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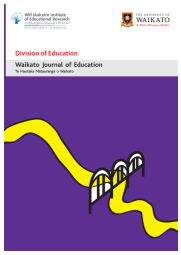

Teaching and learning probability using games: A systematic review of research from 2010–2020

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Abstract

Probability is a relatively new discipline in school curricula in many countries. There is a rich literature on students' personal beliefs and misconceptions in probability. However, less attention has been paid to the development of students' probabilistic thinking in the classroom. Recently, suggestions have been made to use games and simulations to overcome misconceptions in probability. This paper presents a systematic literature review that focuses on identifying games for the teaching and learning of probability at the school level. It maps out mathematics and statistics education research literature from 2010–2020 and targets student participants from Year 1–13 and pre-service teachers along with a set of inclusion and exclusion criteria. The analysis process identified six different categories of games that can be used in teaching and learning of probability. While many games discussed in literature involved the use of tokens, coins or dice, only one study used a cultural game to enhance student learning in probability. The paper draws some conclusions and offers suggestions for further research in this area.

Keywords

Games; probabilistic thinking; primary and secondary schools; culturally-responsive teaching; systematic literature review

Introduction

Probability is the measurement of uncertainty that is omnipresent in our everyday life situations (Koparan, 2019; Malaspina & Malaspina, 2020). Nikiforidou and Pange (2010) state that "every event is characterised by a sort of estimation about its probable, possible, improbable, desirable or unlikely outcome" (p. 305). Probability offers a tool for modelling and creating reality. For example, concepts of risk are closely related to and dependent upon probability. Misconceptions on probability can affect people's decision making in important situations, such as medical tests, jury verdicts and investment. In recognition of the importance of probability in both school and out of school settings, there has been a movement in many countries to include probability at every level in the mathematics curricula (Batanero

et al., 2016; Watson, 2006). These developments are reflected in official documents and in materials produced for teachers throughout the world. For example, probability is one of the three sub-strands of the Statistics strand in the New Zealand Curriculum document and is critical in mathematics learning (Ministry of Education, 2007). The use of meaningful contexts and drawing on students' experiences and understandings is recommended for enhancing students' probabilistic thinking (Naresh & Royce, 2013; Van de Walle et al., 2014). One example of meaningful contexts for probability can be provided through games (Batanero, 2013; Dayal, & Sharma, 2020). Malaspina and Malaspina (2020) argued, "games involve the learners in an active role of constructing mathematics" (p. 57) in a context. Games are often used in mathematics education for promoting the understanding of mathematical and statistical concepts.

Students love games, and playing games in the classroom can improve students' attitudes and motivation and encourage students at all levels to participate. Research has shown that game-based learning enriches the learning environment, improves the students' performance, increases the students' motivation, provides the opportunity to work with the group and provides a fun learning environment (Davies, 1995; Gürbüz et al., 2014; Nisbet & Williams, 2009). Rutherford (2015) asserts that playing games can encourage strategic mathematical thinking and support the development of computational fluency. Games have always played an important role in learning mathematics, encouraging mathematical thinking (Kamii & Rummelsburg, 2008). The games also help in building strong relationships between school and home learning environments. Chow et al. (2011) claim that games are very effective alternative activities that provide students with a learning environment that is fun and educational. Additionally, games help in creating opportunities for independent learning and overcoming challenges for English language learners. Children who are reluctant to participate in other mathematical activities because of language barriers will often join in a game and gain access to mathematical learning and engage in structured social interaction.

Borovcnik and Kapadia (2014) remind us that probability emerged from games of chance. For example, games of chance were important leisure activities throughout the Roman Empire. It is important to remember the historical perspective as it provides pointers to be taken into account when developing a probability unit. Thus, an intriguing recommendation for teaching is often to use culturally diverse games to promote students' understanding of probability (Koparan, 2019). It is argued that a probability lesson embedded in a cultural context can enable students to reflect on the connections between content (probability) and context (cultural). As a result, probability learning broadens students' perceptions of mathematics and statistics (Averill et al., 2009). Culturally diverse games for probability exploration can be used in statistics classrooms because such activities provide a "legitimate case of straightforward mapping of situations onto probabilistic structures" (Greer & Mukhopadhyay, 2005, p. 316). Cultural games also allow for simulations using both cultural artefacts and technological tools. McCoy et al. (2007 suggested the use of six cultural games (Lu-Lu, a Hawaiian game; Hubbub, a native American game; Mancala, an African game; Toma Todo, a Mexican game; Dreidel, a Jewish game; and Ashbii, a native American game) and for learning of probability concepts. They argued that cultural games provide students with exciting contexts to experience and explore mathematics. In addition, culture will help sustain student interest and motivation and help teachers highlight the significance of culture and context in a multicultural statistics classroom (Averill et al., 2009). We need to investigate how the affordances of culturally diverse games can support students' probability learning.

This systematic literature review explores the games used in the last decade (2010–2020) in mathematics education research to promote students' probabilistic thinking. The following inter-related research questions informed the present systematic review:

- RQ 1: What different games are reported in research from 2010 to 2020 on teaching and learning of probability for Year 1–13 students and pre-service teachers?
- RQ2: What cultural games are reported in research from 2010 to 2020 on teaching and learning of probability for Year 1–13 students and pre-service teachers?

In this review, we focus specifically on games and not on the activities used in research for promoting students' probabilistic thinking. Mathematics educators distinguish between an 'activity' and a 'game' (Aldridge & Badham, 1993; Gough, 1999). A student may engage in an activity individually; however, a game always requires two or more players who take turns to win. Oldfield (1991) says that mathematical games are 'activities' that have a clear underlying structure and involve a challenge between one or more opponents who are governed by a set of rules to play. A game always has a purpose (cognitive and social) and distinct finishing point at which one of the players wins. In the next section, we present the methodology used for conducting this systematic literature review.

Methodology

The systematic literature review approach enables researchers to be systematic about the methods to search, survey and select relevant studies to develop a critical analysis of the research literature (Siddaway et al., 2019). The process involves majorly the following four steps: (i) searching and identification, (ii) screening and selecting relevant studies, (iii) coding, and (iv) writing the analysis. This section presents a summary of the key measures taken by the research team to locate the pertinent literature and discard irrelevant research studies. Each of the steps is described in detail in the following section. Figure 1 presents the summary of locating relevant research studies using games for teaching and learning probability at the school level.

Step 1. Searching and identification of studies

A comprehensive search strategy was devised to ensure rigour utilising systematic techniques such as those outlined in PRISMA methodology (Moher et al., 2009) to identify the relevant studies. For searching, a logic grid was used to identify the appropriate key search terms and synonyms. Boolean logic (AND, OR, NOT) was used to develop a combination of keywords to be used for searching the selected databases. The set of keywords included: teach* OR learn* AND math* OR statistic* AND thinking AND probability OR probabilistic OR probability. The databases included ProQuest Education, Education Source (EBSCO), ProQuest ERIC (Educational Resources Information Center), Scopus, and JSTOR. To screen the potentially relevant studies at this step, the following inclusion and exclusion criteria were employed. The inclusion criteria were:

1. Peer-reviewed journal articles and conference proceedings.
2. Studies conducted with participants from Year 1–13 students and pre-service teachers.
3. Qualitative and mixed-methods studies.
4. Studies pertaining to teaching and learning of statistics and probability through games.
5. Studies published in the English language.

The following exclusion criteria were applied:

- All book chapters, teaching activity articles, literature reviews, and theoretical papers,
- Journal articles in a language apart from English, and
- Journal articles with games stated as activities or problems.

The searching step resulted in identifying 486 studies based on screening of titles (see Figure.1).

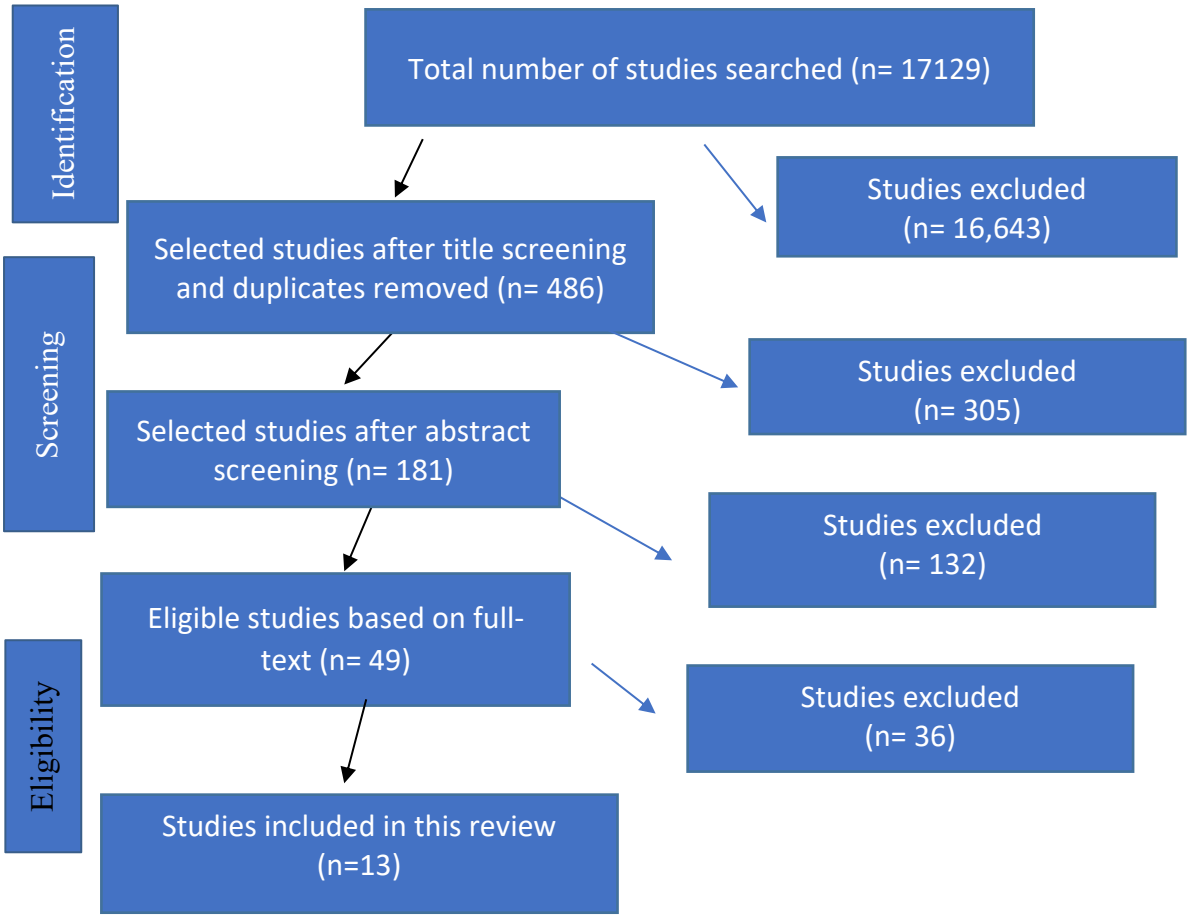

Figure 1. Screening process for identifying relevant studies.

Step 2: Screening and selecting studies

Studies identified at step 1 were further screened by reading abstracts to choose the potentially relevant studies. The screening process focused on identifying the nature of the study and the participants involved in these studies. The screening process at this step resulted in the selection of 181 out of 486 studies (see Figure. 1). Studies involving participants other than students from Year 1–13 classes and pre-service teachers were excluded. The 181 selected studies were further screened by reading sections on methodology and, as a result, 49 relevant studies were identified for coding.

Step 3. Coding and evaluation of the studies selected for analysis

The selected 49 studies from the previous step were coded. To develop a consistent set of codes, two research team members coded a small sample (n=10) of the selected studies independently. This process allowed researchers to come to an agreement regarding the codes and establish inter-rater reliability. Inter-rater reliability is a process often undertaken by researchers to reach an agreement regarding coding and findings (Armstrong et al., 1997). The process of inter-rater reliability was also central in reaching an agreement in identifying the relevant studies for this systematic literature review. This is because, in many research studies, games were often used as activities without any specific condition for winning. During the coding process, a decision was made to reject research studies on game-based activities as opposed to games (based on the definition of games presented earlier). The coding process

resulted in the elimination of 36 studies based on teaching activities. All the selected 13 studies were coded for author/year, country, participants, probability concepts, and games. The overview of 13 selected studies is presented in Appendix A.

Step 4. Conducting and writing the systematic literature review

Based on the coding of studies, 16 games were identified, which were grouped into six different game categories. The following section reports on the identified game categories and presents brief descriptions of the games within each game category.

Results

One way of classifying games is by their format, the equipment used and the sort of actions the players are involved in. Some of the following categories have been drawn from two articles, one by Gough (1999) and another one by Oldfield (1991). The systematic literature review identified 16 games. These games are grouped into six main categories (see Table 1). The table names the game category, identifies the games in each of the categories, and outlines some of the probability concepts learnt through these games in the research.

Table 1. Categories of Games Identified in the Literature Review from 2010–2020

S.No.	Category	Games
A.	Token, Coin or Dice games	Difference of the dice (Koparan, 2019) Game of fives (Ruthven & Hoffmann, 2013) Banana game (Sullivan, 2020) Efron's dice (Sloop & Che, 2011) Token game (Koparan, 2019) Pass the Pigs (Groth, 2015) Flipping out (Degner, 2015)
B.	Card games	Hands-on SET (Gordon et al., 2013) Blood donation game (Koparan, 2019) "Change?" (Malaspina & Malaspina, 2020)
C.	Lotto games	Roulette game (Fernandez et al., 2020) Colour Pick (Lim et al., 2016) Plinko game (Naresh & Royce, 2013)
D.	Board games	The Settlers of Catan (Austin & Molitoris-Miller, 2015)
E.	Embodied games	Rock-Paper-Scissors (Koparan, 2019)
F.	Cultural games	LuLu (Naresh et al., 2014)

Brief descriptions of games identified in each category and the probability constructs embedded in each game category are discussed in the two major sections below.

Game categories and games

This section presents a brief description of the game categories and the identified games within those categories.

Token, dice or coin games

The games that involved the tossing of either a dice, token, or a coin were grouped under this category of games. Seven different games identified in this category (see Table 1) are (i) Difference of the dice, (ii) Game of 'fives', (iii) Banana game, (iv) Efron's dice, (v) Token game, (vi) Pass the pigs, and (vii) Flipping out. Brief details of the games are provided below.

1. Difference of the dice (Koparan, 2019): The game involves two dice and can be played by students in pairs. Each player rolls two dice. The players find the difference by subtracting the smaller number from the larger one. If the difference is 0, 1 or 2, the first player wins. However, if the difference is 3 4, 5, the second player wins. After playing the game about 20 times, they decide whether the game is fair.
2. Game of "fives" (Ruthven & Hoffmann, 2013): The game can be played with the whole class, groups and/or pairs. Each team tosses the dice for 10 rounds. Every time a five appears on a die, the team is granted a point. After 10 tosses, the team that owns the most points wins.
3. Banana game (Sullivan, 2020): The game is played with two players. The players are placed in a context, where they are stranded on a small island with only one banana to eat. In order to decide who will eat the banana, the players decide to play a game. Each of the players rolls dice at the same time. The rule dictates that if the larger number is 1, 2, 3, or 4, then player one wins. However, if the larger number is 5 or 6, then player two wins.
4. Efron's dice (Sloop & Che, 2011): Bradley Efron created a set of four non-traditional dice (Gardner 1970), as shown in Figure 2.

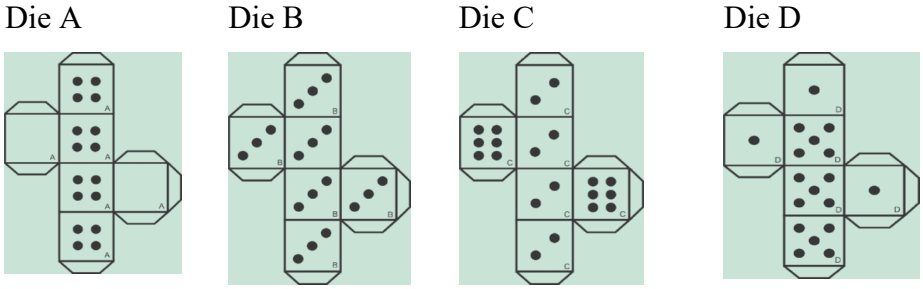

Figure 2. Nets of Efron's Dice

Note. Adapted from Sloop & Che (2011). What a Pip! Probability and Efron's dice. *Mathematics Teaching in the Middle School, 17*(2), 117.

Die A has four faces with four dots, and two faces are blank. All six faces of die B contain three dots each. Four faces of die C have two dots each, and two faces have six dots each. In die D, three faces have five dots on each face, and the other three have one dot each. Different game rules can be created using this set of dice. For example, the player with the larger number wins the game.

5. Token game (Koparan, 2019): The game uses three tokens. On both sides of each token, A, B, or C is printed in such a way that the first token has A and B on its sides. The second token has an A and a C, and the third one has a B and a C side. The game is played in pairs. Player 1 flips all three tokens together. If there is any matching of the sides of the tokens, player 1 wins. If there is no matching, player 2 gets a point. The player who wins the 20 points first wins the game.
6. Pass the Pig (Groth, 2015): The game involves tossing a small toy pig and recording the points as per the scoring sheet provided in Figure 3.

If the pig lands on its—	You get—
Side	0 points
Back	5 points
Feet	10 points
Snout	15 points
Snout and ear	20 points

Figure 3. Pass the Pig

Note. Adapted from Groth (2015). Royalty, racing, rolling pigs, and statistical variability. *Teaching Children Mathematics, 22*(4), 228

The player with the highest score after 10 tosses wins the game.

7. Flipping out (Degner, 2015): Flipping out is a game played by tossing two coins together. The game is played in pairs. Both the players toss a coin each. If both coins show heads, player 1 gets the points. If the coin lands within HT or TH, player 2 wins the point. The player with maximum points after 10 tosses wins the game

Card games

This category forms the second category of games and includes games that are played using different kinds of cards. Four different card games were identified (see Table 1). These games are (i) Hands-on SET, (ii) Blood donation game, and (iii) "Change?" game.

1. Hands-on SET (Gordon et al., 2013): The deck of cards contains 81 cards, and each card is characterised by four different attributes. These attributes are number (1, 2, 3); colour (red, purple, green); shading (empty, striped, or solid); and shape (ovals, diamonds, or squiggles), as shown in Figure 4.

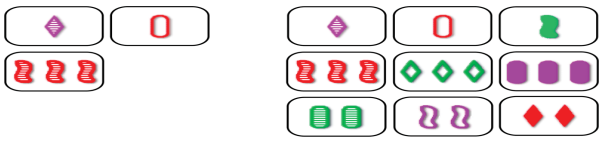

Figure 4. Examples of Sets in Hands on Set Game

Note. Adapted from Gordon et al., (2013). Hands-on SET®. *PRIMUS, 23*(7), 646–658.

A set has three cards, with each attribute independently being either the same or all different. For playing the game, 12 out of 81 cards are laid out on a table. The player who identifies the first set and calls "set!" wins and keeps the set cards. The set cards are replaced by another three cards, and the players again identify the set. If a set is not found by any of the players, three more cards are added to the layout. If a set is then found among this larger group of cards, it is taken and not replaced. The game ends when all players agree that no more sets can be found. The player with the most sets wins the game.

2. Blood donation game (Koparan, 2019): This game integrates the learning area of mathematics with biology. The game uses knowledge about blood groups. The correlation of blood donations needs to be used in the game. Blood type AB is a universal receptor, whereas blood type O is a universal donor. The game involves two bags with four cards in each bag. On each card, one blood type is written (as shown in Figure 5).

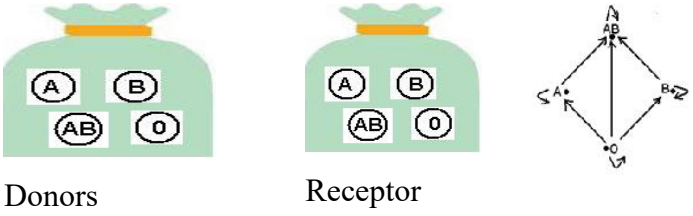

Figure 5. Blood Donation Game

Note. Adapted from Koparan (2019). Teaching game and simulation-based probability. *International Journal of Assessment Tools in Education, 6*(2), 249.

The first bag contains the blood types of the donors, and the second bag contains the blood type cards for the receptors. The game can be played in pairs. If the card drawn by the first bag can be donated to the second bag, the first player wins, otherwise the second player wins.

3. "Change?" (Malaspina & Malaspina, 2020): In this game, 16 cards from a regular deck are used, as shown in Figure 6.

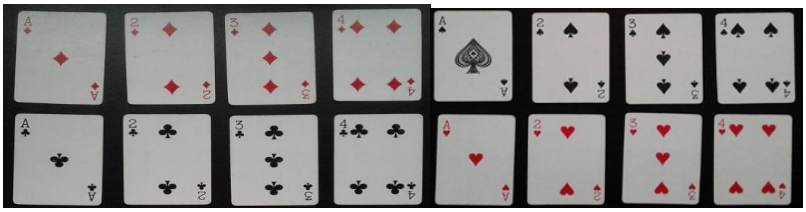

Figure 6. Full Set of Cards for the "Change?" Game

Note. Adapted from Malaspina & Malaspina. (2020). Game invention as means to stimulate probabilistic thinking. *Statistics Education Research Journal, 19*(1), 52

The game starts with shuffling and putting the cards face down on the table so that none of the players are able to see the values on the cards. Both the players draw a card from the deck.

- In the beginning, the 16 cards are shuffled, piled in a stack, and lie face down on the table, so that none of the players can see the values on the cards.
- Each round, each player draws one card from the deck; no other player can see the value on the card.
- Each player shows the card; the player holding the highest-value card takes both cards. In case of a draw, each player takes one card.
- The players are allowed to change their card by replacing it with the card in the deck. The replaced cards are removed from the game.
- The game is played until all the cards on the table are gone. The player with more cards wins the game.

Lotto games

Lotto games are those games of chance in which the winning number or colour is picked by a person other than the players. These games were identified as the third category of games in this review. Three games were identified in this category. These are (i) Roulette game, (ii) Colour Pick, and (iii) Plinko game.

1. Roulette Betting game (Fernandez et al., 2020): The game is played in a group of six players. Within each group, a roulette wheel is spun, and each participant is asked to follow the same betting strategy. The betting strategy involved are:
   "Strategy #1: only bet on single numbers;
   Strategy #2: only bet on rouge or noir;
   Strategy #3: only bet on dozens (twelve numbers as they are arranged on the roulette table, i.e., 1, 4, 7, …; 2, 5, 8, …; 3, 6, 9, …);
   Strategy #4: only bet on odd or even;
   Strategy #5 only bet on zero;
   Strategy #6: only bet on columns" (Fernandez et al., 2020, p. 112).

   The authors asked the students to play the roulette bet 15 times. The winner for each round in each group was noted, and the number of times each player won was also noted. The game allows students to evaluate the different betting strategies for winning in a roulette betting game.
2. Colour Pick (Lim et al., 2016): The game integrates the concepts of probability with permutations and combinations. The game can be played with groups and the whole class. In this game, each player chooses three different colours from a set of five colours for their ticket. Once all the players have chosen their three colours for their tickets, the winning colours are selected by another person. The player with the winning colours in any order wins the game.
3. Plinko game (Naresh & Royce, 2013): Plinko is another lotto game. It involves a player dropping a coin or Plinko card in the Plinko machine (refer to the article for more details) to earn a given amount of money. The player chooses one of the nine slots to drop the Plinko card or coin. The Plinko card hits a certain peg in each row, travels through eleven rows and lands in one of the nine bins of money at the bottom. The game can be played with players in pairs or groups. The one with the highest money wins the game.

Board games

The games identified within this category are games that are played using a board. One probability game identified in this category is the settlers of Catan (Austin & Molitoris-Miller, 2015). This game is a property construction and trading board game. Three to four students can play the game at a time. The game board consists of 19 hexagonal tiles forming a larger hexagonal grid (please refer to the original article for the game board and scoring sheet). Eighteen out of 19 tiles include five different coloured hexagonal tiles, each colour representing a distinctive resource such as lumber, brick, wool, grain and ore. There are four tiles each for lumber, wool and grain, and there are three tiles each for brick and ore. One tile represents the desert in the centre of the board, which provides no resource. These resources help players in the construction of roads, additional settlements, cities and development cards. Each of these constructions counts for various victory points. The game starts with each player rolling two dice. The player with the highest roll places a settlement and a road. During the game, players collect the resources based on the tiles adjacent to their settlement. The first player to collect 10 victory points wins. Different victory points are associated with different construction items (refer to the original article for more details). Moreover, the players receive the "resources based on the tiles adjacent to their settlements when the numbers on those tiles match the sum of the dice" (Austin & Molitoris-Miller, 2015, p. 277). The initial settlements selected by the participants play a crucial part in their overall success.

Embodied games

Games that involve the use of bodily movements to convey information visually are considered embodied games. One game identified in this category is Rock-Paper-Scissors (Koparan, 2019). The game is embodied in the sense that the game uses only sensorimotor resources (Wilson, 2002), in this case, hand gestures. The fist shows the rock, the index and the middle finger show scissors, and the palm shows the paper. Two or more players can play the game at once. Hands are moved while playing rock-paper-scissors, and a gesture is selected in the last motion. The following rules dictate the winner: Stone breaks scissors. Paper wraps stone. Scissors cut paper.

Cultural game

Cultural games are those games that are specific to a culture and use knowledge of a particular group of people. One cultural game was identified in the literature for teaching and learning of probability. The game is called Lulu (Naresh et al., 2014). Lulu is a Hawaiian game. The literal meaning of the word is "to shake". The game involves the use of four two-sided dice, as shown in Figure 7.

Figure 7. Two-Sided Dice for LuLu Game

Note. Adapted from Naresh et al., (2014). Probability explorations in a multicultural context. *The Mathematics Teacher, 108*(3), 186.

The dice can be made from clay, shell, wood or glass stones. The game can be played in pairs or groups of four. Each player tosses all four stones and dots on the fall face-up are counted. The first player to get 50 points wins.

In this section, we discussed six categories of games, which are Token/coin games (Difference of the dice, Game of fives, Banana game, Efron's dice, Token game, Pass the Pig, and Flipping out); Card games (Hands-on SET, Blood donation game, and Change); Lotto games (Roulette game, Colour pick, and Plinko game); Board game (the Settlers of Catan); Embodied game (Rock-Paper-Scissors); and Cultural game (LuLu) and the games within each of those categories. In the next section, we discuss the probability concepts that researchers discussed with respect to these games.

Probability concepts involved in these games

The studies have shown that these games allow students as well as pre-service teachers to develop an understanding of probability concepts of theoretical and experimental probability. Koparan (2019) has used the game "Difference of the dice" and "Token game" with prospective teachers in Turkey. The prospective teachers were asked if these games were fair or unfair. For both the games, the prospective teachers had predicted that the game was fair. However, after calculating theoretical probability, the teachers changed their opinions and stated that the game was unfair based on the sample space for all possible outcomes. He argued that these games helped prospective teachers develop an understanding of tree diagrams and experimental and theoretical probability. Like the "Difference of dice game", the "Banana game" (Sullivan, 2020) based on the sum of the dice was also reported in research. Sullivan conducted his study with Grade 8/9 students and argued that creating the sample space chart for the game allowed students to develop an understanding of theoretical and experimental probability.

Sloop and Che (2011) suggested using Efron's dice to develop Grade 6–8 children's understanding of chance and probability. They argued that Efron dice provides opportunities for students to develop an understanding of theoretical and experimental probability and allows children to notice possible outcomes change based on the dice used for playing. Sloop and Che (2011) also suggested that dodecahedral dice can also be used as an extension game to support students' understanding of probabilistic thinking and written expression of probability. Students can play and find out who has the best chance of winning. Ruthven and Hofmann (2013) reported that the "Game of fives" helped Year 7 students in the United Kingdom develop an understanding of probability scale, focusing on the likelihood and unlikelihood of events and mitigating several misconceptions. One such misconception relates to making a determinate prediction instead of focusing on the likelihood of events. Fernandez et al. (2020) argued that the games provide opportunities for pre-service secondary school teachers to visualise probability patterns in the series of long trials along with probabilistic thinking through Lotto games. On the same lines, Naresh and Royce (2013) and Lim et al. (2016) suggested that the lotto game environment encouraged students' engagement and problem-solving by focusing on the winning strategies along with probabilistic thinking. For example, representing probability using a tree diagram with one colour, say yellow, in the game "colour pick", can be a fruitful exercise for students in developing an understanding of probability (Lim et al., 2016). In the next section, we present the discussion of the main findings.

Discussion

This systematic literature review aimed to scope out the games used for teaching and learning of probability from 2010–2020. Thirteen studies were identified. The studies included in this systematic literature review provide opportunities for learning various probability concepts, including expected value, probability calculations, probability patterns, fair/unfair chance, theoretical and experimental probability, sample space, probability literacy, the likelihood of events, law of large numbers and probabilistic thinking. All these concepts are evident in the Achievement Objectives of Mathematics and Statistics learning area of The New Zealand Curriculum (Ministry of Education, 2007).

The literature review identified six different categories of games used in probability teaching (see Table 1). It is not surprising that tossing dice, tokens, or a coin is the most popular game category for teaching and learning probability. Seven games were identified in this category. In the New Zealand context, Dayal and Sharma (2020) also used a "Difference of dice" (Koparan, 2019) game while teaching probability to pre-service teachers. Dayal and Sharma's (2020) did not appear in the selected databases. Interestingly, non-traditional materials were also used in the category of these tossing games, such as tokens, small pig toys and non-traditional dice. The studies based on these materials have not explored the role of these materials in students' engagement which can be further investigated. The review also highlighted those games can provide context for integrating probability learning with other learning areas. For example, in the blood donation game, participants were able to utilise their knowledge of blood groups with probability concepts. The review also identified lotto games, such as the Roulette game (Fernandez et al., 2020), Colour Pick (Lim et al., 2016), and the Plinko game (Naresh & Royce, 2013). Interestingly, the NZ lotto game has not been used for game-based learning in the New Zealand context, which might be a useful game context for exploring teaching and learning of probability at various year levels in the New Zealand classroom context. However, more research is required in this direction.

It is interesting to note that only one cultural game was identified in this literature review. Only one study, Naresh et al. (2014), identified the use of a cultural game for teaching and learning probability. The authors used a Hawaiian game called Lu-Lu for connecting experimental, theoretical and conditional probability concepts. The authors argued in favour of using cultural games to promote probability learning for culturally diverse students. However, the authors conducted this study with

secondary school pre-service teachers. They found that the use of the cultural game Lu-Lu sustained students' attention and promoted engagement in learning. The authors suggested that probability lessons embedded in cultural context help students to build connections between content (probability) and cultural context and, as a result, students can broaden their perception of mathematics. This suggestion aligns with culturally responsive pedagogy (Averill et al., 2009; O'Keeffe et al., 2019; Rigney et al., 2020) that is being promoted in multicultural settings. The game Lu-Lu can be used with students at the high school level with adaptations. It is interesting to note that McCoy et al. (2007) had suggested six cultural games; however, only one game called Lu-Lu has been taken up in the last 10 years of mathematics education research. The lack of cultural games in teaching and learning probability in literature in the last 10 years highlights the avenues for further research in probability research using culturally diverse games.

Concluding thoughts

This article aims to contribute to the limited amount of research on using games to develop students' probabilistic thinking and reasoning. We conducted systematic literature of studies to identify games, including cultural games used for teaching and learning of probability. The review identified 16 games for the first research question on the use of games in research for teaching and learning probability. The review suggests that game-related contexts offer opportunities for developing probability concepts such as sample space, the likelihood of events, experimental and theoretical probability, variation and law of large numbers, among others. In response to the second question on the use of cultural games, the review identified only one study using a Hawaiian cultural game called Lu-Lu (Naresh et al., 2014). Naresh et al. (2014) suggested that the cultural games provide students with relevant cultural context and promote their probabilistic reasoning. It must be noted that none of the studies reviewed in this paper were conducted in New Zealand classrooms. More research using games for teaching and learning probability is required in New Zealand classroom contexts. Like Van de Walle et al. (2014), we believe that an effective way to help students to connect sample space with probability is to ask them to make a prediction of the event, conduct an experiment using a large number of trials and finally to compare the prediction with what happened. Students can also create the sample space and see how it compares with the prediction and the experimental results. Some of the games described in this paper can provide excellent contexts for such probability explorations. Teachers can adopt the games discussed in the literature review to make probability teaching more engaging and motivating for students (Garfield & Ben-Zvi, 2009). However, teachers should not expect one or two games to have a huge impact on student reasoning. It is hoped that the findings reported in this paper will generate more interest in using games, particularly cultural games in statistics education.

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