RISK LITERACY EDUCATION EXPERIMENT USING A PROBABILITY BOARD GAME

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Abstract: Besides probability and data analysis, there is a trend in education all across the world to include risk assessment into the teaching of uncertainty. Taiwan's "12 Year National Mathematics Education Outline" will be officially implemented in August this year (2019); however, the education system still lacks materials for teaching risk concepts. A probability board game called "Rise of a Singular Cloud" was designed by this study which is targeted at eighth grade students, and explores ways to teach students to understand and solve probability problems via games, while paying special attention to the development of the concept of risk assessment. This experiment also investigates students' ability to express probabilities in words, and their decision-making thought process. It is anticipated that the eighth grade students will be able to improve their probability knowledge and ability to express probabilities in words and will be able to cultivate an understanding of risk. From data obtained before and after the experiment, it was found that after playing "Rise of a Singular Cloud", the students' understanding of probability concepts improved. The study showed that: (1) Most students used intuitive thinking as a problem solving strategy before the game; however, after the game, they were able to use probability thinking to make decisions. (2) In terms of expressing probability in words, most students move from brief description of past experience to the narrative in probabilistic language. (3) When making risky decisions in "Rise of a Singular Cloud" we found that besides considering how to increase their chance of winning, students also considered how to protect their interests (sweets), and avoid losing everything when the wrong decision was made.

Keywords: probability concepts, risk literacy, board game

1. MOTIVES AND PURPOSES

This study looks at the rational methods for decision-making in uncertain situations, that is, the assessment of the chance of an event occurring using probability, then performing risk evaluation according to the expected value. Good decision making requires only the ability to utilize probability and risk evaluation, and the topic of uncertainty has started to appear in assessments for mathematics subjects internationally. Although risk assessment is not an independent subject, its related content can be found in many uncertainty tests all around the world. Not only is uncertainty regarded as important in probability and data analysis internationally, it is also included in risk assessment. Furthermore, studies conducted overseas has indicated that risk literacy can be taught to children from pre-school education onwards (Nikiforidou, Z., Pange, J., & Chadjipadelis, T. ، 2012), and that their understanding of uncertainty can be developed from elementary school onwards. Therefore, this paper conservatively holds the opinion that Taiwan should also implement uncertainty and risk assessment education during the basic education stage to inspire students to apply probability and statistics and perform risk assessments for success and failure in their decision-making process.

Board games have become a popular classroom activity in recent years and studies have shown that board games do more than just raise the interest of students. While playing games, students' motivation for applying mathematics increases which further assists competence development in other activities. In the course of the game, teamwork, problem solving, and communication discussions are involved. More importantly, board games can help students practice and apply multi-disciplinary knowledge and potentially expand their zone of proximal development (Vygotsky, 1978)..

As of 2019, the new "12 Year Basic Education" measures will be implemented in Taiwan. This study will design a probability course for teaching uncertainty and risk literacy by combining real life situations, background experience, and the "Rise of the Singular Cloud" game created by the researchers, in accordance to the mathematical directions set out by the Ministry of Education (2018). The course will combine real life situations and experiential concepts and use the researchers self-developed "Rise of the Singular Cloud" board game to teach probability. This study will reveal how well students can apply probability concepts to explain uncertainty after the experiment.

1.1. Key Questions

1. After playing and learning with the probability board game, will students have a better understanding of probability concepts?
2. What is the effectiveness of the probability board game in helping students develop their ability to express probabilities?

2. LITERATURE REVIEW

2.1. Types of Probability and Education

This paper used the four types of probabilities mentioned by Shaughnessy (1992): classical probability, frequentist probability, subjective probability, and formal probability. Since formal probability is a university level subject, it will not be discussed at this stage. The description for the other three types of probability is shown below (Wei-Chang Shann, Che-Yu Hsu, Fei-Ching Chen):

1. Subjective Probability

Subjective probability is a concept that was developed recently in the 20th century and is an expression of intuitive probability. It uses personal belief, or existing and determined probability values to model uncertain conditions intuitively while subjectively evaluating possibilities. In terms of application, values in subjective probability can be adjusted as new information appears which can be used to model how people rationalize the formation and changes in their own beliefs after obtaining new information (Borovcnik et al., 1991; Fischbein, 1975).

2. Classical Probability

Classical probability uses ratios of quantity to calculate probability. This type of probability includes all possible results (sample space), and the possibility for every type of result is equal. Under this premise, if there are n events in a sample space, then the probability of the occurrence of any event is 1/n.The premise of "equal probability" must be accepted when using classical probability; hence, it is also known as theoretical probability or prior probability.

3. Frequentist Probability

Repeated trials are used in frequentist probability and the relative frequency of occurrences is used as the probability. Under the premise of "independence", a random trial is conducted an infinite number of times and the relative frequency of an occurrence is used as the probability of the event. In practice, it is impossible to perform an infinite number of trials, therefore an estimation of the probability is obtained using a limited number of trial results. Frequentist probability is determined by experimental results. Therefore, it is also known as experimental probability.

This type of probability can be of practical use for performing rational analysis and decision assessments in uncertain situations according to definitions. However, the attitudes, beliefs, experiences, and verbal communication in actual life will affect the development of one's probabilistic thinking (Amir & Williams, 1999; Bognár & Nemetz, 1977). Fischbein also pointed out that children have a weak intuitive feel for probability which must be developed and enhanced via formal education (Fischbein, 1975). In particular, the expressions of conditional probability can easily confuse students, leading to misunderstanding of the topic (Shaughnessy, 1992). Therefore, the aforementioned types of probability should be flexibly applied to solve probability problems in real life situations, to support the learning of uncertainty, and the establishment of risk literacy.

2.2. Risk Literacy

People may encounter uncertainty and risk in everyday life. Therefore, there should be opportunities to learn risk assessment in school which should become one of the competencies that children develop (Little and Eager, 2008). Greenfield (2003, p.5) also indicated that the assessments involved in the games that children play are also essential for their development and education. This paper uses the definition of risk given by Harding (1998, p167) and Bernstein (1996, p377): predicting the occurrence frequency of risky events and the probability assessment of the degree of danger according to the changes in probability, and shifts from helplessness to choice, from loss to gained opportunities, and from primitive design to complexity. While the definition of risk literacy is: the collection of related evidence and the utilization of statistics and probability for decision-making in uncertain events (Spiegelhalter, 2009).

Risk assessment is usually affected by people's subjective consciousness, and their reaction to their psychological state and their intuition can lead to failure in information processing. Adams (2006) pointed out that from a young age, people think about the expected returns and loss resulting from their decisions. Tversky and Kahneman (1973) indicated that when people lack the ability to accurately determine the probability distribution, they tend to use a subjective method of decision-making such as representativeness heuristics, availability heuristics, and anchoring heuristics. These types of methods are effective in general situations; however it is also relatively easy to make systemic and predictive errors.

The aforementioned experiments all involve subjective probability thinking, therefore, that besides learning rational probability

assessment methods, the concepts of subjective probability with a focus on psychology and intuitive reactions should also be included in the curriculum. Hence, this study takes these factors as core elements of the course, in hope that students can learn about risk and communicate risk and probability with words.

2.3. Game Based Learning (Game-Based Learning, GBL)

From 2003 onwards, game-based learning has gradually become an important study topic in global education research (Mingfong Jan, Tieh-Huai Chang, 2018). Games can help learners build their ability for abstract thinking (Vygotsky, 1978), and allow students to learn how to assess risk by using their emotions, understanding, and strategies (Little and Eager, 2008).

In recent years, board games have been commonly used in classrooms and have played various roles in mathematics classes. They have been regarded positively by most. Caldwell (1998) indicated that board games can help improve arithmetic and problem solving skills, and can help vulnerable students to learn mathematics, so that they can catch up to their classmates (Cavanagh, 2008). Robert (2000) showed that board games can help teach learners how to use their money in the future, in other words, they can get a sense of the numbers. Board games also provide an opportunity for students to apply their knowledge and learning for investigation and critical thinking (Crews, 2011).

In the field of education, games are not just for fun, but can be knowledge-oriented at the same time. Games should be designed to connect the user with the objective (Hamari, 2013). Zichermann and Linder (2013) indicated that games should have three characteristics: 1. Personalization: the user should know how they are progressing in the game; 2 Friends: the user should be connected with a community; 3 Fun: the game should be entertaining or fun. This study will also apply the aforementioned design concepts to the self-developed "Rise of a Singular Cloud" board game to enable students to experience probability thinking and risk assessment through the game.

3. METHODS

This section describes the study subjects, the design of the "Rise of the Singular Cloud" board game, and the content related to the teaching of probability. It also describes how qualitative and quantitative analysis methods are used to analyze student performance after playing the game.

3.1. Study Subjects

A medium-size secondary school from Taoyuan, Taiwan was selected for this study (about 30 minute drive from the airport), and four eighth grade classes were taken as subjects for the experiment. Class A had 31 students, Class B had 29, Class C had 30, while Class D had 30 students. Taking away the students that were not present, the number of subjects from Class A was 28, Class B was 27, Class C was 29, Class D was 27, and the total number of students was 111.

3.2. Length of Study and Teaching Materials

This course is estimated to have 9 lessons and will be completed within a semester to reduce the study load of students. The curriculum includes introduction to the types of probability, enumeration and tree diagrams. The course involves a lot of information but this paper will only target the board game design and teaching effectiveness as the main focus. The remaining parts will not be discussed.

The teaching material used in this course was created by the research team, and was named after the author's last name, "Hsu's Probability". The contents include subjective probability, classical probability, and frequentist probability. The teaching material focuses on the use of the board game to help learners participate more proactively in classroom activities to learn about probability using the "learning by doing" approach. It is an alternate approach to the traditional education framework and motivates students to learn. This type of content is designed to comply with the education direction proposed in Taiwan's latest "12 Year National Education" framework.

3.3. Board Game

Design concept: the objective is to be able to communicate, express, solve problems, and perform risk assessment using probabilistic thinking.

History of the board game design: the online game "Splendor" was used heavily as a reference. Based on the experience with the online game and educational games, a fun and educational board game called "Rise of the Singular Cloud" was created which was set in medieval European times.

Introduction to the cards: there are three types of social classes, the poor, the commoner, and the nobility. The upper left side indicates the number of points, and the player will gain these points when they buy the card. Nobility cards have the highest ranking, and therefore, have the highest points. "The commoner" cards have the second highest ranking, while the poor cards have the lowest points. Each card has a different style and limited quantities. As shown in the Fig. 1.

"The poor" are the lowest social class, and are regarded as a commercial product. The value in the poor people cards is as a bargaining chip to be used in transactions to exchange for "the commoner" status, which is then used to purchase

even higher-ranking cards. “The commoner” is the second highest class and its value derives from the ownership of the produce from agriculture (represented as sweets in the board game). “The commoner” cards can also be exchanged to purchase “nobility” chips.

The “nobility” is the highest-ranking social class and has the most wealth and power (represented by sweets, biscuits, and privileges in the board game). For example, the “assign” privilege gives the group the right to choose another group to answer a question. If they get it right, the other group will gain a chip, if they get it wrong, they will lose a chip.

How to play: this is a timed competition, each group can play 2 to 3 times each lesson, and a quiz is given (mostly provability questions, with some cross-disciplinary questions). The game is hosted by the teacher who picks the question, assesses the students’ response (training for expressing probability in words), mediates card exchanges, etc. The market (blackboard) has 9 cards (3 of each class), which represents the scarcity of commercial products on the market, and is also selective (risk assessment). When the card exchange is complete, a card of the same class will be used to replace the card on the market.

How to win: the group with the highest total card score wins and will win a prize.

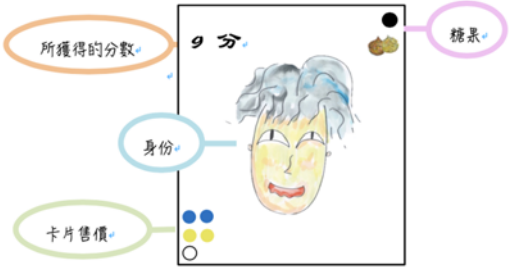

Fig. 1. Board Game Card

3.4. Probability Test

The “uncertainty” teaching material and the analysis standards for assessment (Wei-Chang Shann, Che-Yu Hsu, 2018) was used in this study, and the contents of the test paper were divided into “uncertainty knowledge” and “cognition”. 14 probability tests were developed which included classical probability, frequentist probability, and other probability concepts. After pretesting, the reliability of the test paper content was found to be 0.85.

The objective of this paper is to clarify the educational results of student’s understanding of probability concepts; therefore we will only look at the true or false questions which carry 1 point for every correct answer. The other questions in the paper will not be discussed. There is one question on subjective probability, 2 on classical probability, and 1 of frequentist probability. In terms of cognition, one of the classical probability questions is an uncertainty problem solving question and the other three are concept comprehension questions. The total number of participants in the pre and post-test experiment was 111.

3.5. Information Collection and Analysis

The study uses “quantitative analysis” and “qualitative analysis” methods for information analysis. In terms of quantitative analysis, the R programming language was used for descriptive statistics and *t*-test analysis to understand how well the students learnt with the board game experiment. In terms of qualitative analysis, the words that the students used were collected and analyzed.

4. RESULTS

4.1. Analysis of the tests before and after the course

Sample t-test is used in this study. Two tests were given to the students before and after the course and the probability questions were used for verification. The results are as shown in the table. It can be seen that the *p* value is obviously lower than 0.05, and there was an increase in average score. This shows that after learning with the board game, the students’ ability to answer conceptual true or false questions and ability to use probabilistic language for expression improved. Furthermore, we know from the rate of correct answers from the true or false questions that the students achieved better results in the tests after each topic lesson. This shows that the students showed improvements in their understanding of different concepts, as shown in the Table 1 and Table 2 .

Table1: Paired sample *t-test* - probability test

Type	Number of samples	Average score	Standard deviation	t value	Degree of freedom	p value
Test before probability course	111	5.16	1.97	-2.9619	110	0.003
Test after probability course	111	5.77	1.86			

Table 2: Rate of correct answers in true or false questions before and after the course

	T/F Question 1	T/F Question 2	T/F Question 3	T/F Question 4
Rate of correct answers before	0.65	0.47	0.46	0.69
Rate of correct answers after	0.72	0.51	0.55	0.85

4.2. Teaching of Probabilistic Language with Board Game Interaction

Understanding of the concept of subjective probability (true or false question 1)

> Dudu went to Taoyuan airport to see her favorite celebrity. In the previous 9 attempts, she did not meet her beloved boy band BTS, so therefore on the 10th attempt she should not go again.

This question introduces the concept of "the recency effect". The students had to determine whether Dudu going to try and meet her idol and "throwing a fair dice and getting a 6 after getting 6's on the previous 5 throws" is the same. If the situation is flipped, would the students get confused? The answer is determined either using subjective thinking or probabilistic thinking. We know from the results that in terms of probabilistic language, we notice that during the pre-tests, the students were unable to express the reasoning. However, after the course, they were able to use probabilistic thinking correctly and express it in words, and moved from not even having the right vocabulary to expressing with full descriptions. As shown in the Fig. 2. subjective probability examples.

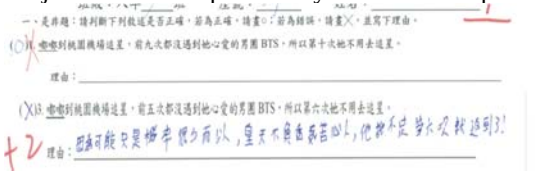

Fig. 2. subjective probability examples

Problem solving with uncertainty thinking in classical probability (true or false question 2)

> In the "Uniform Invoice" lottery, there are only two possible outcomes, "win" and "did not win", therefore the probability of winning is 1/2.

This question was used previously in the Taiwan National High School Examination and introduces the concept of "sample space distribution". We see from the results that before the course, most students would use representative heuristics to make decisions. However, after the probability course, the correct answer rate was approximately 50%, which represents the worst improvements. This shows that students have fallen into the trap of being unable to distinguish the meaning of "win" and "did not win", and failed to learn the concept of sample numbers in non-probabilistic thinking.

In terms of probabilistic language, some of the students were able to clearly understand that the sample number of people that "did not win" was more than the number of people that "won", therefore the probability of winning was lower. The other students relied on their own experience and said that the chances of winning were less than 50%, which means that these students could use their own life experiences to express probabilistic thinking. However, the students that answered incorrectly all intuitively divided the samples using the literal meaning of the question and believed that the probability of winning was 1/2, and were unable to correctly understand the sample space, as shown in the Fig. 3. classical probability examples.

Fig. 3. classical probability examples

Understanding of the concept of frequentist probability (true or false question 3)

> A fair six-sided die is thrown 120 times ("fair" means that the probability for landing on each side of the die is equal), and the number "6" occurred exactly 20 times.

In the test before playing the game, most of the students would use representative heuristic and write down "120×1/6=20", and believed that the description was true. Some of the students would use their previous experience and believe that the dice tosses would not yield 6's exactly 20 times. After learning about probability through the game, most of the students were able to use language to express probability as an ideal value, and was a value is acquired after many trials, as shown in the Fig. 4. frequentist probability examples.

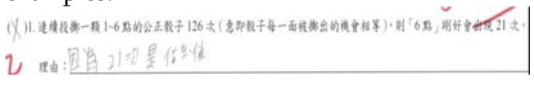

Fig. 4. frequentist probability examples

Understanding of the concept of classical probability (true or false question 4)

> A fair six-sided die is thrown ("fair" means that the probability for landing on each side of the die is equal), and the probability of getting a 10 is 10/6.

In the test before the course, the students were easily able to identify the description as false. From the reason given by students that "a die cannot land on a 10", the researchers determined that the answer was based on previous experience: a type of empirical intuitive inference. After completion of the probability course, the researchers discovered that students were able to express problems much better with words, and they understood how to use probabilistic language to describe the situation, and could describe probability as a value between 0 and 1, as shown in the Fig. 5. classical probability examples 2.

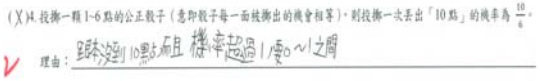

Fig. 5. classical probability examples 2

4.3. Reflecting on how students think about risk in the board game

During the timed quiz section, the students used language to express their answers one step at a time. This helps with their understanding of probabilistic "reading and interpretation". The teacher also gave feedback after listening to the students. When the teacher found that the student had made a mistake, they reminded them to "think again" to give students another chance at thinking about the problem, instead of giving the answer straight away. When the students were explaining their reasoning, they also discussed with their groups. During the discussions, they evaluated how to use probabilistic language to find solutions. The rate of error of their use of the specific language was low, and their accuracy improved. We discovered that students would use probabilistic language found in the examples and use similar concepts to describe the problem instead of describing using intuitive thinking.

The different classes that were presented during the buying and selling phase of the game, all had different cards, chips, points, and privileges. When students gained the privilege to make purchases, they must do so in a limited amount of time, and had to quickly read the limited number of cards on the blackboard and decide what combination to buy so that the group had the highest possibility of winning. Students also needed to consider how to avoid falling behind on points at every round. When they bought a privilege card, they had to decide how to use it to increase their own benefit. After the board game, the students would tally the score of each group and find out how they are doing. If they found that they could not win the game, they would change strategy and purchase agricultural produce cards (represented as sweets in the game). From the aforementioned information, we know that each decision (card group) is closely linked together and involves risk assessment. If only intuitive thinking is used, the chances of either victory or the "sweets" outcome would be higher.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

After the teaching and board game activity, most students no longer used intuitive thinking as their problem solving strategy when solving probability problems, but instead used probabilistic thinking, which relatively reduces the risk of deciding against the odds. In terms of probability language, most students went from having no experience with probabilistic thinking to having the ability to describe situations with probability language. The board game also brought a sense of competitiveness from the students. When purchasing cards and privileges, the students also performed a series of risk assessments. It was also discovered from the board game results that the students would size up the other groups, and will make a choice between buying the highest scoring cards to win the game and buying all the agricultural production cards. From the aforementioned observation, we know that the students actually used risk assessment concepts in order to gain the most benefit.

5.2. Recommendations

Uncertainty and risk assessment education will become a basic requirement for people of the nation. For most people, the neglecting of probabilistic concepts and methods, and the use of intuitive decisions are irrational. This study recommends that students should have the opportunity to learn probability and risk assessment during different stages of learning beginning from their basic education. In terms of lesson planning, "Hsu's probability" can be used as a reference for designing probability courses and the "Rise of a Singular Cloud" board game can allow students to experience risk thinking, and nurture their risk and uncertainty literacy.

REFERENCES

[1] Adams, J., (2006), Risk, Taylor & Francis: Routledge.

[2] Amir, G. S., & Williams, J. S., (1999), “Cultural influences on children's probabilistic thinking”, The Journal of Mathematical Behavior, 18 (1), pp.85-107. doi: 10.1016/S0732-3123(99)00018-8.

[3] Bernstein, P.L., (1996), Against the Gods: The remarkable story of risk, John Wiley: New York.

[4] Bognár, K., & Nemetz, T., (1977),” On the teaching of probability at secondary level”, Educational Studies in Mathematics, 8(4), pp.399-404. doi: 10.1007/BF00310944

[5] Borovcnik, M., Bentz, H. J., & Kapadia, R., (1991), “A probabilistic perspective. In R. Kapadia, & M. Borovcnik (Eds.), Chance encounters: Probability in education (pp. 27-71)”, Boston, MA: Kluwer Academic Publishers. doi: 10.1007/978-94-011-3532-0_2

[6] Caldwell, M. L., (1998). “Parents, board games, and mathematical learning”, Teaching Children Mathematics, 4(6), pp.365-367.

[7] Cavanagh, S., (2008), “Playing Games in Class Helps Students Grasp”, Math Education Week, 27, pp.43-46.

[8] Crews, A., (2011), “Getting Teachers on Board”, Knowledge Quest, 40(1), pp.10-13.

[9] Fischbein, E., (1975), The intuitive sources of probabilistic thinking in children, Dordrecht, The Netherlands: D. Reidel. doi: 10.1007/978-94-010-1858-6

[10] Greenfield, C., (2003), Outdoor play: The case for risks and challenges in children's learning and development, Safekids News, 21, 5.

[11] Hamari, J., (2013), “Transforming Homo Economicus into Homo Ludens: A Field Experiment on Gamification in a Utilitarian Peer-to-peer Trading Service”, Electronic Commerce Research and Application, 12, pp.236-245.

[12] Harding, R., (1998), Environmental Decision-making: the roles of scientists, engineers and the public. The Federation Press, Sydney.

[13] Hsu, C. Y., & Shann, W. C., (2018), “Developing an Analytical Framework to Assess the Uncertainty Teaching Materials and Assessment”, Association for Taiwan Educational Review, 7(10), pp.170-177.

[14] Little, H., & Eager, D., (2008), “Children need risk”, 17th International Play Association World Conference. Hong Kong.

[15] Ministry of Education, (2018), Curriculum Guidelines of 12- Year Basic Education, Taiwan.

[16] Mingfong Jan. and Tieh-Huai Chang., (2018). “Developing an Analytic Framework for Understanding Game-Based Learning”, International Journal on Digital Learning Technology ,10, pp.1-20.

[17] Nikiforidou, Z., Pange, J., & Chadjipadelis, T., (2012), “Risk literacy in early childhood education under a lifelong perspective”, Procedia—Social and Behavioral Sciences, *46*, pp.4830–4833. doi: 10.1016/j.sbspro.

[18] Robert, T. K., (2000), “Board game for teaching fundamental aspects of personal finance, investing and accounting”, Science Computer Review, 35(2), pp.147-166.

[19] Shaughnessy, J. M., (1992), Research in probability and statistics: Reflections and directions. In D. A.Grouws (Ed.), Handbook of research on mathematics teaching and learning: A project of the National Council of Teachers of Mathematics (pp. 465-494), New York, NY: MacMillan.

[20] Spiegelhalter, D., (2009), The Times, Times Newspapers Ltd.

[21] Shann, W. C., Hsu, C. Y., & Chen, F. C., (2018), “Investigation of ninth graders’ spontaneous probabilistic concepts in pop pretests and problem posing”, Taiwan Journal of Mathematics Education, 5(2), pp.39-64.

[22] Tversky, A. & Kahneman, D., (1973), “Availability: A heuristic for judging frequency and probability”, Cognitive Psychology, 5, pp.207-232.

[23] Vygotsky, L. S.(1978). *Mild in society: The development of higher psychological.* Cambridge, MA: Harvard University Press.

[24] Zichermann, G. and Linder, J., (2013), The Gamification Revolution: How Leaders Leverage Game Mechanics to Crush the Competition, 1st, New York: McGraw Hill.