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Article

Investigating the Effectiveness of an Educational Card Game for Learning How Human Immunology Is Regulated

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This study was conducted in an attempt to investigate the effectiveness of an educational card game we developed for learning human immunology. Two semesters of evaluation were included to examine the impact of the game on students' understanding and perceptions of the game-based instruction. Ninety-nine senior high school students (11th graders) were recruited for the first evaluation, and the second-semester group consisted of 72 students (also 11th graders). The results obtained indicate that students did learn from the educational card game. Moreover, students who learned from playing the game significantly outperformed their counterparts in terms of their understanding of the processes and connections among different lines of immunological defense (first semester: $t = 2.92$, $p < 0.01$; second semester: $t = 3.45$, $p < 0.01$) according to the qualitative analysis of an open-ended question. They generally had positive perceptions toward the game-based instruction and its learning efficiency, and they felt the game-based instruction was much more interesting than traditional didactic lectures (first semester: $t = 2.79$, $p < 0.01$; second semester: $t = 2.41$, $p < 0.05$). This finding is evidence that the educational card game has potential to facilitate students' learning of how the immune system works. The implications and suggestions for future work are further discussed.

> Play is necessary for the development of higher intelligence; for if we were provided with perfected instincts, as insects are, life would be automatic and there would be no such thing as education and no increase of ability or intelligence, either in the individual or the species.
> — Mitchell and Mason, 1935, 56–57

INTRODUCTION

Human immunology is never an easy topic for students to learn. The regulation of human immunological defense is a physiological process that intertwines both humoral and cellular interactions among a variety of cell types and antigens, and students often feel confused and have difficulties in learning this subject (Da Rosa *et al.*, 2003; Kelly *et al.*, 2007). This is especially the case in Taiwan, where students may learn the symptoms of immune-related diseases in elementary and junior high school; however, the mechanism of immune responses is not clearly addressed until they enter senior high school. Because the processes and connections among different lines of human immunological defense are much more abstract than any of the other biology topics, and students usually do not have sufficient prior knowledge when they first encounter the topic, student comprehension in human immunology is substantially below average (Cheng and Chen, 2008, 2009). Even for teachers, knowing how to coherently explain the molecular and biochemical aspects of the immune system to students seems to be a challenging task (Eckert *et al.*, 2004); hence, most teachers are likely to employ traditional lectures for teaching human immunology. However, the traditional didactic instructions are often teacher centered without any interaction between students and teachers or between student peers, all of which leads to the lectures being boring and ineffective.

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The importance of play in a child's mental development has been supported by extensive research in a variety of disciplines (Short *et al*., 2011). When children play a game, not only does it simply reflect the level of cognitive development that has been attained, but it also consolidates the skills, actions, and meanings that have been acquired (Verenikina *et al*., 2003). Play facilitates learning as it creates and scaffolds a broader *zone of proximal development* wherein children are involved in tasks slightly above their abilities (Vygotsky, 1967). Children and adults alike do play and learn from play, regardless of whether the play is more goal directed for adults or more simple for children to spontaneously enjoy, engage in, and undertake for its own sake (Mann, 1996). The value of play and games in education is important and should not be underrated.

In terms of games, their features—being challenging, imaginative, and delightful; being embedded within a narrative; and exhibiting clear rules—provide a perfect context for students to engage and learn (Garris *et al*., 2002; Cheng *et al*., 2013). Out of the many and various game types, a card game in particular is the most advantageous for enhancing student learning. First, it is physical and can be played anywhere using actual cards and with face-to-face interaction between players. The cards are convenient and easily produced. Second, it is well structured, so game rules can be easily integrated with instructional content to make abstract and complicated concepts intuitive and lucid to students. Third, it is competitive; players have to conquer their opponents through collaborating with their partners by using different learning strategies, and the collaboration between peers has been shown to have many significant advantages for learning. Finally, it works along the dual lines of not only presenting the instructional content in texts, but also of creating a simulated situation that allows learners to be absorbed in actively manipulating various strategies to construct knowledge and solve problems (Van der Linden *et al*., 2000; Baker *et al*., 2005).

Because the biological process of immune cells interacting with and destroying invasive pathogens is often described by using a metaphor of combat (Kelly *et al*., 2007), researchers argue that it could readily be incorporated into the rules of play of an interactive card game whose theme is often combat as well (Steinman and Blastos, 2002). Therefore, in this study, an educational card game was developed and integrated into the teaching of human immunology in senior high school settings. It is assumed that if the scientific concepts of human immunology can be suitably integrated into a card game format, then students might be more engaged and absorbed in the game context and will achieve better learning results than with traditional, didactic instructions. Hence, this study attempts to investigate the impact of the educational card game on senior high school students' understanding of immunology and their perceptions toward learning through playing educational card games.

ABOUT THE EDUCATIONAL CARD GAME

Scientific concepts of human immunology are involved in the game. The first line of immunological defense is nonspecific and includes physical, chemical, and mechanical barriers that are usually controlled by the skin or mucous membranes to keep pathogens outside the body. The second line of immunological defense, which begins after a tissue is damaged or an antigen is detected inside the body, includes phagocytosis and inflammation to rid the body of invaders. As phagocytes ingest pathogens and present antigens to helper T-cells, the third line of immunological defense is triggered. It is specific immunity, including the activation of B-cells and cytotoxic T-cells, to target a specific antigen and destroy anything carrying it. The physiological process of human immunological defense is shown in Figure 1. The design of the educational card game attempts to embed the concepts of human immunology in the game context (by presenting the scientific concepts in text on the cards) and integrate the complicated process of how the immune system works into the game's rules of play.

Game Cards

The educational card game we developed consists of three types of cards, *immunity cards*, *disease cards*, and *effect cards*. Each card has three components, which include a title, a graphic representation, and a brief description. The description on the immunity and disease cards introduces the scientific facts with regard to their function and attribution, which allows players to review the scientific content while playing the game, and the description on the effect card delineates the game rules of how it can be used. An example of each of the three types of game cards is shown in Figure 2. In addition, the immunity and disease cards each have a number of points that show how many health points (HP) the immunity card can defend or the disease card can attack.

Immunity cards include skin, mucosa, phagocytes, B-cells, helper T-cells, cytotoxic T-cells, and so forth. These cards should be used according to the scientific description of physiological regulation of human immunological defense. Hence, immunity cells of the second line of defense are allowed to be used only when the cells of the first line of defense have been used, and B-cells and cytotoxic T-cells can be used only by helper T-cells that have been activated by phagocytosis. Disease cards comprise immune-related diseases, such as hay fever, Dengue fever, smallpox, malaria, and rabies. The use of disease cards can create simulated contexts wherein a human body is attacked by a variety of invasive pathogens. Effect cards are *crown of the king*, *magic drug*, and *death summoning*, which are cards for increasing the playability and playfulness of the game. For example, magic drug is a card that can cure any disease. If players use this card, then they do not lose any HP, regardless of whatever disease cards their opponents use to attack them. To conquer opponents, players and their partners have to discuss and carefully consider how to arrange their cards to attack their opponents or to defend themselves from the attacks of different diseases played by their opponents.

Game Board

In addition to game cards, an illustrated game board is needed (Figure 3). The game board consists of two components—a layout area and a scoring (HP) column. Players and their opponents each have their own layout area in which a maximum of 14 game cards can be placed. Between the two layout areas is a scoring column indicating the number of HP that each side possesses. The initial value of HP for both sides is 200 points, and it gradually decreases as game progresses and a series of battles between the two sides take place.

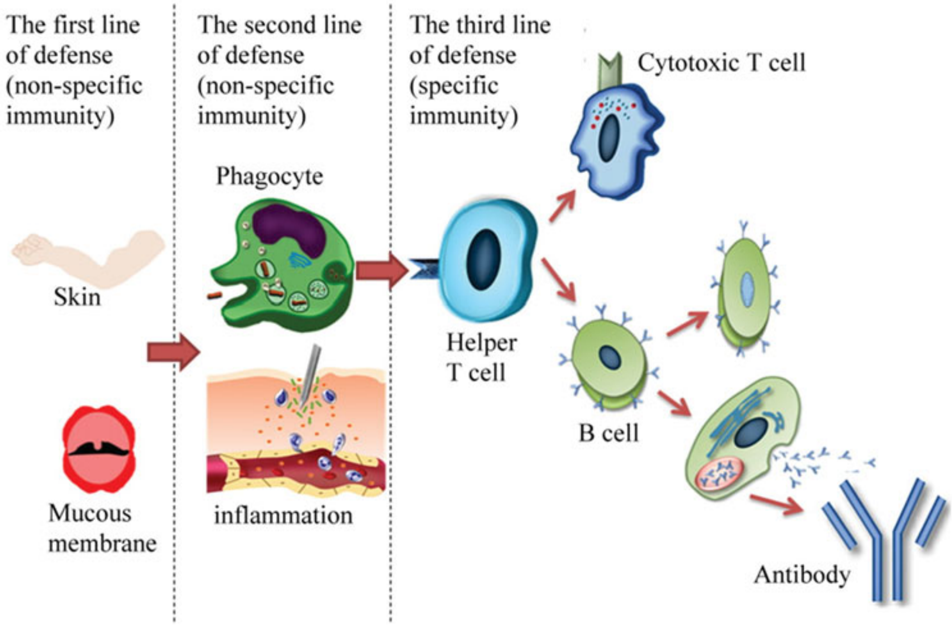

Figure 1. The physiological processes of the human immune system. The educational card game should be played according to the scientific description of physiological regulation of human immunological defense. Immunity cells of the second line of immunological defense are allowed to be used only when the cells of the first line of defense have been used, and B-cells and cytotoxic T-cells can be used only by helper T-cells that have been activated by phagocytosis.

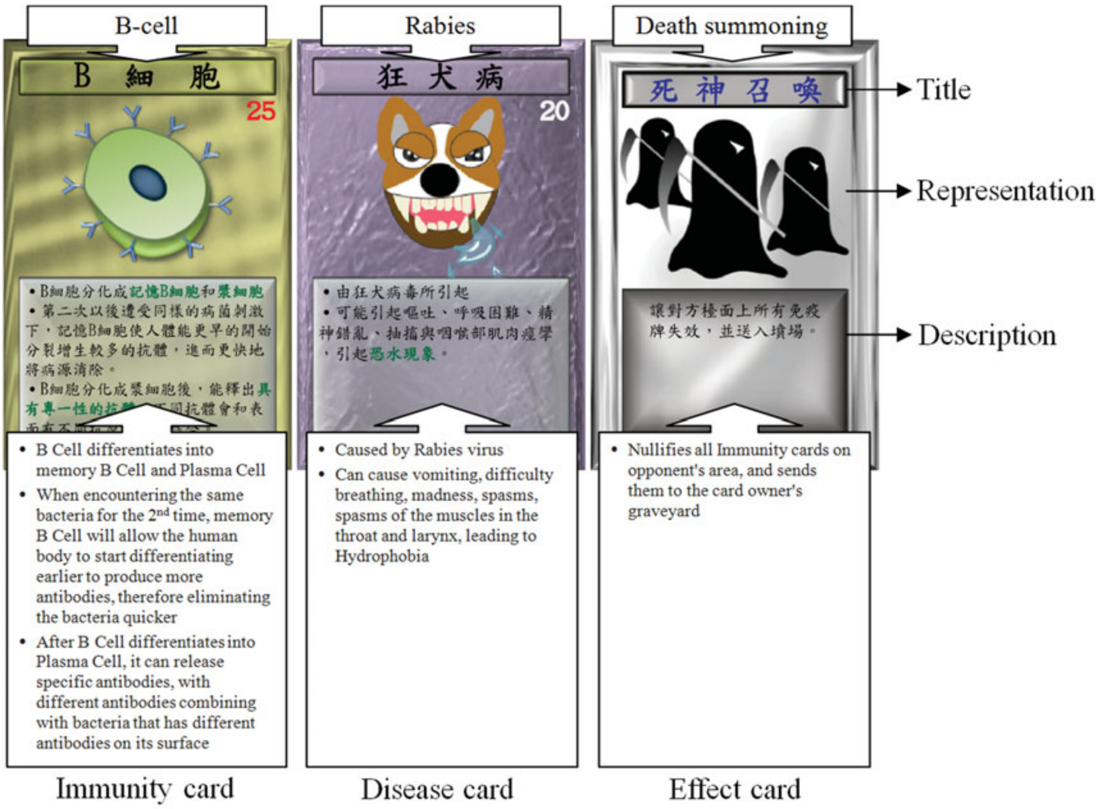

Figure 2. Examples of game cards. The educational card game consists of three types of cards, immunity cards (with yellow background, left), disease cards (with purple background, middle), and effect cards (with white background, right). Each card has three components: a title, a graphic representation, and a brief description. The immunity and disease cards each have a number of points that show how many HP the immunity card can defend or the disease card can attack, and effect cards are designed for increasing the playability and playfulness of the game.

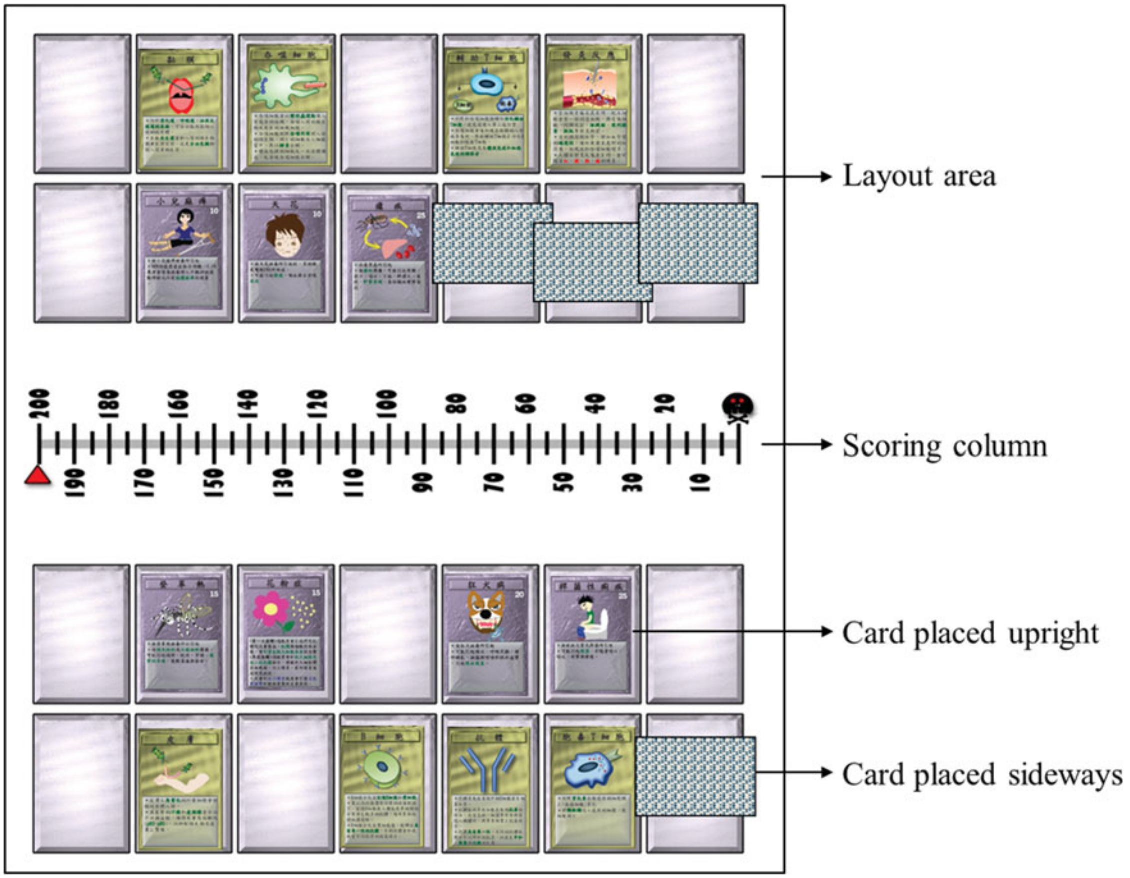

Figure 3. Game board. The game board consists of two components: a layout area and a scoring (HP) column. The players and their opponents each have their own layout area, and between the two layout areas is the scoring column indicating the HP that each side possesses. The cards can be placed either upright or sideways. The cards are used for direct attack if they are placed upright; if placed sideways, they are used for counterattack.

How to Play the Game

The game is a typical battle game involving two players or two teams (each team has two to four players) playing against each other. The round begins with each side having a layout of cards that are initially face down. The cards can be placed either upright or sideways (Figure 3). The cards are used for direct attack if they are placed upright; if placed sideways, they are used for counterattack. After finishing the layout, both sides turn over only their cards that are placed upright for direct attack on the game board, and players use their turns to attack their opponents or defend themselves. The other side can then determine whether a counterattack has been initiated or not by turning over the card placed sideways to resist a direct attack by the opponent. When the HP value of either side decreases to zero, the game is over. Video demonstration of how to play the game is provided (English: http://youtu.be/FmJvufpzU0g; Chinese: http://youtu.be/_m4dTAqmi8k).

Although we drew much inspiration from the game developed by Steinman and Blastos (2002), there are two key differences in our game design. First, we tried to embed the learning materials in the game context (by presenting the scientific concepts in details in text on the cards instead of only providing brief features), with the intention that players can review the content on the cards while playing the game. Second, rather than creating a game with easy attack and/or defense moves occurring on each turn (Steinman and Blastos, 2002), we put much effort into integrating the complicated process of how the immune system works into the game's rules of play. It is the most distinguishing and valuable feature of our game design that the cards should be used according to the scientific description of physiological regulation of human immunological defense.

RESEARCH QUESTIONS

Because human immunology is a topic that is generally introduced to students in the senior high school science curriculum in Taiwan, this study was conducted in senior high school settings. Two research questions were addressed:

1. Does learning through playing the educational card game improve students' knowledge acquisition?
2. What are students' perceptions of learning through playing the educational card game?

METHODS

Participants

To assess the effectiveness of the educational card game, we conducted two semesters of evaluation. We first asked the instructors to participate, and then we recruited all classes of the collaborative instructor as participants. Three classes were included in the first-semester evaluation, while the second semester included two classes.

First Semester. A total of three classes that included 99 senior high school students (11th graders) participated, and a quasi-experimental research design was conducted. The students in the three classes had been taught by the same instructor since they were in 10th grade. Two of the three classes (62 students) were randomly assigned to the experimental group and learned through playing the educational card game, and one class (37 students) was assigned to the control group that received traditional didactic instruction. The three classes were selected from a senior high school located in the middle of Taiwan. In Taiwan, students are required to take the annual Basic Competence Test (BCT), which is a national standardized test that measures educational achievement, in order to progress to senior high school, and only the top 10% of examinees are qualified to enroll in this school. The school randomly assigned all the students into different classes using the method of heterogeneous grouping, which ensured a relatively even distribution of students with different abilities and instructional levels in the three classes. Moreover, there was no significant difference between the three classes in terms of their performance on the pretest of knowledge assessment ($F = 2.14$, $p > 0.05$). This implies that the students in the three classes were equivalent and had the same level of knowledge regarding human immunology before the different instruction format was employed.

Second Semester. The participants from two 11th-grade classes (in total, 72 students) were recruited from a senior high school located in northern Taiwan for the second-semester evaluation. This school has a lower entrance requirement than the first one; the top 25% of examinees of BCT are qualified for enrollment. Similarly, the school randomly assigned all the students into different classes using the method of heterogeneous grouping. A quasi-experimental research design was conducted. One class (35 students) was assigned to the experimental group, and the other class (37 students) was assigned to the control group. The students in the two groups were found to be equivalent with regard to their understanding of human immunology before instruction, as there was no significant difference between the two groups in terms of their performance on the pretest of knowledge assessment ($t = 1.30$, $p > 0.05$).

Instrumentation

Assessment of Learning Outcomes. Two methods were used to assess the students' concept learning. One method was a knowledge test with 30 multiple-choice questions that examined students' understanding of the first (one item), second (eight items), and third (14 items) lines of immunological defense, activation mechanisms (one item), and immunological abnormalities (six items). For details, see the Supplemental Material. All test materials were covered by lectures and the card game (either integrated into the game rules or presented as descriptions on the cards). One point for each item was given if the answer was correct; otherwise the score was zero; hence, a maximum of 30 points was possible. The Kuder-Richardson formula 20 value obtained from a pretrial study ($n = 80$) was 0.81, indicating a good reliability. Moreover, an immunologist was also invited to review the questions for accuracy and errors, as well as to ensure the content validity. As multiple-choice questions often reflect a recognition or comprehension level of understanding, an open-ended question assessing free recall of information from understanding was additionally distributed. This open-ended question was designed to require students to write down the detailed functions of each line of defense and the processes and connections among them.

Questionnaire of Students' Perceptions. The questionnaire has two dimensions—students' perceptions of the instruction (four items) and its learning efficiency (four items). For example, "The instruction is interesting to me" is a statement describing perceptions about the instruction, and "The instruction makes it easier to understand the three lines of defense" is a sentence delineating learning efficiency. A five-point Likert scale (1 = strongly disagree to 5 = strongly agree) was used. Cronbach's α for the two dimensions was 0.83 and 0.76, and for the whole instrument, it was 0.86.

Procedure

Two three-session (50 min each) instructions were developed, and four major concepts of human immunology were involved in the instruction—three lines of defense and immune-related diseases (Figure 4). Considering that senior high school students in Taiwan have insufficient prior knowledge, as the mechanism of immune responses is not clearly addressed before this level, the instructions were designed with the intention that students could name the characters of the human immune system and understand the overarching concepts concerning cell interactions. And because the game was designed to use disease cards and immunity cards to create simulated contexts wherein a human body is attacked by a variety of invasive pathogens and defends via the immune system, the immune-related diseases were limited to mostly infectious diseases. The instruction did not emphasize diseases caused by other mechanisms (e.g., trauma, hereditary disease, environmental toxins), but it did introduce HIV-AIDS and autoimmunity to students through lectures. Specific learning objectives were addressed (Table 1).

Generally, teaching with lectures that used PowerPoint presentations was used in the first two sessions for both groups. However, the game-based instruction for the experimental group was additionally integrated with game cards to introduce related concepts (as the scientific concepts are also presented in text on the cards). Therefore, both groups received the same lecture content in the first two sessions. In the third session, students in the experimental group were initially introduced to the game rules by the instructor and were then divided into small teams to learn through playing the game on their own. The instructor acted as facilitator to help solve any problems the students might encounter and to clarify the rules for students when the students were playing the game.

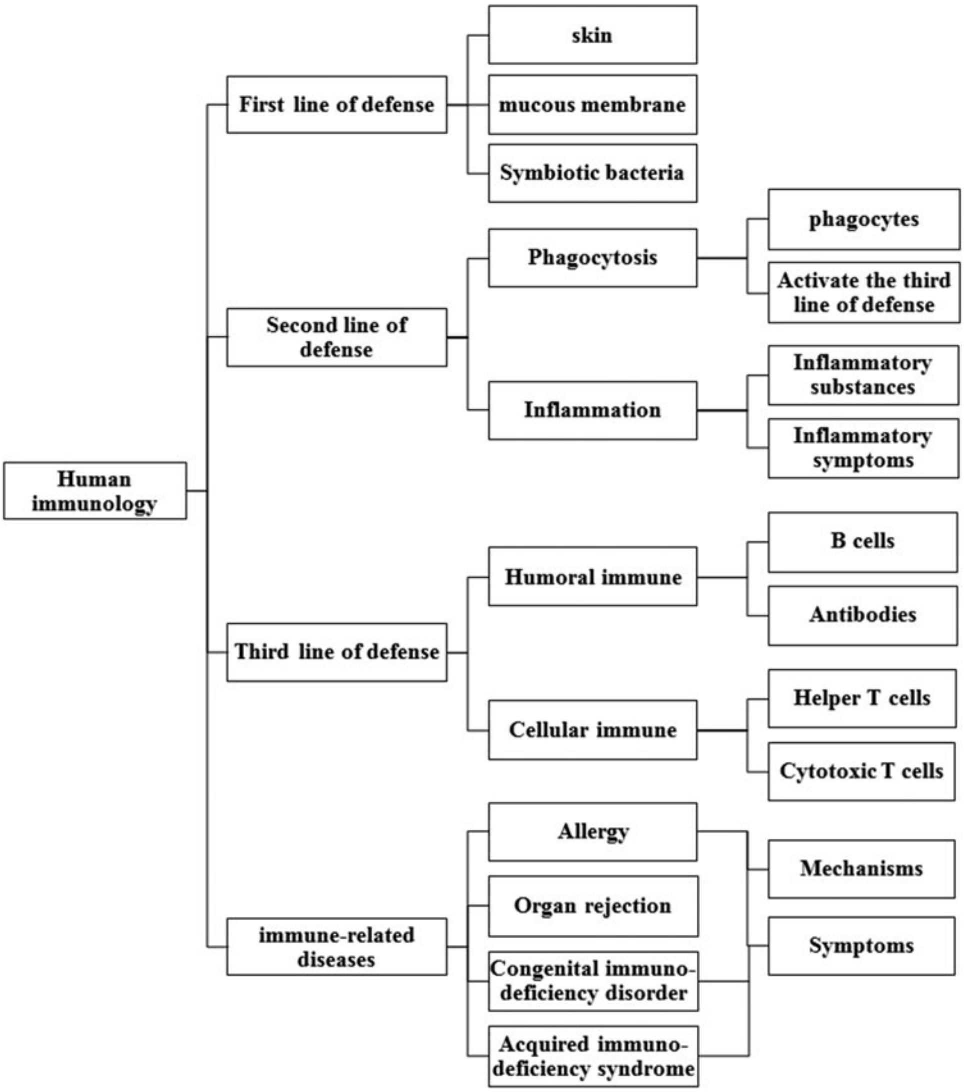

Figure 4. The conceptual framework of the human immune system. Four major concepts of human immunology are involved in the card game–based instructions: three lines of defense and immune-related diseases.

In contrast, the control group reviewed the whole process of human immune system in an instructor-led session (Table 2).

Two slightly different versions of a worksheet, according to the different instructional designs used for the two groups, were developed and used for assisting students' learning in the three sessions. Generally, both of the worksheets included four parts illustrating the four major concepts of human immunology. The worksheets provided students with either many descriptions of the scientific concepts for which they had to fill in the blanks or with a concept map that students were required to complete. The only difference was that the worksheet for the game-based instruction was integrated with the presentations and descriptions on the game cards to introduce related concepts.

The assessment of learning outcomes was administered to students as a pretest before the three sessions of instruction were conducted. Then, the same instructor taught both groups, with different instruction designs, for 1 wk. A posttest of learning outcomes was carried out later. Taking into consideration that the students had no prior knowledge with which to respond to the open-ended question before instructions, it is worthwhile to note that we only administered a multiple-choice knowledge assessment as the pretest. And for the posttest, both an identical knowledge test with different question order and the open-ended question were included. Moreover, the questionnaire of students' perceptions was additionally administered to students in both groups after interventions. In brief, the pretest was conducted a week before the interventions, and the posttest was generally administrated on the day after the interventions.

The research procedure was repeated twice in two different semesters in an attempt to demonstrate that the findings are replicable. All the instruction for the two semesters of evaluation were offered by the same instructor (T.S.), which acted as a control for the three sessions across both groups.

Table 1. Learning objectives of the instruction on the regulation of human immunology

Learning objectives	Specific goals
After receiving instruction on the regulation of human immunology, students are expected to be able to:	
1. Understand the first line of human immunological defense.	1.1. Name the aspects of the first line of defense. 1.2. Describe typical external barriers that organisms present to invading organisms.
2. Understand the second line of human immunological defense.	2.1. Name the aspects of the second line of defense. 2.2. Describe the processes involved in the nonspecific inflammatory response.
3. Understand the third line of human immunological defense.	3.1. Name the aspects of the third line of defense. 3.2. Distinguish between antibody-mediated and cell-mediated patterns of defense.
4. Recognize specific and nonspecific immunity.	4.1. Define what specific immunity and nonspecific immunity are. 4.2. Explain the differences and connections between specific and nonspecific immunity.
5. Comprehend the physiological regulation of the human immunological defense.	5.1. Explain the processes and connections among different lines of defense.
6. Recognize immune-related disease.	6.1. Name some examples of immune failures. 6.2. Identify which weapons in the immunity arsenal failed in each case of immune failures. 6.3. Apply the learned concepts of human immune responses to solve the problems encountered in daily life.

Data Analysis

Paired-sample *t* tests were conducted to investigate the differences between the pretest and posttest in both groups, and one-way analysis of covariance (ANCOVA) was run to examine the difference in knowledge assessment between the two groups. The scores of the pretest were used as a covariate, and the dependent variable was the posttest. Moreover, a scoring rubric devised in consultation with one science educator was developed for rating students' performance on the open-ended question. The scoring rubric includes a total of 13 items divided into four categories: classification of the immune system's line of defense (items 1–2), characters of the immune system (items 3–6), the mechanism of characters of the immune system (items 7–11), and the processes and connections between different lines of defense (items 12–13). Different numbers of points were given according to the integrity of students' answers, resulting in a maximum of 75 points for the question (Table 3).

For the first-semester evaluation, three experienced teachers were invited to individually rate all the student responses based on the scoring rubric. The raters were blind to the student group and did not know what group each respondent was in. Because three raters were included in this study, Kendall's *W*, a nonparametric method to measure the correlation or relationship among several rankings of individuals, was used to determine the interrater agreement (Seigel, 1956; Arrindell *et al.*, 2002). The coefficient of concordance (Kendall's *W*) between the three raters was 0.60 ($p < 0.05$), indicating an acceptable interrater reliability (Nunnally, 1978; Flessi, 1981). Then, only one of the three experienced teachers who were blind to the student group was invited to rate all the student responses based on the scoring rubric for the second-semester evaluation.

A series of independent-sample *t* tests were conducted to investigate students' performance on the open-ended question. For students' perceptions, a series of independent-sample *t* tests were also used to compare the difference in perceptions of the instruction and its learning efficiency between the two groups.

RESULTS

Concept Learning

First Semester. The mean score of the pretest was 14.20 (SD = 3.27) for the experimental group and 12.83 (SD = 3.08) for the control group; and for the posttest, the mean score of the experimental group was 22.76 (SD = 4.19), and for the control

Table 2. The design of instruction for both the experimental and control groups

	Experimental group	Control group
First session	Introduction to the first and second lines of immunological defense: teaching with lectures and game cards	Introduction to the first and second lines of immunological defense: teaching with lectures
Second session	Introduction to the third line of immunological defense and immune-related diseases: teaching with lectures and game cards	Introduction to the third line of immunological defense and immune-related diseases: teaching with lectures
Third session	Learning through playing the educational card game	Reviewing the whole process of the human immunological system response: lectures

Table 3. Coding rubric for the open-ended question

	Scoring categories	Points
Classification of the immune system's line of defense		
1.	Marked out specific immunity and nonspecific immunity	2
2.	Marked out that the body's immune system is separated into a first line of defense, a second line of defense, and a third line of defense	3
Aspects of the immune system		
3.	The main defender in the first line of defense is the physical barrier	2
4.	The main defenders in the second line of defense are phagocytes and inflammation	2
5.	The main defenders in the third line of defense are helper T-cells, cytotoxic T-cells, and B-cells	3
6.	Indicated that the components that will generate memory cells are helper T-cells, cytotoxic T-cells, and B-cells	3
The mechanisms of the immune system		
7.	Marked out the defense mechanism of the physical barrier	10
8.	Marked out the defense mechanism of phagocytes	5
9.	Marked out the defense mechanism of inflammation	5
10.	Marked out the defense mechanism of cytotoxic T-cells	5
11.	Marked out the defense mechanism of B-cells	5
The processes and connections among different lines of defense		
12.	Marked out the essential connection from nonspecific immunity to specific immunity	10
13.	Indicated that the third line of defense requires helper T-cells to activate cytotoxic T-cells and B-cells	20

group, it was 23.49 (SD = 5.06). The analyses of paired-sample t tests show that students' performance on the posttest was significantly better than the pretest in both groups (Table 4). The homogeneity of within-class regression coefficient ($F = 2.23$, $p > 0.05$) and Levene's test of homogeneity ($F = 0.61$, $p > 0.05$) were insignificant; hence, one-way ANCOVA proceeded. The results of ANCOVA show that there was no significance in the scores of posttest knowledge between the experimental and control groups ($F = 0.23$, $p > 0.05$), illustrating that both methods of learning can be effective.

Table 5 presents the results of independent-sample t tests between the two groups regarding student performance on the open-ended question. The results indicate that students in the experimental group significantly outperformed their counterparts in the control group in terms of their understanding of the processes and connections among different lines of defense ($t = 2.92$, $p < 0.01$).

Second Semester. As shown in Table 4, the mean score of the pretest was 12.37 (SD = 3.36) for the experimental group and 13.49 (SD = 3.86) for the control group; and for the posttest, the mean score of the experimental group was 15.54 (SD = 5.35), and for the control group, it was 15.89 (SD = 5.59). The results of paired-sample t tests demonstrate that student performance on the posttest was also significantly better than the pretest in both groups, and one-way ANCOVA indicates there was no significance in student performance on the knowledge test between the experimental and control groups ($F = 0.18$, $p > 0.05$). That both methods of learning can be effective for student knowledge acquisition was again evidenced.

The analyses of independent-sample t tests of student performance on the open-ended question (Table 5) demonstrate that learning through educational card game play was much more effective than traditional lectures in enhancing students' free recall of information with regard to their understanding of aspects of the immune system ($t = 4.62$, $p < 0.01$), the mechanisms of the immune system ($t = 2.13$, $p < 0.05$), and the processes and connections between different lines of defense ($t = 3.45$, $p < 0.01$).

Students' Perceptions

First Semester. Regardless of the students' perceptions of the instruction or its learning efficiency, the mean values of students' responses to each item were greater than 4 in the experimental group (Table 6). Moreover, compared with those

Table 4. Result of paired t test showing the difference between the pretest and posttest of knowledge assessments for both treatments

		Pretest		Posttest		t value	
	n	Mean	SD	Mean	SD	(post − pre)	Cohen's d
First semester							
Experimental group	62	14.20	3.27	22.76	4.19	12.63**	2.28
Control group	37	12.83	3.08	23.49	5.06	9.74**	2.55
Second semester							
Experimental group	35	12.37	3.36	15.54	5.35	3.25*	0.71
Control group	37	13.49	3.86	15.89	5.59	2.73*	0.50

*$p < 0.05$.
**$p < 0.01$.

Table 5. Results of independent *t* tests showing the difference in students' performance on the open-ended question between the experimental and control groups

	Experimental group		Control group		t value	
	Mean	SD	Mean	SD	(E − C)	Cohen's d
First semester						
Classification of the immune system's line of defense	2.54	1.44	3.09	1.38	−1.61	
Aspects of the immune system	6.79	2.24	5.91	2.77	1.75	
The mechanisms of the immune system	5.14	6.24	6.38	7.41	−0.75	
The processes and connections between different lines of defense	24.29	10.65	15.44	14.27	2.92**	0.73
Second semester						
Classification of the immune system's line of defense	0.49	1.09	0.73	1.24	−0.88	
Aspects of the immune system	3.97	2.91	1.16	2.19	4.61**	1.09
The mechanisms of the immune system	2.43	2.54	0.95	3.30	2.13*	0.50
The processes and connections between different lines of defense	10.29	10.14	2.70	8.38	3.45**	0.82

*$p < 0.05$.
**$p < 0.01$.

who received traditional didactic lectures, the students who learned through playing the educational card game considered the instruction to be more interesting ($t = 2.79$, $p < 0.01$).

Second Semester. Table 6 indicates that the means of students' responses to each item of their perceptions of the card game–based instruction and its learning efficiency were greater than for traditional lectures. Significant differences between experimental and control groups were revealed in terms of their responses to the items "The instruction increases my learning motivation" ($t = 2.48$, $p < 0.05$) and "The instruction is interesting to me" ($t = 2.41$, $p < 0.05$).

The results indicate that students positively perceived the card game–based instruction as interesting and motivating

Table 6. Results of independent *t* tests showing the difference in students' perceptions between the experimental and control groups

	Experimental group		Control group		t value	
	Mean	SD	Mean	SD	(E − C)	Cohen's d
First semester						
Perceptions of instruction						
1. The instruction increases my learning motivation.	4.00	0.84	3.86	0.71	0.82	
2. The instruction is interesting to me.	4.21	0.73	3.78	0.75	2.79**	0.59
3. The instruction is effective for me to learn human immunology.	4.14	0.81	3.97	0.69	1.09	
4. The instruction increases my mastery of the content of human immunology.	4.15	0.70	4.11	0.77	0.26	
Perceptions of learning efficiency						
1. The instruction makes it easier to understand the three lines of defense.	4.31	0.67	4.22	0.82	0.63	
2. The instruction makes it easier to understand the activation sequence of human immunological defense.	4.34	0.70	4.19	0.81	0.10	
3. The instruction makes it easier to understand the relationships among the three lines of defense.	4.11	0.80	4.19	0.85	−0.44	
4. Overall, the instruction benefits my learning of human immunology.	4.16	0.82	4.14	0.79	0.17	
Second semester						
Perceptions of instruction						
1. The instruction increases my learning motivation.	3.77	0.84	3.27	0.87	2.48*	0.58
2. The instruction is interesting to me.	3.71	0.89	3.24	0.76	2.41*	0.57
3. The instruction is effective for me to learn human immunology.	3.74	0.85	3.57	0.80	0.90	
4. The instruction increases my mastery of the content of human immunology.	3.89	0.90	3.62	0.83	1.30	
Perceptions of learning efficiency						
1. The instruction makes it easier to understand the three lines of defense.	3.80	0.90	3.62	0.89	0.84	
2. The instruction makes it easier to understand the activation sequence of human immunological defense.	3.86	0.81	3.51	0.99	1.62	
3. The instruction makes it easier to understand the relationships among the three lines of defense.	3.89	0.90	3.51	0.96	1.69	
4. Overall, the instruction benefits my learning of human immunology.	3.86	0.91	3.78	0.85	0.35	

*$p < 0.05$.
**$p < 0.01$.

and agreed that the card game–based instruction facilitated their understanding of how the immune system works.

DISCUSSION

Human immunology, which is usually taught through traditional, didactic instruction in the classroom, is often considered a complicated and confusing topic for students to learn. To improve students' understanding and increase their interests, an alternative method that is more interactive and student centered is really needed. Previous research has revealed that card games can be a useful teaching and learning tool and play an important role in the whole teaching–learning process (Schneider *et al.*, 2012); however, the target audience in previous studies was often medical students. Moreover, although some of the previous studies have demonstrated that many strategies, such as inquiry-based, problem-based, project-based, or technology-integrated approaches, are beneficial for students to learn immunology or cell biology, they often focus on the impact in the undergraduate or graduate context (Allen and Tanner, 2003; Debard *et al.*, 2005; Millar *et al.*, 2012). The conjecture might be that the educational policy in many other countries is different from Taiwan's and that teaching of immunology at the high school level is not common in Western countries. After considering that senior high school students may have difficulties in inquiry-based activities because of their insufficient prior knowledge and skills, a game-based approach was used. Therefore, to facilitate students' learning, this study aimed at developing an educational card game that integrates scientific concepts of human immunology with game features to create contexts wherein students simulate how the immune system works through a series of battles between pathogens and immune cells. Moreover, this study further conducted a preliminary investigation on the effectiveness of the educational card game from the perspectives of knowledge acquisition and students' perceptions of the game-based instruction and its learning efficiency.

The results obtained from this study indicate that the game had a more positive impact on senior high school students' learning of the processes and connections among different lines of defense according to the qualitative analysis of an open-ended question. This implies that learning through playing the educational card game is effective in helping students' concept learning. And especially when the concepts are related to complicated processes and mechanisms, the use of an educational card game might be more useful. Because the physical processes and effects of the human immune system are correspondingly incorporated into the game rules of play, through repeated practice and by employing different strategies to conquer their opponents by working with peers, students' understanding can be improved and elaborated. Namely, the use of the educational card game for learning human immunology is beneficial in improving student learning outcomes in higher-order processing of information than lectures, because the complicated processes and mechanisms of immune regulation can be directly reinforced by the game structure. Moreover, our research also found that students positively perceived the game-based instruction as interesting and motivating, making the abstract concepts of how the immune system works become more understandable. In other words, they felt that learning through playing the educational card game was both a useful instruction and an enjoyable experience. Hence, we believe that the educational card game reinforces the traditional didactic instruction in that it is not only an innovative and easier way of approaching and reviewing concepts of human immunology, but it can also be well accepted by students.

The positive impact of an educational card game found in this research is in alignment with previous studies (Da Rosa *et al.*, 2003; Eckert *et al.*, 2004; Beylefeld and Struwig, 2007; Valente *et al.*, 2009). However, as most of these studies were aiming at improving medical students' grasp of clinical treatment, there is still a lack of evidence showing the influence of an educational card game on senior high school students' learning of human immunology. Therefore, this study further reveals that our game is suitable for teenage students, because it allows students to actively construct their own knowledge and enhances their interests and motivations as well. Educational card game–based instruction can be very flexible, because it can not only be easily modified to fit different target audiences (Steinman and Blastos, 2002), but it also can be readily incorporated into instruction as a teaching and learning aid or used for after-school learning activities. The potential of educational card games in improving learning should not be overlooked.

It is worth noting that much lower knowledge gains across the board among students of the second semester of evaluation were found. Two conjectures are proposed. The lower entrance requirement (the top 25% instead of 10% of examinees of BCT enrolled in the school) might be one of the reasons why students generally had lower knowledge gains than see in the first group. As the participants of the second evaluation across the board have relatively lower educational achievement, it is not surprising that they had lower performance after receiving the intervention. Nevertheless, the fact that the intervention was offered at the end of the semester might be another reason. The second evaluation was conducted in the last week of the semester (just 1 wk before the winter break), when students may not be as attentive to learning materials, as they are looking forward to the celebration of the Chinese New Year in the coming week. This might also explain the lower performance.

Several limitations need to be acknowledged. First, because the multiple-choice test used for assessing student knowledge acquisition in this study is not a standardized or commercial exam, the unequal distribution of concepts being stressed (e.g., six out of 30 questions focused on inflammation, and three out of 30 questions emphasized allergy) might bias the results obtained with regard to student learning outcomes, even though efforts were made to ensure the test's reliability and content validity. Moreover, although we try to embed all the test materials into lectures and descriptions on the game cards with the intention that players can review the scientific content on the cards while playing the game, it seems that the design of the game cards is not as beneficial as we expect in concept learning, as students are so absorbed in competing with their opponents that they tend to neglect reviewing the descriptions on the cards. We suggest that a well-developed, standardized exam and a more optimal measure, rather than the current version of multiple-choice test, should be used and, further, that more scaffolding to ensure that students carefully review the descriptions should be designed in the following study. This would allow the impact of the educational card game on student concept learning to be accurately examined. For example, question prompts based on the descriptions could be embedded into game rules. In each round, students would have to correctly answer the questions first, before initiating their attack. This would require students to more carefully review the descriptions in order to answer the questions.

Second, one session of game play seems too short. In this study, we spent only ∼5–10 min introducing the game rules in order to give students more time to experience and master the game by themselves; however, one session of game play is really not enough to allow students to be exposed to the key concepts and information the game was meant to convey. Learning through playing games needs more playing time, which will allow students to actively grope about; the actual impact of educational card games might be underestimated if only 50 min of play is provided. In our opinion, two to three sessions of lecture still need to be dedicated to learning the fundamental concepts, after which playing the game would be a way to supplement the material already learned. Considering that the schedule of the science curriculum is particularly tight, we suggest the games and learning materials could be given to students or digitalized and made available for use after school hours. In this way, active learning might be more likely to occur and learning outcomes could be more enhanced, as students can carry out their own learning anytime and anywhere.

Third, although this study only reports the impact of the educational card game on senior high school students' learning, we further distributed the game in junior high school settings as well. This work is still in progress. Although human immunology is generally not a topic included in the junior high school science standard curriculum in Taiwan, we really hope that the game could be used for students of different ages to provide students with multiple learning approaches. We believe that if students can be given opportunities to learn immunology earlier in a more interesting way, they might not feel so confused and might have fewer difficulties learning this subject when they are in senior high school. The preliminary results indicate that students who learned through playing the educational card game not only increased their understanding but also used more metacognitive strategies, such as monitoring, planning, and regulating their cognition, to facilitate their learning. Learning through playing the educational card game requires students to collaborate and discuss with their partners how to figure out appropriate strategies to conquer their opponents. This kind of explicit discussion might have a huge potential in promoting students' planning and evaluation of their cognitive processes (Davis, 2003). Hence, because its effectiveness on students' learning is really significant, we suggest that, in the future, students of different ages could be reached using the game-based instructions.

CONCLUSIONS

Sociocognitive theory suggests that learning results from the reciprocal interactions between individuals, environments, and behaviors (Bandura, 1997). Namely, an effective learner should be motivationally involved in a learning activity and should use different strategies to actively facilitate their own learning. Developing a suitable instruction that will enable students to behave like effective learners becomes a challenging issue. Moreover, human immunology is often considered a difficult topic for both teachers and students, due to its complexity and abstract nature. Therefore, the issue of developing an effective instruction for students to learn the topic becomes all the more difficult. In our current research, we preliminarily investigate the effectiveness of an educational card game we developed on students' learning of human immunology and their perceptions of this innovative attempt. It is evident that high school students did learn the processes and connections among different lines of defense and enjoyed playing the game. Hence, we believe the educational card game has the potential to be an efficient learning tool and can be applied to secondary-level science courses in the field of biology. Its benefit in assisting learning needs to be further determined.

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