

The Reliability and Usability Perception of Organic Chemistry Synthetic Pathways Board Game

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Abstract

This study aims to present the reliability and student's usability perception of an educational board game in teaching and learning synthetic pathways at matriculation level. This board game mainly called as Synthetic Pathways of Organic Compounds (COPS). The research design used was ADDIE model. Needs analysis survey on 35 chemistry teachers and lecturers as well as previous literatures proved synthetic pathways and retrosynthetic reactions can be taught using game-based learning approach. Respondents for the research were one year matriculation program students from one of the colleges in Malaysia which was determined using two stage cluster sampling. Analysis of the usability perception data (mean score) shows students agreed on achieving learning goals (4.57) of organic chemistry synthetic pathways via COPS board game. Besides that, they also agreed on attractive board design (4.45), good board organisation (4.43), excellent playability (4.48) and high usability (4.48). Besides that, COPS board game also has showed high reliability with the coefficient value recorded at 0.984. The output of this study implies that COPS board game has high reliability and usability perception in learning organic chemistry synthetic pathways among matriculation students.

Keywords: organic chemistry, synthetic pathways, board game, game-based learning, perceptions

INTRODUCTION

Malaysian education system focuses on acquiring knowledge, developing and expanding it through subjects such as Science, Mathematics and Languages. This has been the case for decades where ability to read, write and count among school children were the measurement of quality education delivered in educational institutes. However, current global education scenario deviates from what we had learnt by insisting on inculcating inquiry learning and higher order thinking skills among children. Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) are two global assessments focusing on quality output by any education system [1].

Based on PISA 2009 and 2012 report, Malaysian students' score were below the global average score of 494 in Mathematics, 496 in Reading, and 501 in Science [2]. The results from PISA survey shows

Malaysian students performed poorly especially in science subject. According to Malaysian Education Blueprint (2013-2025), Malaysia's performance in TIMSS eighth grade science declined every year since participating in the survey except year 2003. The result shows in year 1999, Malaysia's score was 492 and increased to 510 in year 2003. However, since then the score decreases to 471 and 426 in year 2007 and 2011, respectively.

According to TIMSS 2019, content domains for eighth grade science emphasises on chemistry, an upgrade from fourth grade where students generally learned physical science [3]. In Malaysia, chemistry is taught at upper secondary school level beginning at the age of 16. Malaysian Matriculation system was introduced in 1999 with two different streams: arts and science streams. Since 2011, the restructuring of matriculation program by Ministry of Education saw introduction of three different modes for science stream students:

- A. Module One – Mathematics, Chemistry, Physics, and Biology
- B. Module Two – Mathematics, Chemistry, Physics, and Science Computer
- C. Module Three – Mathematics, Chemistry, Biology, and Science Computer

Chemistry is one of the compulsory subjects for science and technical students in matriculation. As students begin to pursue studies in matriculation, they registered physical chemistry in semester one and organic chemistry in semester two. Organic chemistry learnt in semester two matriculation studies will be an important prior knowledge for students who wish to pursue tertiary education in professional fields such as medicine, engineering, biotechnology, nutrition, biomedical, biochemical, environmental studies and many others. Most notably, students found learning organic chemistry in semester two always challenging mentally than semester one and the trend was consistent regardless of the batches of students.

Thus, it is important as an educator, finding appropriate method or tool to facilitate learning chemistry in most effective way.

PROBLEM STATEMENT

Levy (2008) in [4] claimed that organic compound synthesis as one of the difficult concept perceived by students learning organic chemistry. Due to minimal understanding of basic organic synthesis, students face problems in solving advanced organic synthesis questions especially interlinked retrosynthetic reactions [5]. In another research, [6] reported that students not only struggle to solve multi-step synthetic pathways particularly retrosynthetic pathways but they found it hard to plan synthetic pathways as well. Besides that, students also often struggle to synthesise organic compounds especially when they were required to choose proper physical parameters such as temperature and catalyst [7]. In this case, students failed in determining correct chemical reagents to convert one organic compound to another. Furthermore, [8] claimed that students had difficulties with planning synthetic pathways because large amount organic reactions needed to be memorised.

From matriculation perspective, technical students who performed well in semester one (physical chemistry) need not necessarily produced same performance in semester two (organic chemistry) [9].

Based on their Pearson correlation analysis, the researchers concluded that technical students faced more challenges in semester two due to abstract visualisation of organic chemistry compare to mathematical arithmetic of physical chemistry. The results of their study shows students' understanding of organic chemistry still at low level and only excellent students records higher score due to strong pre-requisite knowledge in organic chemistry. In semester two, main challenges come from organic chemistry because paper one and paper two *Peperiksaan Semester Program Matrikulasi (PSPM)* Chemistry has higher percentage of organic questions compare to physical chemistry; 73% and 65% in paper one and paper two, respectively [10].

The inability of learners to write or complete synthetic organic routes addressed by researchers worldwide with different strategies like using mind map or road map [11], web-based leaning [12], and learning via cell phone [13]. A comprehensive solution required to address the issue of learning synthetic pathways since previous approaches suggested had its weaknesses in implementation particularly in matriculation perspective. Thus, the researcher of this study planned to use an approach that draws attention of current generation learners; game-based learning (GBL). According to [14], using games in chemistry classroom can provide engaging and alternative methods of instruction.

In order to justify suitability of this idea in learning organic chemistry synthetic pathways, the researcher of this study developed a needs analysis questionnaire using Google Forms which were distributed to 35 educators consists of form six chemistry teachers and matriculation lecturers from chemistry unit. 88.6% of chemistry educators agree on implementing this approach during teaching and learning session of organic chemistry lessons with 91.4% of them preferred to use GBL as an alternative approach in teaching organic chemistry synthetic pathways.

Research Objectives

Based on the background of the study and problem statement, this research is conducted to:

1. develop an organic chemistry educational game, COPS for learning organic synthetic pathways.
2. evaluate reliability of the COPS board game.
3. evaluate student's perceptions on goals, board design, board organisation, playability, and usability of COPS board game.

Research Questions

This research is conducted to answer the following research questions which are related to development of COPS board game and users' perceptions after playing it.

1. What are the steps involved in development of the COPS game?
2. What is the reliability coefficient of the COPS board game?
3. What is the students' perceptions on goals, board design, board organisation, playability, and usability of COPS board game?

METHODOLOGY

Research Design

Research design will focus on development of COPS board game based on ADDIE (Analyse, Design, Develop, Implement, and Evaluate) model and questionnaire used to analyse students' perceptions after playing the game which were determined from real study after implementing the game in classroom learning session. ADDIE model emphasises on presenting content to the learners without using high technology which suits the media type of this study, a board game. In the first stage of ADDIE model, a need analysis has been conducted to determine teacher's knowledge and exposure in game-based learning. For the second stage, educators have to arrange learning activities and assessments in accordance to the learning contents that they want the learners to master. In the third stage, a prototype of COPS board game will be develop with learning activities on organic chemistry, emphasizing on synthetic pathways and retrosynthetic reactions. For the fourth stage, implementation of COPS board game triggers organic chemistry synthetic pathways lessons where students interact with the game actively and collaboratively.

Finally in the fifth stage, formative and summative evaluation can be conducted to understand the impact of alternative instruction method in learning process [15].

Population and Sampling

Population in this research were from two semester system (Sistem Dua Semester) science students studying at matriculation colleges in session 2020/2021 across Malaysia. In this study, researcher opted to use two stages cluster sampling where in the first stage one of the 15 matriculation colleges was chosen randomly. The matriculation college chosen was Malacca Matriculation College which had 69 science practicum classes in one year program. In the second stage, three science classes were chosen randomly from 69 classes in a similar manner that used to choose the college. Then, researcher prepares a name list consists of students from the three science classes and subsequently set up sample size of 60 respondents.

Research Instruments

There were three types of instruments used in this study which were needs analysis questionnaire, COPS game reliability questionnaire, and students' perception questionnaire. From COPS board game perspective, reliability of game refers to consistency and stability of an educational game in solving learning difficulties as stated in the game's learning goals [16].

Reliability of COPS board game checked after completion of pilot test to determine reliability coefficient. After playing COPS board game, students were given a questionnaire by researcher to collect data on their perceptions of the developed educational game and suggestions on improving it. In this research, student's perception questionnaire were adapted from [17, 18, 19, 20]. Combination of items from these previous researches were adapted to build a questionnaire consists two main section: Section A, demographic of the respondents and Section B, perceptions of the respondents. In Section B, 36 items listed under five main constructs of goals, board design, board organisation, playability, and usability.

Pilot Study

After preparation of reliability questionnaire, it was distributed to sample students who had same characteristics with real study respondents during the pilot study. Before giving feedback, students played COPS board game by participating at each level of the game starting from beginner, amateur, and professional level. Feedback gathered were analysed using SPSS to determine reliability coefficient value for COPS board game. Sample size of 30 students from three practicum classes were chosen randomly for this pilot study. SPSS version 20.0 used to determine reliability coefficient of COPS board game. Table 1 shows COPS board game reliability analysis. From the analysis, reliability coefficient was found to be 0.984.

Table 1: COPS Board Game Reliability Analysis

No	Items	Reliability coefficient	Level
1.	I can understand each rule stated in COPS board game.	0.983	High
2.	I can understand each synthetic chemical route printed on reaction cards.	0.983	High
3.	I can understand each chemical reagent of a specific chemical reaction which is printed on reagent cards.	0.983	High
4.	I can understand extra information of a specific chemical reaction which is printed on reagent cards.	0.983	High
5.	I can write synthetic pathways completely upon collecting reagent cards with routes printed on it.	0.983	High
6.	I can play COPS board game with my classmates or peers.	0.984	High

7.	My classmates and I always had discussion while solving the chemical synthetic routes.	0.983	High
8.	I can recall organic chemistry synthetic pathways while playing COPS board game.	0.983	High
9.	I can learn organic chemistry synthetic pathways while playing COPS board game.	0.983	High
10.	I can understand organic chemistry synthetic pathways while playing COPS board game.	0.985	High
11.	Amateur and professional level in COPS board game enable me to write longer synthetic pathways.	0.984	High
13.	I can answer questions on organic chemistry synthetic pathways after playing COPS board game.	0.984	High
14.	I can understand organic chemistry synthetic pathways after playing COPS board game.	0.982	High
15.	Several coloured cards in COPS board game enhanced my learning motivation.	0.983	High
16.	I am interested in learning organic chemistry synthetic pathways after playing COPS board game.	0.983	High
Average		0.984	High

All the reliability items recorded high values with item number 10 recorded the highest value. Since the accepted Cronbach's alpha value is 0.7 and higher [21], COPS board game has higher reliability.

Data Analysis

Quantitative analysis conducted using SPSS version 20.0 on all the research data gathered. Descriptive statistics analysis was used and all the data processed were organised in tables that contains information on mean score and standard deviation values. Data were analysed in order to answer the research questions of this study. Student's perception on goals, board design, board organisation, playability, and usability of COPS board game analysed based on mean score which were interpreted by referring to Table 1.

Table 2: Interpretation of mean score for each item on student's perception questionnaire

Mean Score	Interpretation
1.00 to 2.33	Low
2.34 to 3.66	Moderate
3.67 to 5.00	High

Source: Jamil, 2012

From the Table 1, mean score interpretation divided into three category: low (1.00-2.33), moderate (2.34-3.66), and high (3.67-5.00).

RESULTS AND DISCUSSION

Student's Perception on COPS Board Game Goals

Table 2 shows mean score of student's perception on COPS board game goals. Based on the table, all five items recorded high mean score meanwhile average mean score recorded high value of 4.5661 as well.

Item 5 shows highest mean score of 4.6610 whereas item 4 shows lowest mean score of 4.4237. However, item 4 mean score still considered as high based on Table 1. Conclusively, student's perception on COPS board game goals were very positive where students understand learning outcomes they would possibly learnt by playing the game. Most importantly COPS board game encourages discussion and interaction on organic chemistry synthetic pathways among players.

Student's Perception on COPS Board Game Board Design

Table 3 shows mean score of student's perception on COPS board game board design. Average mean score shows value of 4.4475 which was high with item 8 recorded highest mean score of 4.5085. On the other hand, item 6 and 7 recorded lowest mean score of 4.4237. Based on the Table 3, researcher of this study concluded various reaction board colours attracted players and at the same time obvious and clear chemical routes printed on the board helped players strategised their moves.

Student's Perception on COPS Board Game Board Organisation

Table 4 shows mean score of student's perception on COPS board game board organisation. Students responded very positively on all the items for board organisation construct with average mean score of 4.4305. Item 14 recorded highest mean score of 4.4915 meanwhile item 12 recorded lowest mean score of 4.3559 which was still considered as high based on Table 1.

Table 3: Student's Perception on COPS Board Game Goals

No	Item	Mean	Standard deviation	Level
1.	Goals of COPS board game are clearly defined.	4.6102	0.66997	High
2.	Purposes of COPS board game are clearly explained.	4.6271	0.66691	High
3.	COPS board game helps retention of knowledge in organic chemistry.	4.5085	0.70400	High
4.	COPS board game helps with my memorising of synthetic chemical routes and reaction mechanism.	4.4237	0.77021	High

5.	COPS board game encourages discussion and interaction on organic chemistry among my classmates	4.6610	0.68507	High
Average		4.5661		High

As a conclusion, student's perception on board organisation shows COPS board game focused on synthetic pathways and allow students to master inter-conversion between homologous series of organic compounds.

Table 4: Student's Perception on COPS Board Game Board Design

No	Item	Mean	Standard deviation	Level
6.	Size of the boards are suitable for learning purpose.	4.4237	0.83467	High
7.	Words printed on the cards are clear.	4.4237	0.81375	High
8.	Colours on board are attractive.	4.5085	0.77399	High
9.	Synthetic pathways printed on the board are clear.	4.4746	0.79559	High
10.	Quality of the boards are excellent.	4.4068	0.79043	High
Average		4.4475		High

Time provided to perform this task in a sequential mode was also adequate.

Student's Perception on COPS Board Game Playability

Table 5 shows mean score of student's perception on COPS board game playability. Average mean score shows value of 4.4787 which was high with item 17 recorded highest mean score of 4.6610. On the other hand, item 22 recorded lowest mean score of 4.4407. Based on the Table 5, researcher of this study concluded COPS board game promotes collaborative and cooperative learning among players.

Table 5: Student's Perception on COPS Board Game Board Organisation

No	Item	Mean	Standard deviation	Level
11.	Instructions provided in COPS board game are easily understood.	4.4576	0.77286	High
12.	Number of cards are reasonable for learning purpose.	4.3559	0.80436	High
13.	Time provided to play COPS board game is reasonable.	4.4746	0.7510	High
14.	COPS board game focused on synthetic pathways.	4.4915	0.72808	High
15.	Synthetic pathways on COPS board game are same level with my organic chemistry knowledge.	4.3729	0.84890	High
Average		4.4305		High

Apart from that, COPS board game makes learning synthetic pathways fun and interesting.

Table 6: Student's Perception on COPS Board Game Playability

No	Item	Mean	Standard deviation	Level
16.	Game rules in COPS board game are fair and provide each player with equal chance of succeeding.	4.6441	0.71348	High
17.	COPS board game promotes collaborative and	4.6610	0.68507	High

	cooperative learning among players.			
18.	COPS board game promotes healthy competition among players in succeeding the game.	4.6271	0.69228	High
19.	COPS board game allows me to learn independently.	4.5254	0.62557	High
20.	COPS board game makes learning synthetic pathways fun and interesting.	4.5932	0.69775	High
21.	COPS board game allows me to correct any misconception in synthetic pathways while playing it.	4.5593	0.74905	High
22.	COPS board game is easy to play.	4.4407	0.72567	High
Average		4.4787		High

Student's Perception on COPS Board Game Usability

Table 6 shows mean score of student's perception on COPS board game usability. Average mean score shows value of 4.4787 which was high with item 30 recorded highest mean score of 4.5932. On the other hand, item 23 recorded lowest mean score of 4.4407. Based on the Table 6, researcher of this study concluded COPS board game enhanced interest and improved motivation in learning synthetic pathways. Apart from that, COPS board game also increased knowledge depth in organic chemistry synthetic pathways.

DISCUSSION AND CONCLUSION

This research inspired by ideas from Mastering Organic Chemistry Laboratory (MOL) by [7] whom clarified several key aspects of organic reaction especially on physical parameters required for synthesis of organic compounds. Functional Group Transformation (FGT) is another method to log fifteen functional groups such as alkyl halides, alcohols, and aromatics into a system to assist learners in solving organic chemistry synthesis problems. [6].

In this study, students' feedback on learning goals achieved via COPS board game clearly shows positive output since mean score recorded was 4.5661. Students claimed that COPS board game created fun and happy learning environment whereby it allowed them to discuss on solving chemical routes on the reaction board.

Table 7: Student's Perception on COPS Board Game Usability

No	Item	Mean	Standard deviation	Level
23.	Participating in COPS board game increased my knowledge depth in synthetic pathways.	4.4407	0.77172	High
24.	Participating in COPS board game improvised my writing on synthetic pathways.	4.4068	0.81195	High
25.	Participating in COPS board game enhanced my interest in learning synthetic pathways.	4.4407	0.81518	High
26.	Participating in COPS board game improved my motivation in learning synthetic pathways.	4.4746	0.77362	High
27.	Participating in COPS board game enhanced my self confidence in learning synthetic pathways.	4.4576	0.83711	High
28.	Participating in COPS board game increased my social skills.	4.4746	0.79559	High
29.	Participating in COPS board game broadened my view on synthetic pathways.	4.4576	0.81626	High
30.	I would recommend COPS board game to all my peers.	4.5932	0.72203	High
Average		4.4787		High

Besides that, COPS board game provides platform for players to memorise organic chemistry synthetic reactions.

Physical appearance the board game encouraged students to participate in the game repeatedly. All the chemical routes can be seen clearly on the reaction board which allowed the players to plan the synthetic pathways in order to collect maximum points possible. Furthermore, colours used to design the board were vibrant and attractive. As mentioned previously, COPS board game focused on teaching and learning of

organic chemistry synthetic pathways. So, information on components of the game organised in such a way that allowed students to learn synthetic pathways in incremental manner: from simple chemical routes to retrosynthetic reactions. Additionally, gameplay time sufficient enough for all the players to complete at least the beginner level of the game. Nevertheless, academically excellent players moved quicker towards amateur and professional level.

COPS board game rules were fair and provided each player with equal chance of succeeding. The opportunity to any player emerge as winners was the uniqueness of COPS board game where no students considered as a loser in the game. It is a healthy competition in which every student had equal chance of learning synthetic pathways despite end up losing the game. Ironically, students collaborate and cooperate in a small group to win the game and to learn organic chemistry synthetic pathways.

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