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Activity

# Development and Implementation of an Online Narrative Game to Aid Studying and Review in an Online General Chemistry Course

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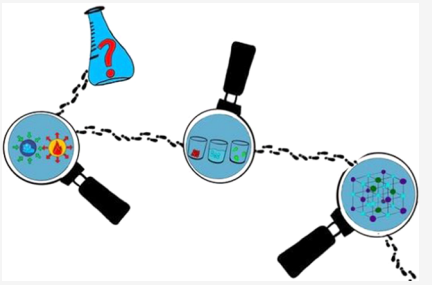
**ABSTRACT:** Success in general chemistry requires active engagement with course material. COVID-19 accelerated the move to online courses, creating a crucial need for engaging course activities. The Mysterious Compound chemistry game was designed to engage undergraduate students in introductory chemistry concepts while allowing the instructor and students to assess students' confidence in course concepts. When comparing pre- and postsurveys, there were significant differences ($p < 0.001$) in students' confidence levels on all the topics included. Positive and negative feedback was elicited and analyzed through student surveys. This game is an easy-to-implement engagement tool due to its versatile online format and adaptable design.



**KEYWORDS:** *High School/Introductory Chemistry, First-Year Undergraduate/General, Organic Chemistry, Humor/Puzzles/Games, Hands-On Learning/Manipulatives, Enrichment/Review Materials*

## INTRODUCTION

Active learning has remained one of the foundational tools to increase student engagement and achievement.[1−4] Traditionally, active learning activities have been completed during in-person instruction. Online learning presents additional challenges to actively engaging students,[5,6] a phenomena which was exacerbated during the COVID-19 pandemic.[7−18] Topic specific mastery is necessary for student success in general chemistry courses, and therefore, our courses must engage students with the course material regardless of the modality.

Teaching math and science with games to increase learning and engagement is a long-tested methodology used to achieve a variety of goals.[19−28] Games have been shown to improve learning outcomes.[29−34] They vary from time-efficient board and card games,[35−37] to those with more significant game preparation needed.[38] Technology often plays a critical role in the development and play of educational games.[18,39−42] Though often the game mechanism and its chemical topic are unrelated, it is worth noting the wide variety of chemical topics already covered by games published in the literature. These include, building reactions,[43] equilibrium,[44] reaction rate theory,[45] drawing Lewis structures,[46] organic synthesis,[47] and organometallic reactions.[48]

While several online games have been implemented,[24,49] these often require experience in app development or other technical expertise.[23,24,30,49] Our activity adds to this body of literature through the development of an online game, played solo, which does not require any coding experience to develop. It uses the mechanics in a well-known survey tool, Qaultrics, to deliver an adaptive game experience. The Mysterious Compound online game turns students into detectives who solve chemistry problems to obtain clues and solve a murder case.

The game was implemented in a large online general chemistry course. This implementation focused on all topics covered throughout the 10-week-long quarter. The structure could be adapted to any topic. Because the desired outcome was student engagement, our interests were focused on student perceptions and experiences with the game. Our interests related to the following questions:

1. How does playing the game impact student confidence in their knowledge of the material?
2. What are the students' positive perceptions of the game?
3. What are the students' negative perceptions of the game?

The learning outcomes were related to all of the course topics. These topics included the following: thermodynamics, gas laws, intermolecular forces, crystalline solids, entropy, enthalpy, and properties of solutions. The learning outcomes for each question are included in the Supporting Information.

## GAME DESIGN AND STRUCTURE

### Story Design and Rationale

A mystery genre was chosen to capture student interest and promote engagement. Students were provided a background

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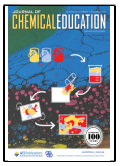

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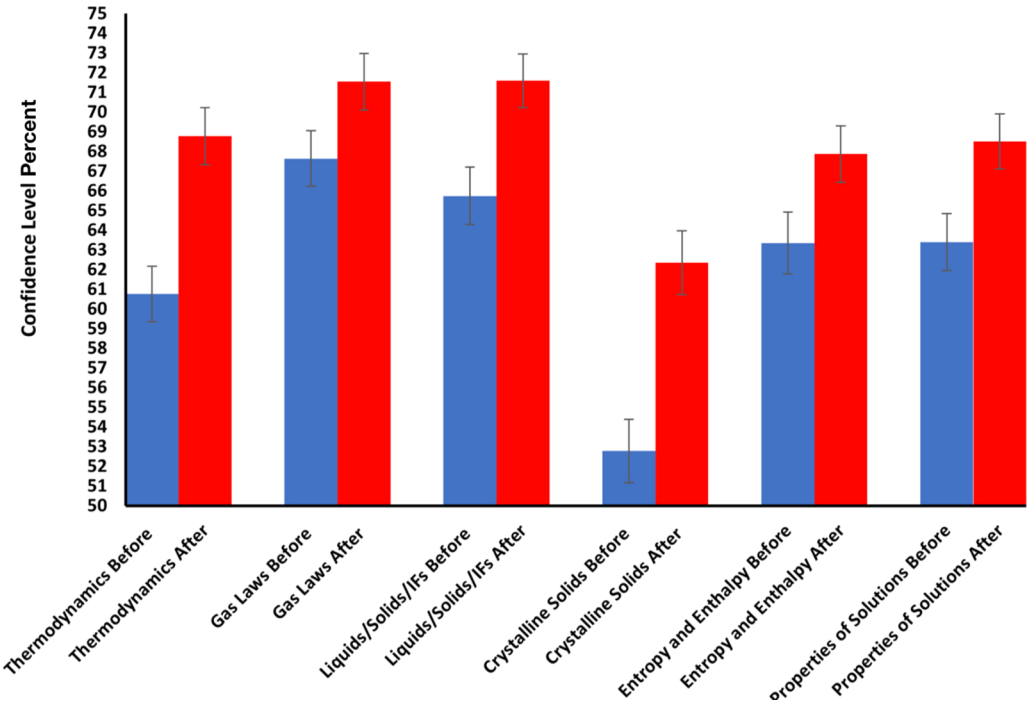


**Figure 1.** Confidence ranking during pre- and postsurvey for individual topics ($n$ = 209). Error bars are based on the standard error.

story that introduced the characters and the setting. The plot takes place in a laboratory where four scientists have discovered a mysterious compound that could potentially allow humans to become immortal. After the death of the lead scientist and the disappearance of the only sample of the compound, a detective was brought in to determine the culprit and find the compound. Students are then challenged to become detectives. They receive clues after each correct answer. They applied their subject matter knowledge and critical thinking skills to obtain the next clue and solve the mystery. At the end of the game, they were asked to guess the culprit, and then, the true answer to the mystery was revealed.

## Qualtrics Platform Use

Qualtrics provides a platform for developing narrative games. Alternative paths can be taken based on student responses. There are no programming language requirements, which makes it accessible for instructors to implement using course-specific questions. Many universities have institutional agreements with Qualtrics making it available at no cost for both students and instructors. The Qualtrics support Web site has many video tutorials and help pages that detail any aspect of survey-making.

Chemistry questions were tied to pieces of the story, creating a low-stakes environment. If students choose the correct answer, Qualtrics directs them to an explanation of why it was the correct answer and then to the next clue. If students chose the wrong answer, they would be given feedback about why that question was incorrect and then directed to another question of the same material. Students see up to three questions on a single topic. If they incorrectly answered all three of these questions, they would then be directed to the explanation of the correct answer and allowed to move on.

The Qualtrics Survey can be accessed at https://uci.co1.qualtrics.com/jfe/form/SV_afVCz7HRHyQdSn4. If, in the future, this link becomes inactive due to changes in licensing, please contact the corresponding author for access.

Qualtrics provides ten different question types which allow for extreme flexibility. This same structure could be applied to another topic, utilizing multiple choice, text entry, text/graphic, matrix table, slider, form rank order, or side-by-side questioning. Because this is a study tool rather than an assessment tool, it is not a problem that drawing is not possible. Courses involving drawing can still benefit from the survey tool, as students can be asked to rank the structures, choose the best structure, or answer multiple-choice questions about a given structure.

## Question Content

The game plot and Qualtrics are content-agnostic, and the game can be adapted to cover any topic for which Qualtrics question types are appropriate. In this implementation, it was used as a final exam review activity, sampling the entirety of the second quarter of general chemistry. These topics included: thermodynamics, gas laws, intermolecular forces, crystalline solids, entropy, enthalpy, and properties of solutions. A full list of questions and associated learning outcomes can be found in the Supporting Information. Question formats used in our activity included multiple choice, drop-down select, form field, and free response. Additional question types that would extend the utility of the Qualtrics platform to a greater range of topics are text/graphic, matrix table, slider, and rank order.

## Survey Content

A pre- and postgame survey was administered. In both, students were surveyed about their current confidence level on each topic, with zero representing the lowest possible confidence and one hundred representing the highest possible confidence. The topics included the following: thermodynamics, gas laws, intermolecular forces, crystalline solids, entropy, enthalpy, and properties of solutions. Students were also asked if they would like to see a similar activity in their future classes.



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## EVALUATION

### Student Selection

All students enrolled in one section of a second-quarter general chemistry course were eligible to participate in the activity and study (Self-exempt IRB #1247). Though students could opt out of the study, none chose to. They received one percent extra credit on their final exam if they played the game. A Qualtrics link was posted on the Canvas Learning Management System and e-mailed to the students. Students were sent two email reminders to complete the game before the final exam to receive their points, and 71.3% of enrolled students completed the game, and all agreed to be in the study.

### Analysis of Student Self-Reported Confidence Levels and Time Spent

According to self-reported data, students took on average 26.6 min (SD 16.6), with a median time of 20 min to complete the activity.

A 2-tailed paired T-Test using the pre/post surveys compared the confidence levels on the aforementioned chemistry topics before and after playing the game. Students were asked to rank their confidence on a 0−100 point scale. Confidence levels for all topics improved.(Figure 1). Below we list each question with its corresponding pre/post averages. A full table with all rankings and the standard error can be found in the Supporting Information.

1. "How confident are you in thermodynamics?". Student confidence rating changed significantly from 60.8% to 68.8% ($p < 0.001$).
2. "How confident are you in gas laws?". Student confidence rating changed significantly from 67.6% to 71.5% ($p < 0.001$).
3. "How confident are you in liquids, solids, and intermolecular forces?". Student confidence rating changed significantly from 65.7% to 71.5% ($p < 0.001$).
4. "How confident are you in crystalline solids?". Student confidence rating changed significantly from 52.7% to 62.4% ($p < 0.001$).
5. "How confident are you in entropy and enthalpy?". Student confidence ratings changed significantly from 63.3% to 67.9%($p < 0.001$).
6. "How confident are you in the properties of solutions?". Student confidence ratings changed significantly from 63.4% to 68.5% ($p < 0.001$).

Though self-reported confidence is not a direct measure of performance outcomes, it is promising that the activity had such a large positive effect on the students' perceptions. Many studies have shown positive relationships between student confidence and learning outcomes.[50−53] However, a more in-depth study designed to control for confounding variables would be required to directly show learning outcome level improvement.

### Student Perceptions and Feedback

Qualitative data analysis may be used to probe the underlying experiences of different students. It allows a deeper understanding of the students' activity experience. After the game was completed, students were surveyed on their experience. They were asked two questions in addition to the confidence ratings:

1. What did you enjoy about this activity?
2. What can be changed to improve this activity?

Of 209 students who completed the survey, 29 left the first question blank (13.8%) and were not considered in the perception analysis. For question two, only one response was excluded due to nonresponse. The remaining data set was inductively coded to determine the trends in student perceptions.

Both researchers completed inductive content analysis[54] and coded all responses independently. When assigned codes for the same text were not in agreement between researchers, those responses were recoded. The initial coding was hidden from the researchers during the recoding. Responses that were still not coded consistently were discussed until an agreement on the coding was reached.

Question one successfully elicited positive perceptions students had about the activity; 98.5% ($n$ = 208) commented on positive student views. Question two successfully elicited negative feedback from students; 74.1% ($n$ = 208) responses commented on things that students saw in need of improvement. In the remaining questions, two responses shared positive feedback or commented that nothing needed improvement. Responses were not coded if they did not give specific reasons why students liked or disliked the activity. Frequently, comments had more than one category of feedback; therefore, the total number of codes significantly outnumbers the total number of surveys.

Most students (56.25%) gave only one positive and one negative response per comment. Though 16.35% stated two positive aspects and only one negative aspect of the activity. Another 16.35% stated only one positive feedback without any negative feedback. For the entire distribution, see Figure 2.

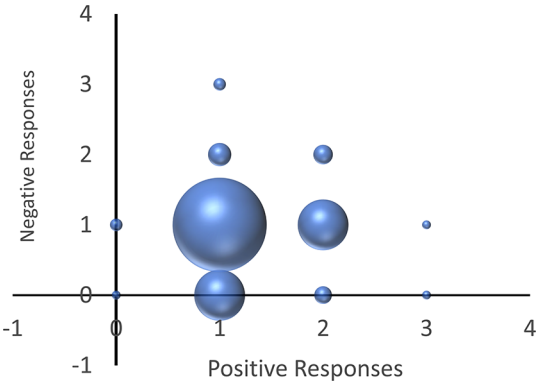


**Figure 2.** Bubble chart illustrating the distribution of positive and negative comments from students.

The last perception question asked students, "Would you like to see a similar activity in your future chemistry courses. 98.5% of students ($n$ = 208) responded positively (either "yes" or "yes but only for optional studying"), with only three responses saying no.

### Positive Perceptions

Most positive descriptors were found in response to question one, although some were also present in question two. All positive responses were inductively coded into the following categories:

1. Students stated the activity helped with studying or provided good explanations.
2. Students stated the activity was engaging, interesting, or entertaining.


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3. Students stated they liked the creative story, clues, or other specific comments about the storyline.
4. Students stated they liked the activity for another specific reason not in the previous groups.

The detailed results are shown in Table 1. For each percentage shown, the total is the total number of positive pieces of feedback given ($n$ = 261). Because many responses commented on more than one positive aspect of the activity, the total number of codes ($n$ = 261) is larger than that of the survey respondents ($n$ = 209).

**Table 1. Positive Student Perceptions**

| Category | Description | Responses $n$ | Percent of Total Response |
|---|---|---|---|
| 1 | Helped with studying/Good Explanation | 113 | 43.3% |
| 2 | Engaging/Entertaining | 41 | 15.7% |
| 3 | Creative story/clues or relating to storyline | 93 | 35.6% |
| 4 | Liked for other reasons | 14 | 5.4% |

### Negative Perceptions

All answers that described negative student perceptions were inductively coded into the following categories:

1. Desired more numerous or more variety in the types of problems or explanations
2. Desired more numerous or more variety in the images
3. Desired more numerous or more variety in the types of clues
4. Felt there were difficulties in the navigation or pointed out technology errors
5. Desired the ability to go back and redo previous problems or review problems they'd already done

The detailed results are listed in Table 2. For each percentage shown, the denominator is the total number of negative responses ($n$ = 175). Due to many students leaving this question blank or instead using it to make positive comments, this is lower than the total number of survey responses ($n$ = 209). We can see from the results that students found room for improvement in the number of questions and technical issues. The technology issues generally pointed to small technical details easily fixed in later iterations. The desire for more questions and a greater variety of topics is promising for the gameplay's ability to engage students. Future course offerings could include several games interspersed throughout the quarter to allow for more questions without overwhelming the students.

**Table 2. Negative Student Perceptions**

| Category | Description | Responses $n$ | Percent of Total Response |
|---|---|---|---|
| 1 | Quality/variety of problems/ explanations | 70 | 40% |
| 2 | Quality/variety of images | 25 | 14.3% |
| 3 | Quality/variety of clues | 13 | 7.4% |
| 4 | Tech./navigation issues | 54 | 30.9% |
| 5 | Redo/review prev. problems | 13 | 7.4% |

The technical and navigation issues primarily consisted of two categories of concern. The first was that clues were not automatically recorded, and students could not go back and view these. This is a limitation of the Qualtrics Survey. When using the required flow elements, it does not allow for a back button. In future implementations, a note was added to each clue which stated, "Please note that you will not be able to go back to view this. Please copy it into a notebook to refer to later". The second category of navigation complaint was that they wanted a progress tracker at the bottom. This was a simple addition and was added for future implementations.

### Student Perception Discussion

The positive and negative perceptions from the students give possible hypotheses for increased confidence. Given the 43.3% of students who commented on positive category 1, this could be related to the time on task with targeted explanations. Additional studies with control activities could be implemented to determine whether the same confidence increase was seen with similar activities that had not been gamified. The 51.3% of students who commented in positive category 2 or 3 would point more specifically to it being the gamified aspect of the activity that provided positive perceptions, which may have translated to confidence building as both games and low-stakes activities can provide a reduced anxiety atmosphere that fosters learning.

## LIMITATIONS

This activity gives students an engaging activity to study for their final exam. The instructor wanted all of the students to have the opportunity to complete the activity. Therefore, no control group was able to compare learning outcomes. Comparing the final exam outcomes of those who completed the game with those who did not would have significant selection effects. In addition, comparing this section to another section of the course would have introduced the confounding variable of a different course instructor.

Future research directions would include giving several opportunities for this style of the game throughout the quarter, alternating which group received a game-based activity and a nongame activity, and comparing learning outcomes at the individual course topic level based on the type of assignment. However, despite this limitation, the activity structure provides a roadmap for instructors interested in using narrative storytelling to engage their students during homework and review activities.

## CONCLUSIONS

The Mysterious Compound online game was positively received by students who found it engaging, helpful with studying, and creative. This is a study guide tool to strengthen students' confidence levels rather than a stand-alone introduction. It positively impacted their confidence ratings in all course topics. The most common criticism was that the activity should have a greater variety of questions. On average, the activity took 26.6 min for the students to complete. Future directions would include creating more of these games to give students a greater variety of questions without affecting individual gameplay.

This no/low-cost tool, which requires no programming language experience, could be adapted to any course topic and narrative plot or setting.



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## ■ ASSOCIATED CONTENT

### Supporting Information

TThe Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c00266.

A Mysterious Compound: Qualtrics Game Questions and Learning Objectives (ZIP)

Supplemental Table 1: Confidence Levels with Standard Error Values (PDF)

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### Notes

The authors declare no competing financial interest.

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