Gamification in the Undergraduate Chemistry Course: A Systematic Review

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Abstract: This systematic review explores the diverse interpretations of "gamification" in education, focusing on its application in undergraduate major's level general chemistry courses when delivered digitally. Despite a limited pool of relevant literature after applying inclusion criteria, the study summarizes the available articles and records the frequency of gamification elements used in these contexts. The most frequently used elements were sensation (visual and auditory stimulation), competition, points, and puzzles. This review highlights the need for further research in chemical education and gamification.

Introduction

Gamification has been a buzzword in educational circles recently, but the word gamification has many different meanings. This review looks at the different elements of gamification and their usage frequency in undergraduate majors-level general chemistry courses. A systematic literature review of the gamification elements and frameworks used in majors-level general chemistry courses is needed to provide a background for future research.

Why Chemistry?

Chemistry has been a historically dreaded subject among undergraduates. Chemistry can be tedious, complex, and math heavy. The challenge in comprehending the threefold aspect of chemistry arises from students' difficulties in harmonizing their understanding across three distinct tiers of chemical knowledge: (1) macroscopic—observable and tangible occurrences like chemical reactions; (2) submicroscopic—invisible entities such as atoms, ions, molecules, or structures; and (3) symbolic—representational symbols, formulas, or equations (Gilbert & Treagust, 2009). Aspiring STEM majors are typically required to take general chemistry. Nearly half of the students majoring in the hard sciences switch fields within two years of matriculation, and non-science majors do not typically change to science (Chang et al. 2008). The graduation discrepancy becomes even more pronounced among underrepresented students, with only 24% of those who started as a science major going on to attain a degree in science within six years of starting, in comparison to 40% of white students. (Center for Institutional Data Exchange and Analysis, 2000) Student performance in introductory science courses influences students' decision to stay in science majors. (Seymour & Hewitt, 1997)

Student Motivation and Student Success Through the Lens of Self Determination Theory

Student motivation plays a role in student success (Orvis et al., 2018). Self-determination theory (SDT) offers insight into human motivation. Motivation to perform well should not be considered a matter of how much but of type. *Extrinsic motivation* is the motivation to perform a task or activity leading to a separable outcome. *Intrinsic motivation* is the motivation to perform a task or activity because it is satisfying or enjoyable. Intrinsic motivation is correlated with reduced dropout rates, diminished withdrawal rates, decreased absenteeism, decreased school-related anxiety levels, and enhanced academic performance (Prospero & Vohra-Gupta, 2007).

The relationship of motivation type to achievement is complex and varies within the literature. There is also an indication that it varies among genders, student populations, and even within groups over a semester (Orvis et al., 2018). It is unclear if one type of motivation points to better student academic outcomes, but both have been linked to academic success (Orvis et al., 2018). Undergraduate chemistry students seem to exhibit extrinsic motivation as the dominant type of academic motivation (Orvis et al., 2018), possibly related to achieving career goals. It is also hypothesized that the distinction between intrinsic and extrinsic motivation is not clear, but it is more of a sliding scale tipping in more in one direction or the other (Ryan & Deci, 2000).

Because student perception of learning in science courses plays a role in student motivation (Nilsson & Stomberg, 2008), we can propose that if gamification can be designed to increase intrinsic motivation among chemistry students, SDT tells us that we can foster authentic learning motivations (Kam & Umar, 2018). Future research on gamification and self-determination theory can help us know which elements can increase intrinsic motivation over extrinsic motivation.

Gamification is applying game elements to activities that would not typically contain them to increase engagement and enjoyment. While gamification has become a very trendy topic over the past decade, there is still no set definition of game elements or a unified gamification strategy. Some have defined gamification as simply the inclusion of a progress stick or in terms of PBL (points, badges, leaderboard), so I was interested in seeing which game elements are typically included in chemistry courses and the frequency of their inclusion. Results that included gamification platforms (game-based learning) used in the college chemistry classroom were also included in the search. Toda et al. (2019) proposed a list of 21 game elements and a gamification framework. This list is comprehensive, so this review examined these gamification elements for frequency.

Background

Kitchenham's systematic review process was followed. (*Procedures for Performing Systematic Reviews*, n.d.). Planning the review, conducting the review, and reporting the review. Literature reviews must be thorough and fair to impart meaningful scientific value to the field. (*Procedures for Performing Systematic Reviews*, n.d.). A predefined review protocol reduces researcher bias and helps ensure thoroughness. This question was created to be answered by the review:

Q1. Which game elements are most frequently used in majors-level undergraduate chemistry courses?

Review Methods

The essential search items identified for the review are gamification, education, elements, general chemistry, and undergraduate. The alternative terms used for gamification: gamif* (any word that begins with "gamif" such as gamification), gameful, game elements, game mechanics, and game components were included. Alternative terms for education used: education* (any word that begins with "education" such as educational), learning, teaching, course, syllabus, syllabi, and curriculum were included in the prompt. The words framework, method, design, model, approach, theory, strategy was used to include papers that included a framework or model of some sort. The phrase "general chemistry" is used to exclude organic and other chemistry disciplines. Papers that include the word "lab" were excluded. The process of designing the search prompt was adapted from Khaldi et al. (2023) and refined to be applicable to our search. If articles included secondary education as well as college, they were included. Articles that did not have full text versions of were excluded. Google Scholar defines the search using the Boolean operators AND, OR, and NOT, so the in-text prompt that was used is:

> *(gamif* OR gameful OR "game elements" OR "game mechanics" OR "game dynamics" OR "game components") AND (education* OR learning OR teaching OR course OR syllabus OR syllabi OR curriculum) AND (framework OR method OR design OR model OR approach OR theory OR strategy) AND ("general chemistry") AND (undergraduate OR college) NOT (lab)*

Only English articles were considered, and review articles were omitted. The search returned 466 articles.

Study selection

Table 1 - *Article Selection Criteria*

Criteria	Inclusion	Exclusion
Context	Digital delivery (regardless of the course type, i.e., in-person, online or hybrid)	In person delivery, classroom games, board games, card games
Educational Level	Higher education	Any other settings (business, medical, elementary)
Participants	Undergraduate stem majors	Graduate students, mixed majors, non-science majors
Course type	For-credit general chemistry courses	Open courses, or courses of other subjects
Setting	Traditional semester	Articles specifically written about strategies during the COVID-19 pandemic

Data extraction

The articles that were produced from the search prompt were manually sorted based on the inclusion/exclusion criteria. Review articles were not included. The search was completed in Google Scholar, and the articles were first screened to remove any duplicates and articles that were not in English. This eliminated 49 articles, leaving 417. Then, the articles were sorted for inclusion by reading the title, abstract and keywords. If it was unclear if they met the inclusion criteria, they were passed to the next stage of sorting. This eliminated 385 articles, leaving 32. The 32 articles were then assessed for inclusion using the full text. This eliminated 27, leaving 5.

Data Synthesis

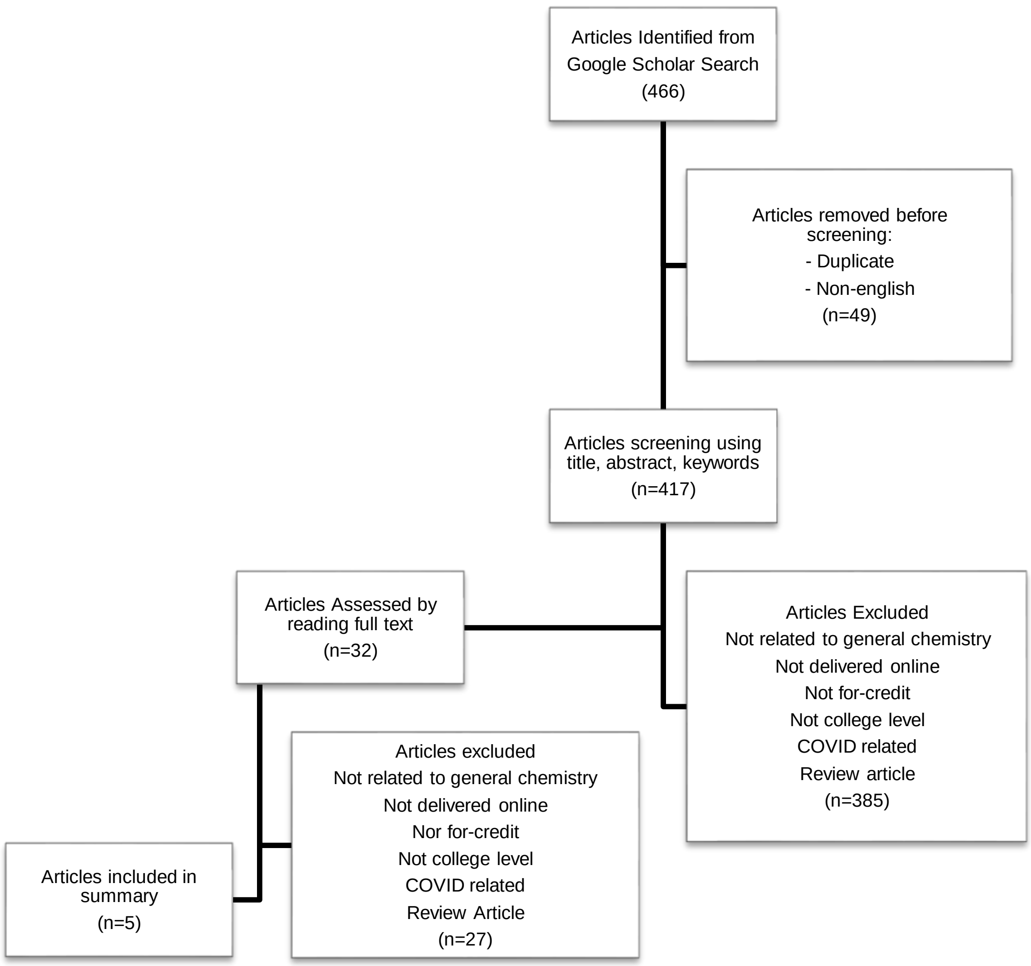

Figure 1 – Flow diagram of inclusion/exclusion process.

Table 2 – Elements of gamification

	Acknowledgment	Chance	Competition	Cooperation	Economy	Imposed Choice	Level	Narrative	Novelty	Objectives	Points	Progression	Puzzles	Rarity	Renovation	Reputation	Sensation	Social Pressure	Stats	Storytelling	Time Pressure
Gupta						**X**	**X**		**X**		**X**	**X**	**X**		**X**		**X**		**X**		
Li		**X**	**X**										**X**				**X**				
Maire			**X**						**X**		**X**				**X**		**X**	**X**			
Yacoub								**X**		**X**			**X**				**X**			**X**	
Youssef			**X**								**X**						**X**				**X**
Total		**1**	**3**			**1**	**1**	**1**	**2**	**1**	**3**	**1**	**3**		**2**		**5**	**1**	**1**	**1**	**1**

Once the articles were sorted, there were only six that met all inclusion criteria. The most used elements of gamification in these articles are sensation (visual or auditory stimulation), competition, points, and puzzles.

Included Papers

In the paper by Gupta (2019) students were presented with a video game (visual stimulation) within their LMS, called Molebots. It is a first-person shooter game that focuses on chemical nomenclature (naming chemical compounds). Students that played the game scored higher on a posttest than students that did not play and had higher final exam scores. The elements of gamification used were visual stimulation (video), imposed choice (choosing to accept or reject molecule pairing), renovation (energy boost), points (scoring), levels (leveling up), progression (energy meter and map), puzzles (correctly pairing molecules), stats (dashboard), and novelty (newly spawned molebots).

Li et al. (2022) describes a scenario where students were given gamified digital worksheets (bingo style) and an atomic orbital visualization tool (Orbital Explorer) to use through their LMS. The students use inquiry-based learning (IBL) to learn atomic orbital theory. The students scored higher on atomic theory test questions than the previous years. The elements of gamification used were chance (random atomic orbitals were presented to identify), competition, puzzles (identifying the correct orbital), visual sensation (video animations).

In the Maire et al. (2018) paper, learners were presented with a blog style mini game ("Clash of Chemists") that allowed them to propose analogies for stoichiometric and non-stoichiometric reaction conditions. Other students reviewed the analogies and argued for or against them (peer-review). Students were then allowed to correct their analogies to earn more points. Each step in the process allowed students to earn or lose points and there was a leaderboard employed that was monitored by a teaching assistant. Any participation in the mini game unlocked a video of the teacher explaining how to solve an exam problem as a participation reward. While 52% of learners enjoyed playing the game, only 49% of participants rated that the game was useful in improving their understanding of the topic. The elements of gamification used were competition (leaderboard), points, renovation (ability to revise the first analogy to earn points back), sensation (visual stimulation through pictures), novelty (the surprise unlock of a solution video), and social pressure ("attack" by other students).

Yacoub et al. (2023) described the use of a a Qualtrics survey is employed for students to answer questions and earn clues to solve a murder mystery. Students found the activity helpful, engaging, and creative. The elements of gamification used were narrative (the story is unlocked based on your choices), objective (mission to solve the mystery), puzzle (the mystery itself), sensation (visual stimulation), and storytelling (the mystery story).

Lastly, in the Youssef (2021) paper, learners used the digital quiz platform Kahoot! every 2-3 class sessions in a synchronous online format. Students responded positively in an anonymous follow up survey. The elements of gamification used in Kahoot! are competition (leaderboard), points, sensation (visual and auditory), and time pressure.

Discussion

Based on this review, the published corpus regarding gamification in the undergraduate general chemistry course is sparse when subjected to this rigorous inclusion criteria. While sensation, competition, points, and puzzles were most used in the undergraduate chemistry courses that were reviewed, the choice to use these gamification elements over storytelling, narrative, time pressure, or other techniques could be a matter of pedagogical strategy and accessibility or ability of the instructor to build. The choice of gamification elements must align with the specific learning goals of the course. In chemistry, there may be an emphasis on problem-solving, critical thinking, and mastery of core principles. Sensation, competition, points, and puzzles are well-suited to reinforce these objectives by directly engaging students with the subject matter. Chemistry is a science that relies heavily on experimentation, problem-solving, and quantitative analysis. Elements like points and puzzles are better aligned with this quantitative and analytical nature, as they can provide clear metrics for student performance. Also, chemistry can involve complex, abstract concepts that might not readily lend themselves to storytelling or narrative approaches. For instance, storytelling may be integrated when discussing the history of chemistry or to provide context for certain concepts. The inclusion criteria resulted in the exclusion of about 95% of the initial search results on Google Scholar, so a broader criteria may be warranted to return more meaningful results.

Conclusion

The choice of gamification elements in an undergraduate chemistry course is not one-size-fits-all and should be tailored to the specific course objectives, content, and the needs and preferences of the students and professors. It is unclear so far if certain elements are more effective for learning or enjoyment for students, but that is where future research can be performed. This review highlights the need for more research in chemical education and gamification. Future research can explore the connections between different gamification elements and the impact that they have on motivation and student success in the General Chemistry classroom. Unlocking the connection between gamification elements and student success in General Chemistry is pivotal for refining targeted and evidence-based educational approaches.

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