped students solidify their understandings in ways that could translate

Table 1. Results of the intervention over three years.

Question	Table Column Head			
	Control class correct	Control class incorrect	Intervention class correct	Intervention class incorrect
1	115	59	167	11
2	143	30	166	12
3	113	60	157	21

to situations that looked different than the ones they had already seen instead.

In addition to looking at the results of the assessment, the researcher spoke with students about their experiences. One comment they came up from multiple students in feedback about the interventions was that the scenarios felt like they were "about the real world". This suggests the intervention scenarios were successful for our students with helping them build connections to their own life worlds where they perceived other in class explanations they had received as part of the chemistry world which they differentiated from their own experiences. The students also had a generally positive response to the design of the in-class work where they could check their answers as they went and discuss with other students if they were not understanding something.

The study's hypothesis that an in-class intervention using a context-based learning strategy to improve student conceptual understanding is supported by the results shown here. The statistics show a significant result with a moderate effect size. Observations made by the researchers based on student feedback also align with this conclusion. Each question showed significant improvement suggesting the method was effective for all questions that were assessed.

5. Conclusion

In this instance, there is clear statistical evidence that using an in-class intervention focused on student group work where students explore narrative style questions about gas law interactions led to increases in student performance on questions related to how gases qualitatively change when their environment changes in a controlled way. As the control course spent the same amount of time working on the same material, although entirely in lecture form, this suggests that the intervention was helpful for improving student learning in a class that was designed primarily as a lecture course.

There are multiple possibilities for why the intervention could have been helpful for students. The activities focused on exploring what types of changes were occurring in different gas systems. It is possible that spending time working through these scenarios gave students additional insights into what was occurring when different properties of a gas were changed. It is also possible that the additional practice helped connect student experiences with the everyday world to explanations that are scientifically accurate in a chemistry class therefore improving their ability to correctly interpret the meaning of multiple-choice answer responses. It is possible that additional in class time to interact with other students generated positive experiences for student learning. Additional follow-up work would be helpful to explore which of the possible explanations for student improvement best explain the changes seen during this intervention.

One of the goals of this work was to demonstrate that it is possible to create specific targeted interventions that allow for measurable change without requiring complete class overhauls. In this instance, a 45-minute in class activity was able to improve student responses on assessment items related to conceptual descriptions of gas law relationships where in the past students had done less well. For continuing development of this particular intervention, it would be helpful to consider ways to explore student understandings of the causes of these relationships. As was noted in the background research, students may not apply consistent models and are not necessarily aware of how the particulate nature of gas molecules relates to these different conceptual relationships.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Avargil, S., & Piorko, R. (2022). High School Students' Understanding of Molecular Representations in a Context-Based Multi-Model Chemistry Learning Approach. *International Journal of Science Education, 44,* 1738-1766. https://doi.org/10.1080/09500693.2022.2095679

Bromen, K., Bernholdt, S., & Christtensson, C. (2022). Relevant or Interesting According to Upper Secondary Students? Affective Aspects of Context-Based Chemistry Problems. *Research in Science and Technological Education, 40,* 478-498. https://doi.org/10.1080/02635143.2020.1824177

Brownell, S. E., & Tanner, K. D. (2012). Barriers to Faculty Pedagogical Change: Lack of Training, Time, Incentives, and Tensions with Professional Identity? *CBE Life Sciences Education, 11,* 339-346. https://doi.org/10.1187/cbe.12-09-0163

Chen, Y. C., Wilson, K., & Lin, H. S. (2019). Identifying the Challenging Characteristics of Systems Thinking Encountered by Undergraduate Students in Chemistry Problem-Solving of Gas Laws. *Chemistry Education Research and Practice, 20,* 594-605. https://doi.org/10.1039/C9RP00070D

Davila, K., & Talanquer, V. (2010). Classifying End-of-Chapter Questions and Problems for Selected General Chemistry Textbooks Used in the United States. *Journal of Chemical Education, 87,* 97-101. https://doi.org/10.1021/ed8000232

Giammatteo, M. T. L., & Valdivia, A. E. O. (2021). Introducing Chemistry of Cleaning through Context-Based Learning in a High-School Chemistry Course. *American Journal of Educational Research, 9,* 335-340. https://doi.org/10.12691/education-9-6-2

Gillette, G., & Sanger, M. J. (2014). Analysing the Distribution of Questions in the Gas Law Chapters of Secondary and Introductory College Chemistry Textbooks from the United States. *Chemistry Education Research and Practice, 15,* 787-799. https://doi.org/10.1039/C4RP00115J

Khumas, A. (2002). Measurement-Evaluation Applications of Context-Based Activities in Hybrid Learning Environments. *International Journal of Assessment Tools in Education, 9,* 197-217. https://doi.org/10.21449/ijate.1111886

Lin, H. S., Cheng, H. J., & Lawrenz, F. (2000). The Assessment of Students and Teachers' Understanding of Gas Laws. *Journal of Chemical Education, 77,* 235-238. https://doi.org/10.1021/ed077p235

Ngozi, O. (2021). Enhancing Science Process Skills Acquisition in Chemistry among Secondary School Students through Context-Based Learning. *Science Education International, 32,* 323-330. https://doi.org/10.33828/sei.v32.i4.7

Niaz, M. (2005). Do General Chemistry Textbooks Facilitate Conceptual Understanding?

Quimica Nova, 28, 335-336. https://doi.org/10.1590/S0100-40422005000200027

Overman, S., Vermunt, J., Meijer, P. C., Bulte, A. M. W., & Berkelmans, M. (2013). Textbook Questions in Context-Based and Traditional Chemistry Curricula Analysed from a Content Perspective and a Learning Activities Perspective. *International Journal of Science Education, 35,* 2954-2978. https://doi.org/10.1080/09500693.2012.680253

Robins, L. I., Villagomez, G., Dockter, D., Christopher, E., Ortiz, C., Passmore, C., & Smith, M. H. (2009). Challenging Our Assumptions: An Investigation into Student Understanding of the Gas Laws. *Science Teacher, 76,* 35-40.

Roehrig, G., & Garrow, S. (2007). The Impact of Teacher Classroom Practices on Student Achievement during the Implementation of a Reform-Based Chemistry Curriculum. *International Journal of Science Education, 29,* 1789-1811. https://doi.org/10.1080/09500690601091865

Sadi-Yilmax, S., Yildirim, A., & Ilhan, N. (2022). Effects of the Context-Based Learning Approach on the Teaching of Chemical Changes Unit. *Journal of Turkish Science Education, 19,* 218-236. https://doi.org/10.36681/tused.2022.119

Saritas, D., Ozcan, H., & Aduriz-Bravo, A. (2021). Observation and Inference in Chemistry Teaching: A Model-Based Approach to the Integration of the Macro and Submicro Levels. *Science & Education, 30,* 1289-1314. https://doi.org/10.1007/s11191-021-00216-z

Sevian, H., Dori, Y. J., & Parchmann, I. (2018). How Does STEM Context-Based Learning Work: What We Know and What We Still Do Not Know. *International Journal of Science Education, 40,* 1095-1107. https://doi.org/10.1080/09500693.2018.1470346

Sevian, H., Hugi-Cleary, D., Ngai, C., Wanjiku, F., & Baldoria, J. M. (2018). Comparison of Learning in Two Context-Based University Chemistry Classes. *International Journal of Science Education, 40,* 1239-1262. https://doi.org/10.1080/09500693.2018.1470353

Shadle, S. E., Marker, A., & Earl, B. (2017). Faculty Drivers and Barriers: Laying the Groundwork for Undergraduate STEM Education Reform in Academic Departments. *International Journal of STEM Education, 4,* Article No. 8. https://doi.org/10.1186/s40594-017-0062-7