Secondary pre-service teachers' views on using games in teaching probability: An international collaboration

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Probability and *statistical literacy* is an important aspect of the school curriculum in many countries. In this study, we report on findings from a larger study that engaged pre-service teachers as key stakeholders in research in exploring teaching probability and statistics using a game-based teaching approach. The current study focuses on 23 pre-service teachers' views about game-based teaching and learning. Our sample of teachers were from two universities in the Pacific region. The findings strongly indicate that pre-service teachers can derive useful pedagogical knowledge by engaging in the game-based teaching intervention. All the pre-service teachers support the use of real-life based practical approaches in their teaching.

In a rapidly evolving world, there is a strong need to understand and be able to use mathematics in all aspects of life. One particular area of mathematics that we use or rely upon on a daily basis is probability and statistics (Koparan, 2019). The use of probability and statistics translates down to the need to understand and use data in almost all aspects of life, such as education, health, or predicting future events such as adverse weather conditions. This aspect of learning mathematics is termed *probability literacy* or *statistical literacy* (Jones et al., 2007). It includes having a working "knowledge and understanding of numeracy, statistics and data presentation" (Pierce & Chick, 2013, p. 190).

Given the importance of statistical literacy, many countries place probability and statistics in their core mathematics curriculum. For example, in the New Zealand school curriculum, probability is part of the three sub-strands in the curriculum document and viewed as critical in the learning of mathematics (Ministry of Education, 2007). In the Pacific education context, many educational jurisdictions have included statistical literacy as an important aspect from the early years of the school curriculum (Fiji Ministry of Education, Heritage & Arts, 2017).

Given the relative importance of probability and statistics in our curriculum, it is imperative that teaching of the probability and statistics curriculum aligns, to a higher degree, with our recent understandings of the term *statistical literacy*. Therefore, it is critical that teachers of probability and statistics are exposed to making use of lots of real world examples and activities in their teaching. One of the ways of doing this is through the use of games. In this study, we report findings about the usefulness of teaching probability and statistics using a probability teaching sequence designed by one of the authors (Sharma, 2015). The paper reports on benefits and challenges of using games from the perspective of our relatively small sample of secondary pre-service mathematics teachers from two different universities in the greater Pacific region. The research questions addressed in this paper are: *To what extent do the pre-service mathematics teachers find the probability teaching sequence useful? What are some of the benefits and challenges they foresee in adapting such games in their teaching?*

After presenting the theoretical framework, a short literature review is presented. This is followed by the specifics of the study's research design. Then, results and discussion are presented. A brief conclusion sums up this paper.

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Theoretical Framework

In this study, we utilised the socio-cultural theories of learning. The influence of socio-cultural context on a learner has been examined mostly from Vygotsky's frame of reference. The sociocultural environment incorporates use of a variety of tools such as language, sign, and cultural tools (artefacts) to assist with reaching higher mental models (Vygotsky, 1978). Given the aim of the study was to explore pre-service teachers' views about the benefits of using a newly introduced probability teaching sequence (reference withheld), it was important to see how they suggest they could make use of the ideas that they could have possibly derived from the teaching sequence. Given that we were exploring pre-service teachers' future intentions, it was critical that most of these are turned into productive actions when they begin teaching mathematics. In this regard, Valsiner's zonal theory (Valsiner, 1997), an extension of Vygotsky's zone of proximal development (ZPD), is seen as a useful framework for viewing teachers' thought processes as well as their actual actions (Goos, 2014).

Vygotsky defined ZPD as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). According to Valsiner's zone theory (Valsiner, 1997), one can assist a learner reach ZPD with the help of available resources and processes within the proximity to enable their *zone of free movement* (ZFM) and *zone of promoted actions* (ZPA) (Goos, 2014). ZFM usually includes contextual factors that limit pre-service teachers' thinking and actions, while ZPA includes all those activities that are designed by other adults, such as university lecturers, that are aimed at developing or promoting new skills. In this study, we focus on the pre-service teacher as the learner. Hence, it is important to critically review the contribution from each zone, in particular, focusing on what benefits and challenges pre-service teachers see in using the probability teaching sequence and how they intend to use the teaching sequence.

Literature Review

Two major interpretations of probability can be distinguished. The classical (theoretical) viewpoint assumes that it is possible to represent the sample space (all possible outcomes) as a collection of outcomes with known probabilities. For example, the probability of rolling a six on a regular six-sided die is one-sixth. In such a case, the theoretically derived probability is an estimate of the actual probability that is not known. Batanero et al. (2004) argue cases of equiprobability that arise in some simple game scenarios, such as rolling a die, may not be the same in complex everyday situations, such as weather predictions, risks and epidemics. On the contrary, the experimental interpretation assumes that the probability of something happening can be determined by doing experiments. A large number of identical trials (e.g., tossing two coins) are conducted, and the number of times a particular event (e.g. one head and one tail) occurs are counted. The greater the number of trials, the closer the experimental probability will move towards the theoretical probability of an event. By comparing inferences from their theoretical and empirical work students can evaluate and modify their hypotheses.

Students leaving school should be able to interpret probabilities in a wide range of situations (Jones et al, 2007). If students are to develop meaningful understanding of probability, it is important to acknowledge the different interpretations, and to explore the connections between them and the different contexts in which one or the other may be useful.

Games can provide a useful context for exploring different interpretations and contexts. Batenero et al. (2004) provide an excellent example of how different probability teaching contexts can be explored using games. They engaged a group of teachers in experiments involving different coloured dice. Although the authors did not specifically seek the participant teachers' views about the usefulness of such gaming experiments, they speculate that teachers do acquire knowledge that would be beneficial in their later professional work.

Research evidence suggests that teachers, including prospective teachers, find teaching probability and statistics difficult or challenging (Batanero et al., 2004; Leavy et al., 2013). For example, the findings from a small sample study conducted by Leavy et al. (2013) in Ireland suggests that prospective secondary mathematics teachers perceive statistics as a challenge due to, among other factors, the need to think and reason statistically. Anecdotal evidence suggests that teaching probability and statistics is also a challenge for Pacific Islands teachers. One possible factor could be the mismatch between the nature of probability and statistics, and the teaching approaches used by teachers. As reported by Dayal (2013), teachers from the Pacific Islands have a tendency to teach mathematics using traditional approaches such as relying heavily on notes and examples followed by routine textbook-type exercises.

The brief review of literature suggests that two different, yet not mutually exclusive, approaches to understanding the teaching probability and statistics are prevalent. This study hopes to add to our understanding of how pre-service teachers can derive potential teaching ideas for both theoretical and experimental aspects of probability and statistics. The literature seems to suggest general prevalence of teaching challenges as well as an acknowledgement of the potential benefits of teaching using games. The current study also aims to add to our understanding of pre-service teachers' perceptions of the degree of usefulness of games in teaching.

Research Design

To conceptualise our larger study, we drew on *design-based research theory* (Cobb & McClain, 2004). Design research is a cyclic process with action and critical reflection taking place in turn (Cobb & McClain, 2004; Nilsson, 2013). Further, all participants are equal partners in the research process (Kieran et al., 2013). Using a case-study design (Yin, 2014), our study itself involved cycles of three phases: a preparation and design phase, a teaching experiment phase, and a retrospective analysis phase. Both mathematics educators were involved in the whole research process. The role of researchers involved posing questions, and observing the research unfold with minimal interference. This paper reports on post-intervention findings, after our pre-service teachers had completed the teaching experiment phase. The teaching experiment, called the *probability teaching sequence*, involves a scenario where two people play a dice game. Each player throws a die and the difference of the two outcomes is calculated by subtracting the smaller number from the bigger number. If the difference is 0, 1, or 2, player A wins. If the difference is 3, 4, or 5, player B wins. The main question that pre-service teachers were required to think about when playing the game was whether or not the game was *fair* and to justify their reasons. From a socio-cultural perspective, the probability teaching sequence provides pre-service teachers an opportunity to 'think' and 'act' within their ZPD. For the full teaching intervention, see Dayal and Sharma (2020). The research context, participants and procedures are described in the table below.

Table 1
A summary of context, participants, procedures and instrument

Research Context	Research Participants	Research process	Research Instrument
The University of Waikato (UW) is located in Hamilton and operates from two campuses, Hamilton, and Tauranga, in New Zealand.	• 10 pre-service mathematics teachers completing their Graduate Diploma in Teaching programme • Equal number of males and females • Six New Zealanders, four international pre-service teachers • All teachers have mathematics as their teaching major. • Participants are represented using letter codes O – Y.	• The second author is the coordinator of the teaching methods course. • Upon completing the intervention, one-to-one semi structured interviews were conducted. • All ethical guidelines, as per UW research ethics approval, were adhered to. For example, each student gave their informed consent and were assured that their non-participation or withdrawal would not affect their performance in the teaching methods course. • All interviews were audio recorded.	Post intervention one-to-one interviews with the following prompts: • Think back on the activity we did today. Did you all like the activity? Why or why not? • Are there any probability teaching ideas that you can take to your classroom? Will you be using these ideas in your teaching? • Suppose you were to recommend this teaching sequence to a colleague. When will you suggest him or her to use it? • Do you feel there are some challenges in doing this activity? • What kind of support, if any, would you require?
The University of the South Pacific (USP) is a regional university that is owned by 12 member countries in the Pacific and is head-quartered in Suva, Fiji Islands.	• 13 pre-service mathematics teachers in their final year of the 4-year BSC GCED programme • Equal number of males and females • All teachers have mathematics as their teaching major • Ten teachers from Fiji, four from Kiribati. • Participants are represented using letter codes A- N	• The second author was not teaching the participants. • The intervention was held on a non-teaching day (Saturday) at the USP. • All teachers gave written informed consent and volunteered to be part of this intervention. • USP ethics approval was sought prior to the intervention. • Post intervention, participants reflected in a focus group set up. • All discussions were video recorded.	Post intervention focus group discussions using the above prompts. • Group 1: Participants A,C,E, H, I (Fiji) • Group 2: B,D, F,G, J (Fiji) • Group 3: K,L,M,N (Kiribati)

Findings and Discussion

The individual interviews and focus group discussions were transcribed and analysed by each author. The following sections present the common themes that arose after analysing pre-service teachers' opinions about the probability teaching sequence.

Affective and Cognitive Benefits

All the participants explicitly stated that they liked the probability teaching sequence. The reasons provided related to the teaching sequence being interesting "because it allowed us to think" (Participant A) about probability and "learn from their own mistakes" (Participant K) rather than learning probability using formulas. In addition, the pre-service teacher participants talked about affective reasons, such as "we liked the dice activity because it is better than giving notes from the textbook" (Participant K) or "this is a very creative way of learning probability" (Participant C).

Similar to the USP participants, UW participants also noted affective and cognitive benefits of the probability teaching sequence. Some of the responses included:

> "Open questions build student self-confidence because students can answer at their own level of understanding" (Participant Q)
>
> "It is different to most tasks with probability, so it will be good for students to get a change from routine" (Participant P)
>
> "The game makes students think logically to show all possible outcomes of rolling two dice" (Participant O).

Deriving affective as well as cognitive benefits and learning about probability teaching ideas was a common theme reported by a number of participants from both contexts when asked about whether or not they liked the activity. It is encouraging to note that the pre-service teachers were able to recognise such benefits and acknowledge that the teaching sequence provided another, interesting way to learn probability. This may be due in part to some of our participants, especially those from USP, being largely exposed to traditional approaches to learning during high school and university, such as completing routine textbook-type exercises (Dayal, 2013).

Deriving Teaching Ideas

In terms of learning about probability teaching ideas, the USP pre-service teacher participants could identify some holistic ideas as well as a number of specific topics that they could explore using this teaching sequence. The pre-service teachers' very general hints about teaching probability included comments such as "we learnt how to create good experiments using dice" (Participant L). In their discussions, the pre-service teachers from USP uttered various probability- and statistics-related terms (e.g., events, trials, chance of events, outcomes, skewness of outcome, expected probability, fairness, graphs, making predictions). In comparison, some USP pre-service teachers appeared to have some difficulty with identifying topic-related terms. For example, when asked to share the probability teaching ideas they could take into their classrooms, some participants in Group 3 stated general themes, such as "conducting experiments using dice" (Participant L) or "teaching probability" (Participant N).

It is worthy to note that these participants were all from Kiribati. In the Kiribati context, these participants mentioned that probability is introduced late in the school curriculum, only in upper secondary curriculum (Years 11 and 12). In contrast, in Fiji and NZ, probability and statistics is introduced from the early years.

Similar to the USP cohort, the UW cohort was able to list a range of teaching topics as well. For example, one participant mentioned the topic of sample space:

> "The lesson sequence allows students to explore sample space by using representations that make sense to them. For example, some students may use grid of numbers whereas others may use tree diagrams" (Participant P).

In addition to naming such probability teaching topics, it was encouraging to note that UW teachers were able to suggest many other pedagogical aspects from the probability teaching sequence, such as the sequence having a clear learning objective and a good range of questions that could promote student learning. For example:

> "The lesson sequence has clear objectives for student learning. The teacher can share these goals with students." (Participant O)

> "The sequence includes a range of questions. Asking questions can give teachers information about students' thinking" (Participant S).

Overall, the pre-service teachers derived a number of useful general teaching ideas, such as conducting experiments, as well as ideas about specific subtopics that are present in probability and statistics. The need to have practical activities using dice or coloured cubes, or even coconuts, were mentioned by USP and UW participants. The need for more real-life based activities were also mentioned:

> "It is important that students make connections to everyday life situations" (Participant U)

> "Students will be actually doing the thing. They will actually see what is happening by throwing the dice…and recording the data…" (Participant A).

As well as thinking about connections to real life experiences, participants thought about how the activity allows students to make connections to existing mathematics they may know. One UW participant noted:

> "It provides opportunities for students to make connections between probability concepts with everyday life and with other topics of study such as fractional number" (Participant Q).

Making connections to real-life and between different representations is critical in developing probabilistic understanding (Nilsson, 2013; Van de Walle et al., 2014). The findings suggest that the probability teaching sequence will likely benefit teachers as it provides them opportunities to ask students to play around with chance generating mechanisms, and use multiple representations such as tables, diagrams and graphs to explore probability concepts in a meaningful context. Since students can draw different representations to determine the theoretical probabilities, there is scope to make connections to real-life as well as among these different representations as reflected above.

Future Teaching and Challenges

All our pre-service teachers explicitly stated that they will be using this teaching sequence in their actual classroom teaching. When asked to suggest ways in which they would recommend this teaching sequence be best used, the groups seemed hesitant in providing specific answers. However, they stated a few specific scenarios, such as teaching a probability topic or as an assessment. Some responses included:

> "In conducting experiments about chance" (Participant L)

> "This activity would not be accessible at the start of a junior mathematics probability study, however it could be used as formative assessment" (Participant V)

Some participants reiterated general teaching ideas, such as:

> "teaching probability in a real-life situation" (Participant A)

> "use of experiments instead of textbooks, by using real-life context we can also help students learn probability more effectively." (Participant X)

In terms of teaching challenges, the major challenge noted by participants was the time factor. The reasons given by the USP cohort was mainly that the school teaching period was only of 1 hr and this activity could not be well implemented in an hour's time. Upon inquiry by the researcher if the teaching sequence could be broken down into smaller bits, the groups seem to agree that the time factor challenge could be overcome through this. Views such as giving a lesser number of trials was one of the ways suggested to overcome this challenge. In addition to time, the USP and UW participants mentioned class management as a possible challenge, "challenging and disruptive classroom environment that results in a lack of engagement" (Participant V). Some participants though stated that this challenge could be overcome by having smaller groups or by asking students to work in pairs.

In the context of mathematics lessons in Fiji and Kiribati, there is high importance placed on preparing students for external examinations. Hence, the limited lesson time, as mentioned by some of the participants, is a realistic challenge faced by many teachers. There was a consensus among the USP participants that covering the teaching syllabi well-ahead of time was critical for ensuring that ample time was left for students to attempt past-year examinations as part of their examination revisions. It was no surprise, then, that Participant I suggested that the use of these activities be reserved for "during a revision class", instead of part of the introduction of the topic or prior to revision.

Overall, our findings support, to a large extent, that some participants may use this probability teaching task or any shorter variant of it in their actual teaching. However, some may front load probability content first using more direct teaching methods, then use a game like this at the end of the unit to apply the learning. Seen from a socio-cultural perspective, the study provides evidence that our pre-service teachers' potential to learn new skills and develop (ZPD) is enhanced by engaging with the probability teaching sequence (ZPA), as well as via thinking and interactions with their peers in small group settings (ZFM).

Summary and Implications

While this study can be seen as a step forward in collaboration among teacher educators, it had its own limitations. One major limitation was that the two research contexts were quite different in terms of many factors, such as high school and teacher education curriculum. We negotiated such challenges by frequently discussing emerging issues through emails and Skype (e.g, the research process). Achieving exact consistency was not seen as critically important (Moss, 1994); instead, we made sure that an in-depth exploration was carried out while being within the ambit of our university learning and teaching regulations. The pre-service teachers registered an overwhelming support for the probability teaching sequence. They saw the probability teaching sequence as having affective and cognitive benefits for them, as well as the students. In addition, we noted a strong degree of support in terms of using this or a similar teaching sequence in their later teaching career. Lesson time constraints and class management were among the few challenges mentioned by the pre-service teachers if they were to implement the teaching sequences. Overall, our findings suggest that pre-service teachers find the probability teaching sequence useful and they could derive useful teaching ideas by engaging in this game-based teaching intervention.

From a socio-cultural perspective of learning, we note how our participants could challenge and modify their probability teaching ideas. Exposing pre-service teachers to such activities could be seen as extending their ZFM. However, only a few participants were able to suggest actual teaching ideas, yet suggesting some very general ideas which can be seen as a development of their ZPD. The fact that these pre-service teachers were cognisant of the teaching challenges suggests that while teachers may have noble ideas or intentions, not

all of it could be easily translated into action (Goos, 2014). In terms of future research, we intend to follow a small sample of our participants, with an aim to explore if and how they implement these ideas in their classroom.

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