Game-Based Learning in Science: Can Video Games Simplify Organic Chemistry?

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Abstract

Organic chemistry has been taught in the same way for decades, and students still have difficulty understanding and comprehending the subject material. Perhaps it is time to change the methods by which this subject is taught. Video games have been successfully used in education to create learning environments that increase student motivation and engagement as well as challenge students and promote collaboration. It is difficult for students to maintain a growth mindset in organic chemistry within the classroom. However across different genres, video games create a unique environment where an individual is encouraged to try again when they fail. This paper examines the potential that video games have in changing the way organic chemistry is taught to undergraduate students in the classroom.

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Few things have been as impactful as the emergence of technology in the world. As technology has become more advanced, so have games. Games have been an integral part of society for centuries as a means to entertain and challenge individuals. Around the 1890s, coin-operated slot machines were used for amusement (Bristow, 1977). Soon after that, jukeboxes were created. Pinball machines took the stage in the 1930s as electromechanical games became more popular. Around the 1960s, video games were created with rudimentary computers, but they were only available to those with access to computer labs through universities. In 1971, a coin-operated arcade game, *Computer Space,* was created, and it holds the title for the first video game available to the public (Slavin, 2014). Gaming systems are comprised of software and hardware, including electronics, control devices, and a computer screen. Video games are a part of a relatively young industry, having been around for only the past 50 years, but they greatly have impacted the world in such a short period of time.

Since the mid-90s, interest in video games has exponentially increased, and video games have permeated a variety of disciplines. In 2020 alone, the global gaming industry generated $179.7 billion, and mobile gaming accounted for $87.7 billion in revenue (Witkowski, 2020). 95% of households with adolescent children own some type of gaming platform, and contrary to popular belief, the average age of gamers is 35 years old (Entertainment Software Association, 2017). Video games have profoundly impacted American culture causing educators to wonder how gameplay might improve education (Squire, 2008). The virtual environments created by video games can engage and motivate students to discover, challenge, and construct their own knowledge in order to facilitate learning (Annetta, 2009). The generations that have grown up with technology embedded into their social lives are characterized by having a natural aptitude

and high skill levels towards learning new technologies and are known as the *net generation* (Jones, et al., 2010). In 2003, gameplay was part of an initiative called *serious games* in order to use video games in education to more deeply impact the net generation (Annetta, 2009). There are many skills that can be taught through effective video games: logic, memory, problem-solving, critical thinking skills, visualization, and discovery. Based on the nature of gameplay, using video games in education is not a matter of feasibility but rather, possibility (Squire, 2005). Video games have been used to help students learn about topics ranging from social skills with *Sims*, to resource gathering and building with *Minecraft*, and arithmetic with simple games on the web. Many games have not necessarily set out to be educational but end up teaching players a variety of concepts anyways. If games were intentionally designed to be informative as well as engaging, the educational landscape would be forever changed for the better.

Because of the potential that video games have in supplementing education, they were brought into the classroom. Games used in the classroom fall into the edutainment genre. These games can supplement classroom learning and complement students' experience and grasp of material during independent study time (Squire, 2008). Video games can be used to enhance learning and improve education. The process of gamification has been a significant development in educational institutions. The principle of integrating games within the classroom is called "game-based learning" (Graham, 2015). *Kahoot!* is an example of a highly successful game-based learning platform that has been used in classrooms to assess students' understanding of various concepts, review material, teach new subject matter, and stimulate classroom discussions. *Kahoot!* is just one of many examples of how games can be incorporated into the classroom in a successful manner. With the development of game-based learning and the copious amounts of research that supports gamification in the classroom, games that promote learning are

invaluable to educators in the twenty-first century (Dellos, 2015). Video game environments can be designed to efficiently teach complex subjects. Organic chemistry is a subject area that has the potential to be transformed by game-based education and edutainment-focused video games.

The Educational Landscape

Proper and effective education has the power to impact generations for the better. Unforunately, the exact learning process is still not fully understood, so measuring the efficacy of learning is difficult. Learning analytics can help provide some insight into the current educational landscape. Learning styles have been used throughout the classroom for years, but new research shows that it might not be the best way to tailor learning to students. The theory of multiple intelligences looks more promising.

Learning Analytics

In order to create a video game that crafts the best learning environment for students, one must first understand how students learn. Learning analytics contribute greatly to the understanding of the learning process as they can show how success is currently being measured within a subject or field of study. Learning analytics are composed of seven components: environment, objectives, stakeholders, meta-data, meaningful data, background data, levels of analytics, process, and technique (Banihashem, 2020). The environment takes students' background, culture, and communication into consideration as this can vary depending on the context. Some objectives to consider are optimization, learning, awareness, feedback, self-regulation, personalization, motivation, supervision, and assessment. By taking these components into consideration, one can begin to understand how to optimize the process of learning within virtual and classroom environments (Schumacher & Ifenthaler, 2018).

The Myth of Learning Styles

Many educators have utilized the concept of learning styles within the classroom in an attempt to personalize education. The theory of learning styles posits that there are specific ways that students learn best. There are three categories of learning styles: visual, auditory, and tactile (Kirschner, 2017). In light of research, teachers have designed their curriculums based off of the concept of learning styles. Researchers put this theory to the test by observing individuals in a controlled environment due to the lack of empirical evidence on this concept. As part of this study, students were grouped by their learning styles. They were then randomly assigned one of many types of instructional methods (Pashler et. al., 2009). Theoretically, if a student learns best through one method, then they should not be able to learn as effectively using other methods. Researchers tested their hypothesis by assessing the participants of the study after they had been taught through their assigned learning method. Literature shows that people will readily state their preference for how they learn best, and evidence suggests that people with specific aptitudes process information differently. However, the empirical data gathered from this study did not support those findings at all (Pashler et. al., 2009).

Although this topic is heavily researched, there is very little empirical evidence that supports the theory of learning styles (Newton & Miah, 2017). Besides the lack of experimental data on this topic, there are a few other issues with the concept of learning styles. First, there is no clear conceptual framework when it comes to defining learning styles (An, 2017). Another study also showed that there was no statistically significant relationship between a learning style and how students actually learn (Kirschner, 2017). Without a unified active field of research around this topic, methods and results, no matter how groundbreaking, hold no merit as they cannot be applied to studies within the same discipline (Sternberg, 2001). Because of this

confusion, the measurement of success within this area of study is also convoluted (An, 2017). Moving forward, this area of research needs to be clearly defined and then, and only then, can measurements of success be created. Creating virtual learning environments that are tailored to specific learning styles is not the best way to design video games for educational purposes due to the theory of learning styles itself. Instead, games should be personalized for players based on other factors.

Student Diversity & Multiple Intelligences

If learning styles are not indicative of which method to use to best teach students, then what is? Educators are aware that teaching is not an exact science. There are no formulas on how to best teach students because all students are different. They have different personalities, motivations, natural aptitudes, family and socioeconomic backgrounds, capacity for structured environments, and levels of awareness. One research study found trends in four different groups of students: those with high-ability, high-creativity, high-practicality, and high-stability (Dunn et al., 2002). The high-ability group was made up of Caucasians from middle to high socioeconomic classes. The groups of students that were in the high-creativity and high-practicality groups were of diverse racial, ethnic, socioeconomic, and educational backgrounds. The last group of high-stability students, or highly balanced students, were in between the other categories. Researchers found that as they considered a larger demographic of students, individuals showed intelligence through a larger range of abilities.

The theory of multiple intelligences posits that there are eight distinctive types of intelligence: linguistic, logical-mathematical, visual-spatial, bodily-kinesthetic, musical, interpersonal, intrapersonal, and naturalist (Gardner, 2011). Unlike the theory of learning styles,

this topic has empirical research that supports this hypothesis. Different people have different natural aptitudes towards these specific types of intelligences. The core cognitive units of each intelligence type are unique, and research has shown that these intelligences also require the use of different areas of the brain (Shearer & Karanian, 2017). General intelligence is most closely associated with linguistic and logical-mathematical intelligence (Gardner, 2011). Linguistic intelligence includes speech, reading, writing, and multimodal communication of meaning, and logical-mathematical intelligence includes mathematical reasoning and logical reasoning. (Shearer & Karanian, 2017). These skills are those that are most commonly taught and assessed in schools. The multiple intelligences theory and social cognitive theory can be incorporated into video games using a framework called the cognitive behavioral game design (Starks, 2014).

Growth vs Fixed Mindset

Students who do not have a natural aptitude towards linguistic or logical-mathematical intelligences (or towards intelligences that do not come naturally to them) approach education with one of two mindsets. Those with a growth mindset believe that intelligence is a trait that can be improved with effort, whereas those with a fixed mindset feel that intelligence is a fixed trait that cannot be improved (Dweck, 1988). Fixed mindsets are detrimental, (Macnamara & Rupani, 2017) and those with a fixed mindset typically exert less effort to succeed (Hochanadel & Finamore, 2015). Growth mindsets are beneficial, (Macnamara & Rupani, 2017) and those with a growth mindset are able to persevere when faced with challenges (Hochanadel & Finamore, 2015). In any learning environment, it is important to make sure that students feel that they are capable of learning concepts, even difficult ones. Without a growth mindset, students will easily begin to believe that they cannot understand the material or concepts being discussed. As a teacher, it is important to continually encourage students as they learn so that they can build the

confidence they need to confront obstacles that come their way. This can be done with accepting any and all questions to let students know that their doubts are welcomed. Educators can also break the class up into smaller groups in order to be able to discuss things with students who may be afraid to speak publicly. Educators can help students develop a growth mindset by creating an academic environment where they foster growth and instill a sense of grit and perseverance in their students (Hochanadel & Finamore, 2015).

Video Games in Education

There are many barriers to effective learning, but video games can help minimize those barriers. In recent years, video games have been implemented into the classroom in order to improve learning. Researchers have attempted to apply learning analytics to educational gameplay, but no singular framework has been successful due to the many genres available for analysis. Effectively using learning analytics to assess the efficacy of gameplay and mechanics can offer better insights into how video games can be used within education. Video games have the potential to transform the educational landscape.

The Potential of Video Games in Education

Researchers from Complutense University of Madrid proposed a two-step approach to apply learning analytics to technologies like educational videogames (Serrano-Laguna et al., 2014). The first part of this approach is to identify what to trace in generic educational games; the second part consists of assessing games based on their specialty. Game-based learning initiatives do not typically focus on assessing how students interact with the media. Video games can utilize assessment tools that supplement traditional learning and provide insights on the efficacy of the educational process (Serrano-Laguna et. al., 2012). Regardless of video game genres, researchers have been able to identify traces or sets of significant interactions that can

record the basics of video game mechanics for assessment purposes (Serrano-Laguna et al., 2014). These traces include when a game starts, when a game ends, when a level starts, when a level ends, and inputs from the joystick, mouse, or buttons. All these traces can have analytics and reports created showing how long users took to complete a certain level or what point of a game lost the players interest. These valuable metrics are not available in a traditional classroom setting. Homework and quizzes can be helpful to teachers as they seek to understand their students' comprehension of different subject matter. However, in higher education, the majority of students' grades come from exams, and students might not know exactly where they're struggling which makes asking for additional help that much more difficult.

Gardner's theory of multiple intelligences took off in the field of education (Gardner, 2011). A study conducted with119 primary school students assessed how students fared in different intelligence categories before and after using serious games (Prez et al., 2018). Qualitative measurements showed significant improvement in logical-mathematical intelligence, naturalistic intelligence, and linguistic intelligence. This research shows that video games can be effectively used to enhance specific intelligences. Experimental games and simulators help enhance naturalistic intelligence by developing problem solving skills by way of observation, experimentation, and reflection regarding physical environments (Ferrano at al., 2005).

Video games can also help instill a growth mindset in its players. One study created a game that rewarded effort and persistence in terms of *brain points* (O'Rourke et al., 2014). Their study aimed to show that educational games should incentivize and promote the development of a growth mindset. Their study of 15,000 children found that *brain points* encourage persistence in low-performing students, increases time played, and improves strategy use. Video games also seem to do something that traditional learning environments tend to miss. In many disciplines

and areas of life, one needs discipline and the ability to learn and grow from mistakes. Students can easily get discouraged in the classroom setting as they see red marks all over their graded assignments. After a while of the seeing the same result despite increased effort, students can begin to think that they are just not smart or capable enough to understand such material. Then they might gradually begin to stop exerting effort and stop trying to do well in school. That experience is the complete opposite when comparing it to that of playing video games. A player starts playing a brand-new game, but instead of feeling discouraged, feels motivated to dedicate hours to master the game. After they gain experience in the game, they continue to build their confidence as they progress through the game. Even after failing a level multiple times, players are driven to keep going and try to beat the level. Players ultimately play until they have completed the game, hit an insurmountable roadblock, or lost interest. The motivation to overcoming obstacles that comes from gameplay can be transferred into the classroom to enhance students' educational experiences.

Successful Learning Applications

There are a large number of learning applications that have been developed for students, but few have been as effective and well received as Duolingo, Quizlet, and *Kahoot!*. These apps have gained a huge amount of popularity in the demographic of students. Each of these apps excellently executes different processes. A video game that could be used as a supplement to classroom material must possess each of these components at a high caliber as well. These applications will be analyzed in terms of efficacy in implementing game-based learning.

Duolingo

Duolingo is a language learning website and mobile app that has twenty-five language courses available for people of all ages, backgrounds, and linguistic skill levels (Teske, 2017).

Duolingo is not specifically marketed as a video game but rather an educational application. Users can choose what language they would like to learn and then can complete lessons within the app. These lessons can be played for a certain time in 15-minute intervals, or users can choose to learn about a specific topic like food or clothing. Each lesson is comprised of *activities*: speaking, listening, translating, reading, short-answer translations, multiple-choice, short oral translations and repetition activities, and conversations via bots (Teske, 2017). Duolingo has reached millions of individuals and currently has 4.7/5 stars with 1.1 million ratings from across the world. Currently, it ranks #1 in the Apple app store under educational applications.

Two components of Duolingo's game mechanics contribute to its high level of success. The first component is the winning streak. A study conducted with 1000 Duolingo-users shows a positive correlation between the streak and motivation (Huynh, 2018). This motivation enhanced users' learning activities within the game. This winning streak helps maintain the attractiveness of continuous learning. Activities like learning a language requires just a small amount of consistent, disciplined focus, and that motivation process was exploited by Duolingo's winning streak. Another component that makes Duolingo successful is in the range of activities within lessons themselves. There are many different brain functions that are used when learning a new language. In fact, different areas of the brain are activated when writing, speaking, reading, and translating back and forth. Broca's area, located in the left hemisphere of the brain, is responsible for producing speech and articulation (Fedorenko & Blank, 2020). Whereas Wernicke's area is responsible for language development and comprehension (Jäncke et al., 2020). The gameplay of Duolingo's activities are very effective because they test skills that use multiple parts of the brain. For example, Duolingo doesn't just ask users multiple choice questions as to what

questions mean. It also asks users to speak or even translate audio. These simple game mechanics make Duolingo an effective tool and a great example of the potential of game-based learning. Future educational applications should seek to incorporate similar attributes in order to engage users in virtual learning materials.

Quizlet

Quizlet is a vocabulary acquisition website and mobile app that allows users to make online flashcards in order to learn terms and their definitions (Sanosi, 2018). Quizlet is also classified as an educational application rather than a game. Quizlet users can create study sets for any topic of interest. Once a study set has been made, there are options to utilize different learning modes in order to thoroughly understand the material on flashcards. The website has more functionality than the mobile app. The learning modes available are learn, flashcard, write, spell, test, match, gravity, and live (Sanosi, 2018). Quizlet has influenced hundreds of thousands of people as well. It currently has a 4.8/5-star rating based off of 461,000 reviews. It ranks #14 in educational applications in the Apple app store.

There are three main components to Quizlet's success. Quizlet seems to hack into user motivation as well, but unlike Duolingo, Quizlet does not use streaks. Researchers observed high school students' motivation as they used Quizlet to study English vocabulary using a nonequivalent control group design (Setiawan & Wiedarti, 2020). After using the Wilcoxon test to measure student motivation, the researchers concluded that Quizlet is an application that successfully increases students' motivation in learning vocabulary. The second component is also similar to that of Duolingo. Quizlet has many different kinds of learning modes available. Again, this type of studying requires the use of different parts of the brain. By offering students a wide range of functionality, students can learn material in new and exciting ways. A third

component that has made Quizlet a successful learning application is its degree of personalization which further enables its intrinsic motivation (Barr, 2016). Users can create their own study sets and learn terms that they are interested in or different concepts for class. Instructors can add students to their own *class* within Quizlet as well. These factors help students retain information and also contribute to the success of Quizlet as an educational application.

Kahoot

Kahoot is a game-based learning website and mobile app that creates quiz-based games. In the Apple app store, Kahoot ranks #7 under educational apps. Kahoot users can be teachers, students, or other individuals. Teachers can create quizzes to engage students in the classroom. Students can join a quiz and get immediate feedback on their answers. College students might use this quizzing platform to get feedback from a club, and office professionals might use Kahoot to shake things up when doing a survey. Kahoot's reach isn't quite as broad as that of Duolingo or Quizlet. It has a rating of 4.6/5 stars from 29,000 ratings.

There are three things that Kahoot has done very well. First, it utilizes competition in a healthy way. This healthy level of competition motivates students to answer questions quickly and correctly in order to get the highest score. This increase in motivation and classroom dynamics in turn improves the learning experience and boosts class morale (Licorish, 2018). Kahoot has also positively reinforced learning by awarding academic achievement which in turn, increases student engagement as well. Researchers decided to put Kahoot to the test and they compared it with traditional classroom learning and another quizzing application. Academic achievement and student engagement was increased when gamifying activities with Kahoot (Göksün, 2019). However, this increase in student engagement does not necessarily mean an increase in student performance. Another area where Kahoot excels is in its ability to give

immediate feedback. Scores, badges, rankings, and rewards are game elements that engage students within the learning environment (Glover, 2013). This feedback mechanism also allows teachers to understand where students are misunderstanding class material (Shute & Spector, 2010). All three of these factors tie strongly into the idea of increasing student engagement. Obviously, an approach like this has done extremely well in the current educational climate, and future educational applications should highly consider how to best engage students and convey educational material.

Duolingo, Quizlet, and Kahoot have all had success in varying degrees. Upon analysis, the core principles that make them such successful learning applications is that they focus on student engagement and interest while also motivating students through rewards, points, and badges. Future educational applications should seek to incorporate the core elements of these applications in order to have as great of an impact or better. Increasing motivation through video games is a sure-fire way to increase student engagement and help students learn material better. Creating different learning modes will help students learn the same material in different ways while using different parts of their brain.

Addressing the Hesitancy of Educators

Game-based learning has been used in the instructional setting for quite some time, but video games have the potential to be used in an even more effective manner. Educators have been hesitant to implement video games in the classroom because of fear that they may promote violence, aggression, negative portrayals of women, or social isolation (Squire, 2003). There are positive and negative outcomes associated with implementing video games within the fabric of everyday life. Research has suggested that there is an ideal profile for gamers and that a game's

impact on health and well-being is affected by one's level of social interaction and motivation for playing, and other variables (Halbrook, 2019).

Video games can provide a challenging environment or a collaborative one. At its best, players enjoy gameplay because of the social interaction that the game provides. They are challenged and seek to implement critical-thinking skills to overcome obstacles. At its worst, players can become so engrossed in gameplay that they become isolated and develop a behavioral addiction towards video games. Both are two sides of the same coin. In order to use game-based learning in the most effective way possible, the positive factors must be maximized, and the negative factors must be minimized.

Public and academic communities theorize that those who game digitally compensate for their social disintegration and lack of satisfaction in their real lives (Herodotou, 2014). One study conducted a large-scale online survey in order to assess associations between basic psychological needs and gaming. The relationship between socio-emotional status and gamers' proclivity to spend time gaming was minimal, meaning that there were no clear links between life-dissatisfaction and one's tendency to game. The stereotypes for gamers came from an old-fashioned stereotype for internet-users: those who lacked friendships, had low self-esteem, and looked to the internet as a means to escape a miserable life (Young & Rodgers, 1998).

Researchers then analyzed individuals' self-reported reasons for gaming in order to gain further insight on players' motivations. 67% of the target population of 16 to 25-year-olds stated that they play video games due to the nature of social interactions (Herodotou, 2014). 15.6% played as a form of escapism, 10.6% played because they were interested in the nature of gameplay, and 6.3% played for fun. Playing video games for social engagement and competition is a positive component of video games. However, that can very quickly turn into isolation if

players begin to neglect other types of social interactions. This research proposes that games themselves are neither good nor bad, but rather that there are other variables that lead to positive or negative outcomes in individuals. These factors must be taken into consideration when creating the best experience for students when using video games to learn. Educators have the ability to utilize these powerful learning tools in order to improve the education of their students. Video games and educational applications have the potential to transform the way students learn, and that technology should be embraced.

Another challenging aspect of implementing video games into the classroom is how it causes teachers to shift instructional practices. New curriculum that accounts for gameplay is necessary if video games are to be successfully used in the classroom (Bell & Gresalfi, 2017). A large portion of this depends on the teachers' familiarity with the use of technology within the classroom. Unfortunately, many educators are technology averse, lacking the desire to innovate within the classroom. That must change for students to be able to receive the best learning experience.

The Discipline of Organic Chemistry

In 1884, Willian Perkin Jr. began closely studying carbon rings as part of his doctoral studies (Partington, 1964). In 1886, he opened up a research laboratory in Manchester in order to continue his research. While there, he and Frederic Kipping began writing a textbook together based upon their research. In 1894 the textbook *Organic Chemistry* was published, and a new scientific discipline was created. 126 years later, the discipline of organic chemistry is required for many undergraduate students in scientific disciplines. Its reputation precedes itself even to those who are not in the scientific community. Organic chemistry is a difficult subject for many students to learn. It was proposed that computers be used in teaching organic chemistry as early

as the 1970s (Smith, 1970). Researchers postulated that the combination of words, numbers, formulas, graphs, diagrams, and images could help individuals better visualize the concepts present in organic chemistry. Scientists and educators have been searching for ways to improve how students learn organic chemistry for decades. Despite this interest in bringing new technologies to this subject field, not much has been done to truly transform the way students learn this material. Being a focal point of the curriculum of many science majors and health profession schools, organic chemistry is an important subject (Wilson & Varma-Nelson, 2021). Therefore, it is important to increase the retention of students in STEM-focused disciplines through the implementation of video games as a means of academic intervention.

The subject of organic chemistry has many different components within it. The Examinations Institute of the American Chemical Society (ACS) has a standardized exam that is typically taken as the final for Organic Chemistry I & II. For this exam, students are expected to know nomenclature, structure, hybridization, resonance, aromaticity, acids and bases, stereoisomerism, nucleophilic substitutions and eliminations, electrophilic additions, nucleophilic additions at carbonyl groups, nucleophilic substitution at carbonyl groups, enols and enolate ion reactions, electrophilic and nucleophilic aromatic substitution, free radical substitutions and additions, oxidation and reductions, spectroscopy, and synthesis and analysis (Eubanks & Eubanks, 2018). These topics are typically taught in class throughout the semester.

An exploratory study conducted by researchers analyzed the commonalities and differences in organic chemistry education by gathering metrics and data from twenty-three professors who taught organic chemistry (Duis, 2011). The study asked professors what general chemistry concepts are covered in their curriculum, which concepts are fundamental to introductory organic chemistry, what topics are most difficult for students to learn, and what are

the most common misconceptions undergraduate students have. Up to a third of professors chose acid-base chemistry, orbital hybridization, bonding, Lewis dot structures, and 3-D structures as the top five general chemistry concepts that were fundamental to a proper understanding of organic chemistry. Only acid-base chemistry was chosen by more than half of the professors in this study as a concept that needed to be well understood for success in organic chemistry. The study found that there were a variety of general chemistry concepts that were required to have a proper understanding of organic chemistry.

Many students succeed in organic chemistry, but many more fail after repeated efforts. Students who take organic chemistry in the first place are the stereotypical type-A, high-achieving students. However, the failure rates for organic chemistry are still well-known and students are pessimistic towards this subject matter despite this demographic (Mooring, 2016). Case studies have shown that certain behaviors can cause previously low-performing students to succeed and the lack of implementing such behaviors can cause previously high-performing students to struggle (Szu et al., 2011). High-achieving students seek assistance and engage in practice problems earlier in the semester than their counterparts. This research also supports the notion that simply spending more time with the material does not necessarily lead to success. The behaviors of high-achieving students lead them to have confidence in their abilities (Pungente & Badger, 2003). They are able to apply a growth mindset to learning organic chemistry. Technology can be used to improve the learning experience for students in order to help motivate them to seek help and practice problems earlier in the semester.

Organic Chemistry as a Video Game

Earlier in this paper, the efficacy of successful learning applications was assessed. Duolingo, Quizlet, and Kahoot have all have great success in improving education by creating

applications that increase motivation, engagement, healthy competition, and learning methods or modes. Research also illustrates that a key component of increasing student performance in organic chemistry is by having students engage with professors and class material earlier in the semester (Szu et al., 2011). Video games have the capacity to improve student performance in organic chemistry. This can be done by increasing students' motivation, engagement, and confidence.

This concept is not particularly new. There are a few "games" on the app store that set out to help people understand concepts associated with organic chemistry. More often than not, these applications are sets of rudimentary online flashcards that already have reactions, compounds, or mechanisms on them. There is no attempt in creating more engaging material for students to use. Another thing to note is that flash cards may not even be the most successful way to keep students engaged in this subject matter. Video games in the educational setting can be used to complement and supplement the traditional educational model. Perhaps someday soon, hours spent playing educational video games can be as effective or more effective in helping students learn material than spending hours studying. That theory alone lends to the fact that educational video games till have huge a potential that is largely untapped.

Educational video games are not typically role-playing games (RPGs). However, RPGs offer players the most immersive experience in the gaming environment, which in this case would also be the learning environment. For this reason, a role-playing game would suit the needs of the audience, those who are trying to learn organic chemistry. This game would also have gameplay mechanisms that align with other genres through the use of quests and challenges from the adventure genre as well as problem-solving from the puzzle genre. Generally, students in the science and health professions fields do not have countless hours to spend playing video

games. Instead of being seen as a time-waster, video games can be an additional educational resource that students can invest in. Because of that, the best platform for this application would be iOS and Android devices. If the game proves to be successful through beta testing, then the game can be pitched to Nintendo, Xbox, and PlayStation devices. There are a lot of things to think about in terms of game concept and narrative. A video game that takes these things and into consideration and incorporates specific gameplay mechanics in order to best convey complex topics could potentially transform the educational industry.

A video game that supplements classroom lectures must be very practical as well as engaging. Students should be able to practice and apply different concepts that are being learned in class. Organic chemistry requires a solid understanding of certain topics covered in general chemistry: acid-base chemistry, orbital hybridization, bonding, Lewis dot structures, and 3-D structures (Duis, 2011). On top of this, students should be able to understand nomenclature, diagram structures, functional groups and mechanisms, as well as SN1 and SN2 substitution reactions and E1 and E2 elimination reactions (Eubanks & Eubanks, 2018). Video games can be targeted towards improving specific intelligences present within the multiple intelligence's theory specifically regarding organic chemistry. Video games can be tailored to many different facets of organic chemistry. The following section will evaluate what types of intelligences are used in the most fundamental organic chemistry topics.

Acid-Base Chemistry

The acidic or basic properties of a molecule are one of the most fundamental concepts covered in organic chemistry (Eubanks & Eubanks, 2018). A proper understanding of acid-base chemistry allows one to make predictions on how certain molecules will react. This concept uses logical-mathematical intelligence as well as spatial intelligence. This topic can be challenging for

students who have a hard time with formulas that convey mathematical concepts. Acid-base chemistry can be taught simply using formulas similar to basic arithmetic problems. These can be fill-in-the-blank or matching type questions. Creating simple diagrams might be used a bit here too, but more information on that topic will be found in the Diagram Structures section.

Orbital Hybridization

Orbital hybridization is another topic that comes from general chemistry. Having proper understanding of orbital hybridization allows one to better understand SN1, SN2, E1, and E2 reactions. A challenge associated with this topic could be visualization of 3D structures which can make it difficult to understand chemical reactions that take place within organic chemistry. Spatial intelligence is used here the most because students must be able to visualize where on a molecule electrons are at any given point in time. This section could have question formats that help students with improving their spatial intelligence. This could include having 3D visualizations of molecules and asking where the electrons might be.

Bonding

Different types of chemical bonds have different strengths. Based off of the strength of two molecules that are being put together, one can predict what type of bond would be created between both the molecules. Understanding the strength of the bonds would also play a part into acid-base chemistry as you consider the types of compounds that would be made. There are different types of bond length and bond strength. Different bonds are formed when different compounds are combined. This makes chemical bonding a challenging subject to understand if one does not comprehend basic principles of chemistry. This subject would require logical-mathematical intelligence and maybe a little bit of spatial intelligence. Ultimately understanding

how bonds work is just a matter of knowing what the order of bond strength is. This section could use flashcards and multiple-choice questions.

Lewis Dot Structures

Understanding Lewis dot structures is another one of the most foundational skills in the field of organic chemistry. Almost all concepts are built on top of this one concept. Understanding the methods to Lewis dot structures relies heavily on spatial intelligence and goes hand in hand with orbital hybridization, bonding, and acid-base chemistry. Without a proper understanding of valence electrons, lewis dot structures can be difficult to create and understand. Logic-mathematical intelligence could be used slightly within this section as well. As previously mentioned with orbital hybridization, 3D visualization might be beneficial for students to learn about Lewis dot structures. Questions can also contain a picture of a molecule and ask the player to create the Lewis dot structures for them by placing the dots where they should go. Multiple choice questions could also help make this material more engaging.

3-D structures

Organic chemistry requires spatial intelligence in understanding how 3D structures look when drawn in 2D. This also plays a part in the concept of stereochemistry. This is a relatively difficult topic for students to understand because of the need to visualize structures (Duis, 2011). This topic would utilize spatial intelligence. Students can match the chemical formula for a molecule with its 3D structure in order to practice this skill.

Nomenclature

Nomenclature consists of understanding word parts and roots. When additions are made to a compound, the molecule’s new name reflects that change. This concept seems to utilize linguistic intelligence. It can be difficult for students to remember word parts. Nomenclature can

be taught by using game mechanics that contribute to the student's understanding of compound and molecule names through translating an image into its name by combining word parts and vice versa. This would also be a great place to create multiple choice questions.

Functional Groups

A basic carbon ring is called a benzene ring and it contains six carbons, one for each vertex. Functional groups are sets of molecules that can be added to benzene rings in different locations in order to create different structures. This topic goes hand in hand with nomenclature. Functional groups are one of the earliest specific concepts that students learn in organic chemistry. If this topic is not learned quickly and effectively, students will face many challenges throughout the rest of the course. This requires linguistic intelligence and spatial intelligence in equal part. When a functional group is added to a benzene ring, its name changes. A proper understanding of how the shape of the molecule changes is also needed in order to understand how functional groups build on top of each other. This can be taught with matching problems as well as those used for nomenclature.

SN1 and SN2 Substitution Reactions

SN1 and SN2 reactions are two different kinds of substitution reactions. The type of reaction that takes place is dependent on the reactants and products used. It is pretty simple to understand what happens in the reactions once one determines which types of reaction takes place. This is often difficult for students to get a hold of because of the number of reactants and variations of products that can be created. This concept would primarily rely on spatial intelligence and logical-mathematical intelligence. Here a video game can help with specific visual and pneumonics that can help users remember specific reagents and what they do to the product.

E1 and E2 Elimination Reactions

E1 and E2 reactions are similar to S1 and S2 except they are two different kinds of elimination reactions. This means that one part of a reactant is not within the product. Again, it depends on the reactant to truly determine what the outcome of the product is. This concept is similar in difficulty to SN1 and SN2 substitution reactions. Elimination reactions also require spatial intelligence and logical-mathematical intelligence. Teaching this concept would be more about helping students understand the mechanisms than memorization which can be accomplished through gameplay mechanics.

Conclusion

The current educational landscape is being transformed by recent research. The well-known learning styles have been used to promote personalized learning. Indeed, learning should be personalized but not in terms of learning styles. Crafting education towards specific intelligences would be a much more effective. Video games have been a relatively recent addition to the field of education as they have only been around for a few decades. Unfortunately, there are only a few examples of highly successful educational learning applications. Duolingo, Quizlet, and Kahoot are examples of excellent learning applications that have tapped into the educational industry. They excel in increasing student motivation, engagement, and therefore performance, and for that reason, educators should not be hesitant to using these technologies to supplement their teaching.

Organic chemistry, being a difficult subject to learn, is in dire need of innovation. When computers were first created, they were seen as having great potential in creating visualizations that could help students learn organic chemistry. Even though there is an abundance of visualization programs, technology can still pave the way for learning organic chemistry. Video

games can bring excitement into the classroom and help students understand material in new and engaging ways. Video games can create an immersive experience that helps students understand the true implications of the material that is being taught in class. The collaborative nature of video games can boost class morale and help motivate students to engage with the material. With continued research in this field and the development of new technologies that support STEM students, bright minds can be retained in scientific disciplines instead of being intimidated. The creation of a video game that teaches students organic chemistry has the potential to greatly impact the STEM field as well as the educational landscape

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