Creating an Interactive Environment for Learning Microplastics VIA a Board Game at the Museum

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***Abstract*—A Museum is an important place to promote science literacy for people. Recently, museums have developed educational materials and exhibits for learning and raising awareness of global issues. Microplastics have become a global environmental issue. A board game has been used to implement many environmental problems effectively. This study, therefore, aimed to develop a board game with simple simulation in a spreadsheet to create an interactive environment to learn about microplastics and their impact on the environment. The developed board game was implemented at the natural history museum in Thailand with six undergraduates studying life science who voluntarily participated in the study. The multi-answer questions, mind map, and worksheet were used to assess the understanding of microplastics when the participants completed the first game. Data from observation of the participants' interaction during the game was also used to support the result. Data pointed that the participants gained some information from the action and information provided in the board game. Participants could clearly state the sources of microplastics. They also demonstrated the knowledge of microplastics' cause and effect on living organisms and how to manage microplastics concentrations in the environment. However, the concept of a microplastic pathway was missing, which would be discussed.**

***Index Terms*—boardgame, game-based learning, microplastics, spreadsheet, museum**

I. Introduction

Plastics are cheap and have ideal properties such as being lightweight, strong, resistant, flexible, and transparent [1]. However, they also contain several toxic chemical contaminants [2]. Plastic waste can be degenerated and fragmented into tiny particles primarily by nature degradation, such as sunlight or soil bacteria [3]–[5]. When the particle size is less than 5 mm, it was defined as microplastics (MPs) [6].

The major source of MPs pollution is human activity, especially from daily used products, laundry, household waste, landfills, wastewater from factories and agriculture, etc. Rivers and winds have carried most MPs from a land-based source. They then travel through the waterway into the ocean and accumulate in the ecosystems [7], [8].

According to the small sizes of microplastics, they were found in edible fruit and vegetables, especially apples and carrots [9]. The plants uptake the MPs-contaminated water, and then the MPs accumulated in the fruit of the plants. In addition, MPs in the ocean were the same size as the fish's typical food [10]. That is why there are MPs contaminated with seafood. The MPs ingestion transpires across taxa in the different levels of organisms, including invertebrates, fish, marine mammals, and fish-eating birds [6], which (most of them) are human food. To sum up, human activity produces MPs into the environment, and finally, we intake back from the food we have consumed [6], [11].

Many studies reported that MPs affect human health, including inflammatory response, particle toxicity with oxidative stress, and cell damage [6], [11], [12]. The effect of MPs had been shown not only to the human health but also to other living organisms such as in the mammalian systems can translocate across living cells, accumulated in organs, and broke the immune system and the cells [6], then in case of sea birds, exposure by the plastic fragments has a negative effect in causing the alteration of feeding behavior, reproduction, and mortality [3]. Moreover, it can cause problems to the abiotic factor. For example, the soil's physical property was changed when MPs accumulated, resulting in the soil's water dynamics and microbial communities activity [13], [14]. Therefore, MPs and their impact on human health and the environment reduce microplastics' contamination in daily life.

The ultimate solution to preventing MPs contamination is reusing the plastic product as much as possible, increasing recycling activity, and reducing the usage of the plastic product by replacing plastic-free items [15]. Raising awareness and consciousness to change the habits is also needed.

To limit microplastic pollution, the accountability of individuals is more crucial. There are many educational programs and citizen science projects that educate and raise individual responsibility for MPs reduction. For example, Raab and Bogner (2020) created a module, "Plastic Detectives – The search for plastic" to raise the awareness in young students to environmental concerns via hands-on activities [16]. The module provided students' insights regarding the microplastic and plastic sources in daily life and eco-friendly alternatives. Moreover, Vortmann *et al.*'s study (2019) conducted simple laboratory experiments of MPs at the secondary level [17]. They found that students quickly recognized the negative consequences of MPs in the environment.

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Similarly, Mostowfi *et al*. (2016) used recycling and waste separation education board games for the students ages 7- 12 [18]. This study showed that the game could introduce the recycling concept to the students, cultivating positive changes in the future. Additionally, Cheng et al.'s study used the issue-situation-based board games to enhance high-level cognition and foster students' empathy about an environmental problem [19]. All the participants had experienced and interactions with others that helped them reflect on social phenomena in daily life.

These previous studies indicated that direct experience in an interactive environment would promote conceptual understanding and awareness of environmental issues. However, there is no holistic view of MPs in the environment. Especially there is a missing link of how MPs return to living organisms and affect human health. The reason why people need to manage the plastics used properly was also little mentioned. Therefore, this study focused on the cause and effect of MPs on living organisms and the environment by presenting the significant pathways of MPs to habitats.

Since learning is not only limit to the classroom. Learning in an informal setting like the museum could motivate intrinsically and process the knowledge through observation, curiosity, and activity [20]. It is also essential to teach life's values and form the foundation of long life [21]. Also, it could provide an experience that leaves better than study in the classroom [22]. The museums todays develop educational materials and public outreach to promote science literacy for people of all ages and backgrounds. Global issues such as climate change and environmental problems are popular exhibits and activities in science museums or nature centers worldwide. However, there are not many exhibits or activities in the museum introducing MPs and their impact on human health. This study, therefore, aims to develop a board game for creating an interactive environment to learn MPs and their impact. The conceptual understanding of MPs was also assessed to determine the effectiveness of a board game in learning.

II. Theoretical Framework

Game-based learning offers several advantages for students to develop their cognitive, social, emotional, and motivational well-being [23]. The games succeed if they positively influence players and facilitate the experience flow [23]. In terms of cognitive skills, the games have a positive impact on helping the learner with problem-solving, visualizing, and establishing the concept link [24]. The cognitive development was supported by Garris' model of game-based learning [25], which showed that the educational characteristics' game is the collaboration between the instructional content with the game characteristic. The game should increase student motivation to repeat the cycle and improve their inspiration in the study. By repetition, it expects the students to develop the desired outcomes based on repetition from their behavior, feedback, and interactions while playing the game. Last, the debriefing process is the bridge between the game cycle and the learning outcome. This model can link simulation and the real world by connecting the experience from the game and learning activity.

For the educational game, debriefing is a critical step in increasing the student's achievement, especially the concept [26]. Debriefing is a post-experience analytic process that provides an opportunity for participants to reflect on their progress and enable them to carry away lessons that enhance their knowledge. The participants were forced to share their experiences. The teacher as facilitator uses their responses to generate the discussion to the learning point [27]. The objective is to provide feedback on student performance to help them realize their learning goals.

Game-based learning can be described as a play to develop cognition by activating the schemas so that the players transcend their immediate reality. It should be noted that construction happens when new knowledge assimilates and accommodates prior knowledge [28]. The player's zone of proximal development has been considered to develop a good game Vygostky (1978) [29]. Moreover, the social negotiation in the game-based learning process that makes players actively involved in the game is also led to construct their understanding. The game characters engage the learner emotionally, while the social features support sociocultural engagement.

An educational game could improve student's achievement and motivation. A study from Rosas et al. (2003) [30] showed that using an educational video game could acquire reading comprehension and mathematics skills and enhance motivation. Liu and Chen [31] and Coil, Ettinger, and Eisen [32] also supported that using educational games in science learning improved the students' scientific knowledge. It helps to understand the process and content of science when the students are utterly familiar with the game rules [33].

The serious educational game has been adopted in a museum setting by linking the game to museum content that fulfills the educational needs. In the museum setting, the educational game effectively delivers information to visitors [34]. In addition, a study from [35] reported that digital games and museums have particular value in the capacity to extend knowledge, increase engagement, and empathy through playing the game.

III. Methodology

A. *Microplastic Board Game*

A microplastics board game aims to introduce the source of MPs and the effect of microplastics on a living organism in the ecosystem. It also integrates ways to manage plastic waste by assigning the players' roles to 4Rs (recycle, reuse, reduce, and recover), which refer to recycling, reuse, reduce, and recover.

The board game was developed based on Garris's model of game-based learning. This model can link simulation and the natural world by connecting the game and learning activity experience. A microplastics board game is a cooperative board game that adopted and adapted the game mechanism of a commercialized board game entitled "Forbidden Island". Players in the microplastics board game have to help each other manage the system's plastic waste to control the level of microplastics accumulation in the ecosystem represented by the spreadsheet simulation.

A developed microplastics board game consists of two parts: a board game and a spreadsheet, as shown in Fig. 1.

Figure 1. An overview of a microplastic board game setup

The components of a board game are:

1) Player cards

The player cards consist of 4 roles which are recycle, reuse, reduce, and recover duty. Since it represents the action that people are responsible for, the players have to collaboratively work to decrease the concentration of accumulated MPs in the environment by taking care of different plastic cards that match their roles. For example, the chip packaging can be managed by the players who acted as reusers and recyclers.

2) Plastics and waste cards

Twenty plastic cards (located at the center of Figure 1) were the daily plastic used items, such as toothbrushes, ketchup bottles, plastic bags, etc. Some of them were MPs-containing products. For example, a facial wash can produce MPs from the plastic container and the microbeads containing in the product. Moreover, each plastics cards have symbols relating to the response that the players could act.

The twenty waste cards were the same set as the plastic cards with black-and-white color. At the end of each player’s turn, they must open these cards to match the number of actions they got from dice rolling to turn the plastics into waste. The number of the waste card was put in the simulation to show the accumulation of MPs in the ecosystem.

3) Green cards

There are twenty-one green cards, including positive and negative effects on the gameplay. The positive effect includes the mission to gain reward from the game in either reducing MPs concentration or getting more chance to win the game such as collecting a piece of the puzzle. The negative one refers to the action to add more MPs concentration to the environment.

4) Mission cards

The mission card consists of several questions and answers that help students gain more information about the MPs. In addition, there is a mission card with a QR code link to the clip showing the holistic view of MPs starting from the community and return to the community in the form of food.

5) A dice

The dice used in this board game are unique. It has six sides with only the repetition of numbers 1, 2, and 3. This number represents the action that students have in the board game.

Microsoft excel had been used to create the spreadsheet simulating the number of MPs accumulation in the ocean and some marine organisms. The players would add the numbers of waste cards in each turn into the black cell shown in Fig. 2. The concentration of MPs production and accumulation in plankton, shrimp, mackerel, and tuna would then calculate and display numbers in the cells and line graph. Players had to observe the graph and managed the plastic waste in the game. The game would be lost when the graph reaches the designated level.

Microplastic Releasion in Each Turn							
Turn	Plastic (black card only)	Plastic accumulation	Microplastic	Plankton	Shrimp	Mackarel	Tuna
1		0	0	0	0	0	0
2		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
5		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
6		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
7		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
8		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
9		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
10		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
11		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
12		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
14		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
16		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
17		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
19		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
20		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
21		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
22		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
23		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
24		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
25		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

*Fill the number of plastic waste in the black cell

Figure 2. A screen of the spreadsheet for recording the concentration of accumulated MPs in the environment

To play the game, the players started by rolling the dice. Then they decided to act from the given actions that are (1) move to the designated card, (2) draw and use green and mission card, and (3) flip the plastic card from the black-and-white side (represent the waste) to the colored side. The number of actions was equal to the number given by dice rolling. Each turn of play would end with open the waste cards as the same number of actions in that turn. Once the waste card was opened when the plastic card is shown on the black-and-white side, this was then disappeared from the board. Finally, the player added the number of waste cards in that turn to the spreadsheet. For the disappearing card, the fixed number of 5 each had to be added every turn since it was out of play.

To win the game, all players should collaboratively work to complete the puzzle. They can minimize the accumulation level of MPs in the game environment shown in the spreadsheet responsible for their roles.

B. Participants

The developed board game was implemented with six science undergraduates at a museum in Thailand. All participants were from different universities but had a similar background in life science. They knew about MPs very little, which was received from the news or media. The participants in this study were volunteers at the museum. They worked as a communicator and supporter for visitors’ learning. As the volunteer at the museum, it was important for the participants to enrich their knowledge on MPs to communicate this issue to the museum's visitors.

All participants voluntarily participated in the study. In terms of ethical issues, the participants agreed to give consent after introduced the research study.

C. Data Collection

Participants in this study were asked to participate in the gameplay. They all rotated to play when they had free time by forming a group of 3–4 members to meet the researcher at the activity area. Each round of play took 45–60 minutes, depending on the group member.

After finished the first play, all participants were asked to do the six multi-answer questions and wrote a mind map to assess (1) the sources of MPs, (2) the cause and effect of MPs in the environment, and (3) the plastic waste management.

The worksheet was also used to determine MPs students' conceptual understanding. Participants were asked to record the role and action occurring in the game by writing in the worksheet while playing. Moreover, the researcher observed the interaction of the participants along with the gameplay.

Each of the tools was reviewed by the two content experts and one experienced museum academic staff. In addition, method triangulation had also been used to ensure the validity of the research.

D. Data Analysis

The multi-answer questions, mind map, and worksheet were analyzed by using thematic analysis. The responses had been examined to the group in the common themes.

IV. Result and Discussion

Students ' knowledge after playing the developed board game was categorized into four categories based on the item analysis score from the multi-answer questions, mind map, and worksheet.

A. Sources of Microplastics

The multi-answer questions, mind map, and worksheet showed that all participants knew MPs' sources. They understood that plastic household products (e.g., plastic bags, plastic bottles, and milk bottles) could produce MPs.

Regarding the sources of MPs production from the filling, the multi-answer questions showed that two participants fully understand this concept. They selected all proper packaging and filling responses, while the other four participants showed partial understanding. Participants in this concept decided on correct and incorrect answers for partial understanding, even though they correctly stated in the worksheet.

Data from the observation found that some participants gained knowledge of microbeads producing MPs from the mission in the game. Therefore, it could be claimed that a developed board game had introduced this concept.

B. The Cause and Effect of Microplastics on Living Organisms

This result was from the multi-answer questions only. The participants were asked to explain the cause and effect of MPs from the given picture. The responses were short. However, all participants' answers demonstrated that MPs could kill the organisms. Some of them stated that MPs could destroy the environment.

C. The Microplastic Pathways

Participants understood that humans could consume MPs from seafood and plants we eat, but they did not understand where MPs accumulate in the foods. This concept should be added to further development.

D. The Prevention

From the participants' answers (N=6) in the multi-answer questions and mind map, the participants understood how to prevent the spread of marine litter. The student proposed solutions to reduce the MPs level in the environment, such as recycling plastic products, reducing plastic products, and replacing some plastic products with eco-friendly products. Additionally, the worksheet results showed that all participants were familiar with 4Rs, recycling, reusing, reducing, and recovering plastic waste management. It could be assumed that the participants have some prior knowledge before playing the board game. They could apply their prior knowledge to the content representing in the game and present the solutions mentioned earlier.

The participants in this study represented the MPs concepts they had after playing the developed board game, including sources of MPs, the cause and effect of MPs to the living organisms, MPs pathways, and the possible solution to decrease MPs in the environment. Like the previous studies, game-based learning motivates and engages students to learn biological content of varying academic levels [36], [37]. In addition, the students prefer to learn from the game rather than traditional lectures.

Data from observation during the participants' play the board game demonstrated that the participants gained some information from the action and information provided in the board game, such as the plastics cards and the mission in the game. However, participants did not take much consideration of graph generating by a spreadsheet to the gameplay. The spreadsheet was developed to help students manage the concentration of MPs in the environment, which is an important message. Wenzler and Chartier (1999) [38] in the study of why do we bother with games and simulations, stated that collaboration between games and simulations giving a holistic view about the whole process of a particular topic. However, the connection of a board game to the spreadsheet needs to be further improved.

In addition, we found that all participants played a board game more than one time. There was one of the participants played the game more than six times. This participant gained the concept provided in the board game more than the others because he could clearly explain game mechanisms and contents to peers, especially in the sixth round. It is in line with the game-based learning model by Garris et al. (2002) study where the game should increase student motivation, so the learners can repeat the cycle and increase their motivation in the study [25]. With repetition, it is expected that the students develop the desire to learn based on their behaviors, feedback, and interactions while playing the game.

Indeed, this board game belongs to a serious game. Data from the observation in each play showed that participants started to share their knowledge with members in the second round. It takes time to gain knowledge from the game. When playing the first time, the participants might master the game's mechanism but have less catching knowledge because they focused on understanding the game rules. After participants understand how to play the game and form a strategy to win the game, the participant gains some information from the action and information provided in the board game, as mentioned by Clough [33].

The process of gathering and constructing knowledge happens while playing the board game. According to the sociocultural perspective, a board game is considered the approach that provides contextual information and interactions for learning MPs. A board game itself acts as a leading factor in creating a proximal development zone for players Vygotsky (1978) [29]. Players in this study could play with peers who had various experiences in board gameplay, MPs knowledge. The collaborative play supports sociocultural engagement that players enjoyed and learned.

V. Conclusion

The developed board game introduced concepts including the source of MPs as the participants could state plastic waste and where that plastic came from correctly. It also provided the effect of microplastics on biotic organisms living in both marine and land. Lastly, the reduction of accumulated MPs in the environments was mentioned by all participants. However, the participants stated a few of MPs pathways starting from human and return to the human. This is a critical concept showing how humans consume MPs from foods. This board game still needs to improve the mechanism to connect a board game to a spreadsheet representing the concentration of MPs in the environment. In the future, this board game could be implemented and played for museum visitors and the family who want to learn about microplastic.

Conflict of Interest

The authors declare that there is no conflict of interest.

Author Contribution

Riris Sejati Adjiningsih has conducted the research, analyzed the data, and wrote the paper. Namkang Sriwattanarothai is the research adviser, organized the research content, and made essential revisions. All authors had approved the final version.

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