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ISOCHEM: Development of an Interactive 3D Game on the Web in Augmented Reality to Enhance Students' Learning of Isomers of Organic Chemistry

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Abstract: During the semester 2020, the COVID-19 pandemic has become a global health issue and impact on education. Many institutions abruptly transitioned their courses from face-to-face instruction to distance learning. This prompts us to optimize the teaching strategies for chemistry courses during online teaching mode. In particular, distance learning is not easy to engage student focusing on a difficult concept, especially organic chemistry. Therefore, the researchers have developed a new interactive 3D game on the web in augmented reality (AR) with a tutorial namely ISOCHEM, which is used as a door engaging activity for the online flipped classroom. This game could enhance the students' interests in isomers of organic compounds. Not only the high-school students, the first-year undergraduate students can also learn either in person or in group activity. ISOCHEM has two levels in which the players are requesting to respond the correct answers for guaranteeing the passing into the next level. Level 1 is matched with the structures of isomers, while Level 2 is relevant to the construction of molecular model sets in learning of structures and spatial orientations of organic molecules/compounds via building a molecular model. To gain more challenges, students have to show the molecular structure in a ball-and-stick model verified by the app. Moreover, ISOCHEM has tutorials consisted of basic isomer concepts, which provide the infographic and AR setups that allow students to learn by their own pace prior starting a game. The work presented herein could enhance students' comprehensive learnings and understandings through the individualized and self-directed learning experiences.

Keywords: Augmented reality, distance learning, 3D game, flipped classroom, isomers, organic chemistry.

1. Introduction

In the 21th centuries, technology is becoming an integral part of a modern classroom (Baldock et al., 2021). It is mandatory to discuss how to bring technology to the classroom environment. Mobile device and wireless internet were used to support learning environment for ubiquitous learning teachers and students can access a variety of educational resources that could inspire any time creativity, critical thinking, communication, and collaboration from elsewhere (Thanyaphongphat & Panjaburee, 2019).

During the semester of 2020, the COVID-19 pandemic has forced academic institutions around the world to rapidly adapt the traditional courses into the online platform. As the online education continues to rise, many colleges and universities are interested in how to deliver course content for online learners. The advantage of online education is that it allows students to attend the class from any location of their choice for synchronous learning. Additionally, online lectures can be recorded, archived, and shared for asynchronous learning (Ranga, 2020; Lapitan et al., 2021). This allows students to access the learning material at a time of their comfort. Therefore, to support student learning via online, the rapidly shift of the instructional on-site learning into the appropriate web-based learning was afforded (Tang et al., 2020), especially the abstract concept in organic chemistry.

Mastery of the structure of organic compounds is crucial as it involves the interaction and reaction of organic molecules. Isomers of organic compounds are key concept, which can be applied to the other contents (Jones & Kelly, 2015; Elford et al., 2021). The introduction of organic chemistry has to provide the structural theory of isomers, albeit this subject was evaluated by many students as one of the most difficult subjects. It is an abstract concept in which students cannot create their own imagination and most of the learning activities required ingenuity and higher problem-solving skills (Da Silva Júnior et al., 2018). The teaching in traditional classroom as a cookbook causes lack of the motivation, challenging to critical thinking and applying knowledge to other chemistry topics. These made it difficult to learn, think and engage, thus making students are under stressfulness, causing lack of motivation and enthusiasm to study in organic chemistry. Moreover, teachers are still lacking of a variety of teaching techniques and modern innovative media. Considering these difficulties faced by students in their learning process, the use of 3D model and augmented reality (AR) technology has the potential to fill gaps in some abstract topics. Therefore, to support student learning, teachers can use a variety of teaching materials to assist and support the student critical thinking (Winter, 2016; Aw et al., 2020; Abdinejad et al., 2021). In addition, AR technology can preferably support a difficult task or complex structure rather than learning via 2D paper (Wiedenmaier et al., 2003).

For a decade, various fields of learning including medicine, architecture, engineering, museology, physics, chemistry, biology, and mathematics have been attempted to incorporate AR technology into the classroom. However, very few chemistry educations have created a mobile applications or web-based application for teaching such as "Chirality-2" (Jones et al., 2018), "Time Bomb Game" (Da Silva Júnior et al., 2020), "Nucleophile's Point of View" (Winter et al., 2020) and BioSIM^{AR} (Fernandes, Cerqueira & Sousa, 2021). Using AR technology is more challenging to understand an abstract concept because it facilitates student to visualize the microscopic level and allows them exploration and analysis of information about objects in physical environment (ElSayed, et al., 2016). Moreover, there were the previous reported study using ubiquitous games that influence learning achievement and motivation through a context-aware ubiquitous learning environment (Liu & Chu, 2010), an online educational game can promote students learning attitudes, learning interest, improved learning achievements, self-efficacy and collaborative environment (Sung & Hwang, 2010; Hwang et al., 2012). However, very few researches that combine AR technology with game for teaching in isomers of organic chemistry.

AR technology has been combined into a game concept known as gamification. The gamification theory in education proposes that the learners learn best when they are having fun. The connection between gaming and learning is the mirror between the game design and the course design. The game (course) designer will incrementally introduce new skills (concepts) to be mastered, while the gamer (student) must subsequently apply these skills (concepts) to increase challenging puzzles (problems) that ultimately apply the prior knowledge to new scenarios (Varonis, 2015). Although an online community cannot be substituted for in-person classroom experiences, learning activities using gamification can engage students learn at home as the virtual classroom (Fontana, 2020).

In this research, researchers have designed a new interactive 3D game on the web in AR with a tutorial that covers the isomer of organic compounds concept namely ISOCHEM. Moreover, it provides an infographic tool of the isomer of organic compounds concept for students learning elsewhere. In addition, ISOCHEM aims to enhance students gaining better understanding and positive-attitude learning of the structural isomerism concept. Researchers propose to use this game design for flipped classroom on both online and on-site classrooms.

2. System Development

ISOCHEM was developed from the real stakeholder's feedback. A survey of chemistry teachers in Thailand teaching about the isomer of organic compounds concept showed that they still lack a variety of modern innovative media for teaching and learning about isomers (Table 1). They used only 2D platform that it could be difficult to engage student learning in an abstract concept, especially during COVID-19 pandemic. Therefore, ISOCHEM was designed to bridge this gap of teaching for supporting learners.

Table 1. *The Results of a Survey of Chemistry Teachers in Thailand: Using Technology and Digital Media for Teaching and Learning of isomers of Organic Chemistry*

Type of technology and digital media	Percentage (%)
Video	12
Microsoft PowerPoint	31
Textbooks-worksheet	42
e-learning	4
Mobile application	8
Digital game-based learning	3

From a survey, the technology that chemistry teachers used for teaching and learning on the isomers of organic compounds concept were textbooks-worksheet, Microsoft PowerPoint and video. To support student learning, ISOCHEM was developed by integrating the multi-features in one material for teaching such 3D model in AR technology, game-based learning, interactive activity and flexibility for learning as shown in the comparison of the effectiveness of teaching materials (Table 2).

Table 2. *Comparison of Teaching Materials*

Property	Textbooks-Worksheet	Microsoft PowerPoint	Video	ISOCHEM
2D/3D	2D	2D/3D	2D/3D	2D/3D
AR	-	-	-	+
Real time of environment image	-	-	-	+
Animation	-	+	+	+
Game	-	0	-	+
Audio	-	+	+	+
Self-learning	0	0	0	+
Interactive learning	-	0	0	+
Flexible	-	0	-	+
Quiz and assessment tools	0	+	-	+
Log in system	-	-	-	+
Device access	Easy	Easy	Easy	Easy

Note. Symbols represent the fulfillment level with regard to the requirements as follows: + = completely fulfilled; 0 = partially fulfilled; - = not at all fulfilled.

At present, ISOCHEM has two levels in which the system provides the supporting multiple language options in the web-based application game. For practices, a mode display contains an interactive 3D model in AR, e-learning system with the quiz and question, construction of molecular model sets in learning structures and spatial orientations of organic molecules/compounds by building a molecular model that show the structure of the molecule using ball-and-stick models.

3. Designing ISOCHEM Tutorial Mobile App

ISOCHEM was developed with the Laravel framework, PHP and HTML5 languages, and created a

user login system with PHP and MySQLU. Users initially login with an e-mail and password to create an account, select a language on the second screen and choose one of the following options: Play, Practices, Setting, My profile and Logout.

3.1 Play Mode

The play mode is chosen by the players who select the "Level" on the next screen. When the "Level 1" button is clicked, the players are moved to the next screen to read the rules (instructions). Click the "Start" button, the competition will occur. The players must select the isomer of organic compounds by shaking the mobile phone when two organic compounds are isomer within 20 sec/item. The total scores for this Level are 200. When the players choose a correct answer, they can earn coins equivalent to points. If the players choose an incorrect answer, the game will show the correct answers. For Level 2, the players click the "Random" button, then a molecular formula of hydrocarbon and organic compound containing oxygen will be occurred. The players must find total possible numbers of isomers, build a molecular model using ball-and-stick model, take a photo and then upload it within 15 min/compound. When the players build a structure correctly, points are earned with a total score of 500. This level provides a bonus with 100 coins when the players build a special structure compound and the winner is the one who possesses a higher coin.

3.2 Practices Mode

The practices mode is chosen and the players are moved to the next screen which has one of the following options: isomerism definition, constitutional isomers and subtopic (chain, position, functional group isomers), stereoisomers and subtopic (geometric and optical isomers) and hydrocarbon reactions Each of subtopic has a tutorial. Then the players can take a study based on their pace learning anytime. When clicking the AR button, the AR structure will be appeared. It facilitates players to see at the molecular level. Moreover, the players can adjust the molecule by their own fingers and turning around structure in 360°. In addition, this mode can check the players understanding with interactive question by answering short and multiple-choice questions.

3.3 Setting Mode and My Profile Mode

The setting mode includes the setups for music performance, sharing link with other users and seeing list of software development team. For my profile mode, the players can view username, e-mail and app history. It will collect login user statistics, plays chart and scores on device over the last month.

4 Implementation with ISOCHEM

Thirty twelfth grade students from the secondary school in Thailand enrolled in courses of introductory organic chemistry were implemented with ISOCHEM. It was used in online flipped classroom activity among the groups of students who used their knowledge of the isomers of organic chemistry to win matches. Students learn concepts of isomer of organic compounds include constitutional isomers (chain, position and functional group isomers) and stereoisomers (geometric and optical isomers) via textbooks and online videos prepared by the teacher and the practices mode in ISOCHEM. In online class, students play ISOCHEM and act like a gamer. They have to compete with friends to win it.

Feedback from students after using ISOCHEM showed the positive attitudes (Figure 1) with comments that the app helped them recalling the concepts of isomer of organic chemistry they had forgotten and clearly visualizing the model of isomers via AR. The aspects were found most enjoyable and interesting with design and playability, ease of use, relevance of content, easy-to-understand navigation, music, calm feel, pressure level for casual playing/learning and usefulness. The agreement (agree plus strongly agree) results showed in a range of 77.8-88.9% of evaluators. It can be implied that ISOCHEM is very favorable tool for learning. Moreover, students have additional feedback as follows:

"The game is wonderful. I am having a good time. The application is dependable and simple usege."

"The application includes entertaining games. There is a summary for self-study and a quiz to check how well you understand it."

"This is the best app for learning chemistry. It is possible to clearly visualize the 3D and AR structures."

ISOCHEM is designed to support classroom learning in isomer of organic compound which is the difficult concept. The contents in game are the same as in lectures or textbook, but the activity was designed to reinforce an idea and motivate students learning. They can play ISOCHEM by themselves and also share and discuss with their friends. Moreover, the use of AR incorporated into the classroom provides a few lessons for them, so ISOCHEM is very attractive tool. In Level 1, for example, students can find 3D models of the chemical structures, which can help them gain more understanding before pairing isomers. Similar to Level 1, in Level 2 students must think critically before building a structure of isomers and have a chance to discuss with friends.

5 Conclusions and Future Perspectives

This research has developed an interactive 3D game on the web in augmented reality (AR) with a tutorial namely ISOCHEM that is a beneficial tool for students to learn the isomer of organic chemistry by themselves anytime and anyway. This game has two levels of practice. The development of the ISOCHEM is continually based on user feedback from students who evaluated the first version of the application. Although the vast majority of comments were positive, there are some suggestions needed to be addressed further for improvement in future works. In addition, researchers are planning to incorporate more subjects in chemistry to ISOCHEM, *e.g.*, adding more practice levels as Level 3: move the spaceship to hit *cis/trans* isomers and Level 4: halogenation reaction. Researchers aim to develop ISOCHEM to allow students having more interactions via using AR setups by themselves.

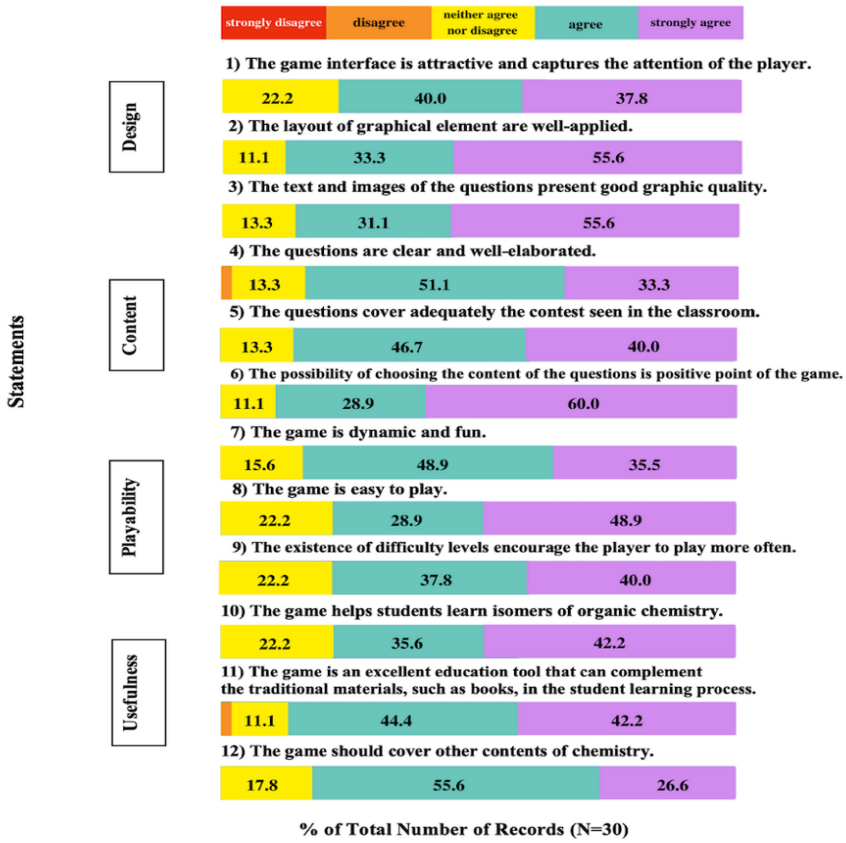

Figure 1. Evaluators' responses by survey statement: distribution of Likert categories.

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