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Demonstrating Pedagogical Content Knowledge Through the Development of Educational Science Board Games

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ABSTRACT

Preservice teachers who are specialising in the teaching of the subject natural science at a primary school level, ought to demonstrate the ability to present lessons that provoke a joyful yet meaningful educational experience amongst learners. One such approach that was taken, was when natural science preservice teachers were tasked with developing educational science board games as a means to enrich their teaching practice during a recent school visitation opportunity. However, given this educational exercise, what remains a mystery from a teacher development perspective is whether this exercise provoked some form of 'pedagogical thinking' among preservice teachers? It is with this question in mind, that the study investigated whether the task of developing educational science board games sparked the ability of preservice teachers to demonstrate knowledge of pedagogical content. The study draws on a modified understanding of Shulman's pedagogical content knowledge model, which in the context of gamification requires one to effectively transmit 'subject knowledge' in an interactive manner through 'educational board game practices and engagement'. Using a focus group discussion and photo-voice methodology as data collection techniques, this qualitative study uncovered how preservice teachers demonstrated i) knowledge of the curriculum, ii) knowledge of instructional strategies, iii) knowledge of learner-thinking, and iv) knowledge of assessment. This study holds a series of implications for future research in the field of initial teacher development and STEM education. For example, it will be interesting to uncover how preservice teachers experience the use of educational board games in their teaching. In addition, it will also be interesting to discover how educational board games can be used in other STEM subjects such as mathematics, technology, and physical science. Ultimately, more research is also required on the learning benefits of educational board games from a learner's perspective.

Keywords: educational science board games, pedagogical content knowledge, natural science education, natural science preservice teacher development

INTRODUCTION

Gamification is a popular trend in education that uses game mechanics to make learning more engaging, interactive, and fun. In recent years, gamification has gained a lot of attention in science education, as it has the potential to transform the way learners learn and understand complex scientific topics (Metwally et al., 2021). Natural science, as a primary school subject, has always been considered a challenging subject for learners with complex topics stemming from fields such as chemistry, physics, biology, environmental studies, and astrology (Sahin and Yilmaz, 2020). Given the challenging nature of the natural science school syllabus, the introduction of

gamification in science education serves as a mechanism to aid the learning process of learners. A key advantage of gamification in science education is that it increases the motivation of learners. Hursen and Bas (2019) explain that gamification in science education can help create a more immersive and interactive learning experience. Hillmayr et al. (2020) add that science education is all about experimentation and exploration, and gamification provides an excellent platform for learners to do just that. The use of gamification allows learners to simulate scientific experiments and concepts in a joyful, yet meaningful learning environment, which provides a practical and hands-on experience to learners (Sahin and Yilmaz, 2020). By creating a fun and interactive environment that encourages learning, learners can retain scientific knowledge and apply it in real-world situations more effectively (Bayeck, 2020).

One particular teaching technique informed by the notion of gamification is the use of educational science board games. Educational science board games are games designed to teach scientific concepts and terminologies to learners of all ages in a fun and engaging manner (Botes, 2021; Chen et al., 2021). These games combine game mechanics with educational content, making learning a more interactive and immersive experience. In the context of natural science education, such educational board games may cover a wide range of scientific topics that centre around matter and materials, energy and change, life and living, and earth and beyond. These topics inform the natural science school syllabus in the South African schooling context. The gameplay may involve trivia questions, problem solving exercises, simulation and role-playing activities, as well as other mechanics that are designed to promote learning and reinforce scientific knowledge acquisition (Botes, 2022).

Bustamante et al. (2020) explain that the use of educational science board games promotes collaboration and competition among learners. This gaming experience encourages learners to learn with and from each other. Selco and Habbak (2021) add that this approach enables learners to share knowledge and skills in order to work towards common goals of the board game. In terms of learner evaluation and assessment, educational science board games provide immediate feedback to learners. Educational science board games allow learners to track their progress and identify their strengths and weaknesses regarding knowledge acquisition. Such immediate feedback is essential in motivating learners to continue to learn. The use of educational science board games further prompts critical thinking and problem solving, since learners are expected to think creatively and strategically to solve challenges and overcome obstacles offered by the educational board game.

Given the learning benefits associated with the use of educational boardgames, the Department of Natural Science Teaching (DNST) in the School of Education (SoE) at Sol Plaatje University (SPU) prioritised the introduction of game-based education in its Science Teacher Development Programme. In particular, preservice teachers specialising in natural science teaching were tasked to develop and use educational science board games in their teaching practise. With this task in mind, it will be interesting to determine whether their development of educational board games stimulated a level of 'pedagogical thinking', as a core teacher quality. Pedagogical thinking, in this regard, deals with the ability of the preservice teacher to convey content knowledge in a creative and inclusive manner to stimulate a meaningful learning experience (Shulman, 1986). For this study, there was an interest to investigate whether the task to develop educational science board games sparked the ability of preservice teachers to convey content from the natural science syllabus effectively through board game dynamics and features. In doing so, the study will uncover whether the task of developing educational science board games required a level of 'pedagogical thinking' on the part of the preservice teacher.

Conducting this study is important for several reasons. In the first instance, the study sheds light on the effectiveness of gamification and board game education in stimulating the pedagogical thinking of preservice teachers. Second, the study shares how the task to develop educational science board games enabled preservice teachers to demonstrate the four interrelated knowledge domains of the pedagogical content knowledge model proposed by Shulman. These knowledge domains include the preservice teacher's knowledge of i) natural science subject knowledge, ii) knowledge of instructional strategies applicable to natural science teaching, iii) knowledge of learner-thinking, and iv) knowledge of assessment applicable to natural science education.

PROBLEM STATEMENT

An outcome of the Bachelor of Education degree in the School of Education is that preservice teachers who are specialising in the teaching of the subject natural science ought to demonstrate the ability to present lessons that provoke a joyful yet meaningful educational experience amongst learners. One such approach that was taken, was when preservice teachers were tasked to develop educational science board games as a means to enrich their natural science teaching experience during a recent school visitation opportunity. The expectation was that they use their education science board games in their practicum teaching with the ideal to elicit a more inclusive natural science learning experience amongst primary school learners.

However, given this educational exercise, what remains a mystery from a teacher development perspective is whether this approach provoked some form of 'pedagogical thinking' among preservice teachers. In other words,

which 'pedagogical thought processes' were demonstrated in the design and development of these educational science board games? More specifically, were the preservice teacher able to draw on i) the subject knowledge of the natural science school syllabus, ii) the knowledge of instructional strategies, iii) the knowledge of learner-thinking, and finally, iv) the knowledge of assessment in the quest to design and develop educational science board games. The knowledge domains listed above constitute Shulman's model of pedagogical content knowledge.

Currently, as a module lecturer in the Department of Natural Science teaching, little is known about whether the task to develop educational science board games served any purpose in allowing preservice teachers to display a level of pedagogical content knowledge. It is with this argument in mind, that this study seeks to investigate whether the development of educational science board games prompted the preservice teachers' demonstration of pedagogical content knowledge.

PEDAGOGICAL CONTENT KNOWLEDGE AS A CONCEPTUAL MODEL

The study draws on the conceptual understanding of the pedagogical content knowledge (PCK) model. The concept 'pedagogical content knowledge' was first introduced by Lee Shulman decades ago and represents the alignment between the subject knowledge of an educator, pedagogical knowledge, understanding of the classroom context, and finally understanding the learner-thinking (Shulman, 1986). Since this inception, seminal scholars such as Howey and Grossman (1989) seemed to provide a similar understanding of the term PCK when they referred to it as the "link" between the educator's understanding of content knowledge and that of the learners. Penso (2002), on the other hand, presents a more simplified understanding of the concept when it is suggested that PCK serves as the type of knowledge that enables an educator to connect the 'what to teach' with the 'how to teach'. In other words, PCK serves as that core teaching quality that enables educators to transmit content knowledge in ways that learners can understand.

The ability of an educator to demonstrate PCK is beneficial in the quest to enable learners to access concepts, theories, and terminology related to the natural science school syllabus effectively (Carlson et al., 2019). Simply put, the demonstration of PCK enables the educator to organise subject content knowledge in a manner that will be easily understood by learners during instructional teaching. In the context of natural science teacher development, the expectation is that preservice teachers show a mastery of PCK within their science teaching. At its core, PCK is informed by four interrelated knowledge domains. These knowledge domains are referred to as i) natural science content and curriculum knowledge, ii) knowledge of instructional strategies applicable to natural science education, iii) knowledge of learner-thinking, and iv) knowledge of assessment applicable to natural science education. For the purpose of this study, I intend to investigate whether the preservice teachers could draw on all four knowledge domains in their quest to develop educational science board games.

As a start, the preservice teacher should be able to identify relevant content from the natural science school syllabus that should be taught in a meaningful manner. Healy et al. (2020) more formally express their understanding of curriculum knowledge as the theoretical principles and behaviours associated with the planning, implementation and evaluation of the intended and planned curriculum. In the context of natural science education, this would include subject content that is associated with themes such as 'live and living', 'planet earth and beyond', 'matters and materials' and 'energy and change', which are common topics in the South African school curriculum.

Second, a preservice teacher specialising in natural science teaching should show mastery of instructional teaching methods that are applicable to the teaching of natural science. Instructional teaching methods are considered diverse teaching methods that can be employed in the science classroom, which promotes the learning experience of learners (Jdaitawi, 2020). For example, in the context of natural science education, methods such as practical experimentation and demonstrations, cooperative learning, discussions, and inquiry-based learning are a perfect fit to elicit a meaningful learning experience in the natural science classroom (Botes, 2021). Third, it is essential that the preservice teacher demonstrates an understanding of learner-thinking. Important here, is that the preservice teacher prompts the learner's acquisition of factual, conceptual, procedural, and metacognitive processes in acquiring knowledge (Eshuis et al., 2022).

Finally, it is critical that the preservice teacher practice quality assessment before, during, and at the end of instruction (Margot and Kettler, 2019). In doing so, the preservice teacher will have a 'snapshot' of what learners know, what learners should know and what learners do not yet know. This information will, in turn, inform the teaching practice of the educator. Assessment, in this regard, serves as an indicator of the effectiveness of teaching by linking learner achievement to learning outcomes.

RESEARCH METHODOLOGY

This study was qualitative in nature and followed a case study research design. The case included that of seven natural science preservice teachers who are in their final year of study and the role in which the development of educational board games allowed them to demonstrate pedagogical content knowledge. The aspects of the research methodology and approach are briefly described below.

Data Collection and Procedures

The study considered a focus group discussion and a photo-voice methodology as data collection techniques to capture rich empirical data. The data collection process took place over a period of one week during normal contact sessions on campus. A thematic content analysis was employed to interpret and describe the rich empirical data generated by the four secondary research questions of the study. In an attempt to respond to the aim of the study, which was 'to investigate whether the development of educational board games enabled preservice teachers to demonstrate pedagogical content knowledge', several secondary research questions were considered. These questions were as follows:

1. How did the development of educational board games enable preservice teachers to demonstrate 'knowledge of the natural sciences curriculum'?
2. How did the development of educational board games enable preservice teachers to 'demonstrate knowledge of instructional strategies'?
3. How did the development of educational board games enable preservice teachers to demonstrate 'knowledge of learner-thinking'?
4. How did the development of educational board games enable preservice teachers to demonstrate 'knowledge of assessment'?

The use of a focus group discussion in this study served two purposes. In the first instance, the focus group discussion enabled the seven preservice teachers to share their views on how the development of educational board games enabled them to demonstrate the four knowledge domains that inform PCK. These knowledge domains include the ability to demonstrate i) knowledge of the natural science curriculum, ii) knowledge of instructional strategies, iii) knowledge of learner-thinking, and iv) knowledge of assessment. Secondly, in making use of the focus group discussion, the team of preservice teachers were able to physically present their educational board games that they developed to their peers. This approach allowed for the amplification of the preservice teacher voice (Sim and Waterfield, 2019). In this instance, the focus group discussion created a space for the preservice teachers to respond to the four secondary research questions. The discussion was audio recorded on a handheld device, and the audio recording was made secure and password protected. To ensure anonymity, the names of the preservice teachers were kept confidential.

In addition to the focus group discussion, the study also considered the use of a photo-voice methodology to give expression to the physical footage of the educational board games that were developed by the preservice teachers. The use of a photo-voice methodology in this study was specifically meaningful, since it allowed the preservice teachers to physically display their educational board games and simultaneously share input on how the development of their educational science board games enabled them to demonstrate the four knowledge domains that inform the pedagogical content knowledge model. In doing so, a correlation was established between the verbal responses from the focus group discussion and the captured photographic evidence of the educational board games. This approach provided for an in-depth exploration and interpretation of the responses of the participants, which promoted the aspect of triangulation in the study (Shea, 2022).

Trustworthiness in the Study

The study responded to the aspect of methodological rigour through measures such as 'confirmability', 'credibility' and 'neutrality' (Creswell and Creswell, 2017). In terms of confirmability, which deals with the manner in which the findings of the study can be confirmed by others, the use of a focus group discussion allowed for a space that encouraged open dialogue between myself as researcher and the preservice teachers. Additionally, the photo-voice methodology used in the study also promoted the confirmability of the data. The aspects of credibility and neutrality, on the other hand, were elicited through my prolonged interactive engagement with the preservice teachers during the focus group discussion that took place. It should also be mentioned that the findings of the study were shared with all preservice teachers who participated in the study. This approach ensured that the empirical findings were accurately described.

Research Setting and Participants

The research site for this study was located in the School of Education at Sol Plaatje University. The School of Education offers a range of teacher development programmes, which focusses on early childhood development, primary school education, and secondary school education. From this particular site, the study population included several preservice teachers who enrolled for a Bachelor of Education degree with a focus on primary school education. Given this population, the purposive sample, on the other hand, included seven final-year preservice teachers who were specialising in natural science teaching. These participants provided their availability during our contact session.

Positionality of the Researcher

Positionality serves as the position that the researcher adopts within a given research study (Savin-Baden and Major, 2013). It requires the researcher to acknowledge and locate his/her views, values, and beliefs in relation to the research process (Holmes, 2020). Positionality is normally identified by locating the researcher in terms of the subject under investigation, the research participants, and the research context.

In this study, I acknowledged my combined roles as researcher and module lecturer of the seven final-year natural science preservice teachers. Given these combined roles, I was aware of the potential power imbalances that could have existed between me as the module lecturer and researcher in the study and my students who served as research participants in the study. With this in mind, I was prompted to be cautious of power dynamics and forms of intimidation that could have existed between myself and the preservice teachers. By no means did my role as module lecturer affect the ethical processes in this study. In addition, my role as module lecturer also did not influence the preservice teachers to partake in this study since they had the right to form part of the study on a voluntary basis.

Ethics

For this study, permission was granted by the Postgraduate Research Ethics Committee of the University of the Free State (Ethical clearance number-UFS-HSD2018/0073). All seven natural science preservice teachers were consulted before the study to give their consent to participate in the study. The preservice teachers were also ensured confidentiality throughout the duration of the study. Furthermore, preservice teachers were also allowed the right to withdraw from the study at any time.

RESEARCH RESULTS

This study investigated how the development of educational board games enabled preservice teachers to demonstrate pedagogical content knowledge. In pursuit of this aim, a focus group discussion and a photovoice methodology were considered as data collection techniques to clarify how their development of educational boardgames enabled them to demonstrate pedagogical content knowledge. Qualitative data from the focus group discussion and photographic evidence of educational board games yielded rich empirical data.

The next section provides evidence of how the seven preservice teachers responded to the four secondary research questions of the study. Each of the secondary research questions are introduced next. Thereafter, complimentary themes that capture empirical data from both the focus group discussion and photographic evidence are provided. The themes associated with the secondary research questions are also interpreted in detail.

RESPONDING TO SECONDARY RESEARCH QUESTION 1

The first secondary research question sought to determine 'whether the development of educational board games allowed preschool teachers to demonstrate knowledge of the natural science curriculum'. Curriculum knowledge is regarded as the first knowledge domain that informs the PCK model (Healy et al., 2020). When asking the question to preservice teachers during the focus group discussion, multiple verbal responses were provided. From these responses, three prominent themes were formulated that were associated with their knowledge of the natural science curriculum. The first theme was centred around preservice teachers' selection of applicable content from the natural science school syllabus to include in the board game design. The second theme dealt with the ability of preservice teachers to draw on the prior knowledge of the learners to promote more advanced forms of knowledge of subject content. Finally, the third theme focused on the integration of natural science content knowledge into board game designs. These themes are discussed next.

Theme 1.1. Selection of Relevant Content from the Natural Science School Syllabus

The first theme that was associated with the demonstration of knowledge of the natural science curriculum by preservice teachers was centred around their selection of applicable content from the natural science school syllabus that was integrated into their educational science board games.

For example, participant 1 mentioned the following:

> This task required me to think carefully about my learners in the classroom. I had to think carefully if the questions on the quiz cards were not too tricky for my learners. I had to look at the work we covered in the textbook and [clarify] how [the content] might be asked in the exams. (Participant 1)

The response provided by participant 1 suggests that the preservice teacher was aware of the learners' varied cognitive abilities in the classroom. In particular, the phrases "think carefully" and "the questions on the quiz cards were not too tricky" serve as evidence that the preservice teacher is showing the ability to structure written questions on the "quiz cards" that were applicable to the cognitive ability of the learners. Furthermore, the phrases "had to look at the work we covered" and "[clarify] how [content] could be asked in the exams" suggest that the preservice teacher had to consult the prescribed school curriculum as well as the school syllabus of natural science to select the applicable content that could be included for summative assessment purposes.

Another verbal response provided by participant 3 provides evidence of a preservice teacher's ability to demonstrate 'knowledge of the curriculum' as witnessed below:

> It was quite challenging to develop the game in such a way that the kids not only play but also learn the concepts that I taught them during the term prescribed by the department. (Participant 3)

The response delivered by participant 3 provides different meanings. In the first instance, from the response, the participant claims that play-based education can promote a joyful, yet meaningful learning experience. This is supported by phrases such as "kids should not only play, but also learn". Surprisingly, the learning experience offered should also be closely related to the curriculum and assessment. For example, the phrases "learn concepts taught during the term" and "learn concepts that will be asked by the [department]" suggested that the educational board game provided learners the opportunity to engage with relevant topics offered by the school syllabus of natural science.

In support of this verbal response, participant 3 further shared photographic evidence of the board game that was developed as shown in **Figure 1**. In this particular board game, participant 3 intentionally included content topics from the natural science school syllabus, namely "the solar system", "solids, liquids and gases", "ecosystems and food webs" and "fossil fuels and main electricity" as witnessed in the left-hand corner of the image.

Figure 1. A board game developed by research participant 3

Theme 1.2. Use of Prior Knowledge to Promote the Knowledge of the Subject Content

The second theme that was associated with the preservice teachers' ability to demonstrate knowledge of the natural science curriculum dealt with their skill to draw on learners' prior knowledge as a means to promote more advanced forms of knowledge of the natural science syllabus. For example, participant 6 had the following to say:

> So basically, in developing the game, I had to constantly think of basic examples... You know, those examples that they [learners] are used to so that they can link it to the content that I taught them in term 2. For example, I added a picture of a block of ice and a boiling kettle producing steam, and if they threw the dice and landed on this block, they had to provide a scientific explanation of what they see. (Participant 6)

Another participant seemingly shared a similar sentiment by stating that:

> The game is closely linked to the 30 seconds game, so learners may already think that the game involves teams and questions, and the blocks may paint a picture to the learners that they will need some dice to play the game. The game serves as a sort of 'revision game', so questions will be asked based on the content covered. For example, learners know that the process by which plants make their own food is called photosynthesis, and learners know that a system that transfers energy is called an electric circuit. The pictures used in the board game tell the learners that this game is related to the subject of natural science. (Participant 1)

An analysis of the response provided by participant 6 made it apparent that the preservice teacher intentionally developed the board game to allow learners to use their prior knowledge in order to acquire more complex forms of knowledge, as depicted in the natural science school syllabus. This assumption was supported with the following phrases, namely, "I had to constantly think of basic examples" and "those examples that they [learners] are used to". In other words, the preservice teacher was well aware that the learners in the classroom will be familiar with "how a kettle, as a household device, can boil water". What made this learning experience meaningful was that learners should link their prior knowledge, for example, "how a block of ice can melt into a liquid form", with the understanding of the topic "different states of matter" that inform the natural science school syllabus. This approach clarified whether learners understood the three common states of matter, namely, ice (solids), water (liquid), and steam (gas).

A similar response was shared by participant 7, when it was mentioned that:

> I agree that linking your [learners] knowledge with textbook knowledge is so important. I followed a similar approach as [Lesego]. I tested multiple topics in grade 8 with a couple of pictures that I pasted on the board. What was quite nice was the picture of a tea bag in boiling water, and then I tried to link the tea bag in boiling water with the concept of diffusion and osmosis. I actually had questions in the note cards that tested their understanding of diffusion and osmosis with this basic example. (Participant 7)

This response was yet another example of how the preservice teacher relied on learners' prior knowledge as a driver to develop more advanced forms of knowledge. Similarly, to the previous response, the participant used the example of a "tea bag in boiling water" to illustrate the concept of "diffusion and osmosis" as topics in the natural science school syllabus. The response also made it apparent that the participant had to strategically develop note cards that tested learners' understanding of "diffusion and osmosis" by linking it to the picture of a "tea bag in boiling water".

Theme 1.3. Integration of Content Into the Design of the Board Game

The third theme associated with the preservice teachers' ability to demonstrate knowledge of the natural science curriculum focused on their ability to integrate content relevant to the subject natural science into the design of a board game, as found in the responses of participant 4 below.

> My board game covers a variety of topics from all 4 terms namely, live and living, matter and materials, energy and change, earth and beyond. I also tried to bring in topics from mathematics, English, and life skills. By including topics from maths, English and life skills, learners can realise that natural science can be integrated with other subjects. (Participant 4)

In addition to providing a verbal response, participant 4 displayed her board game that she developed, as seen in **Figure 2**.

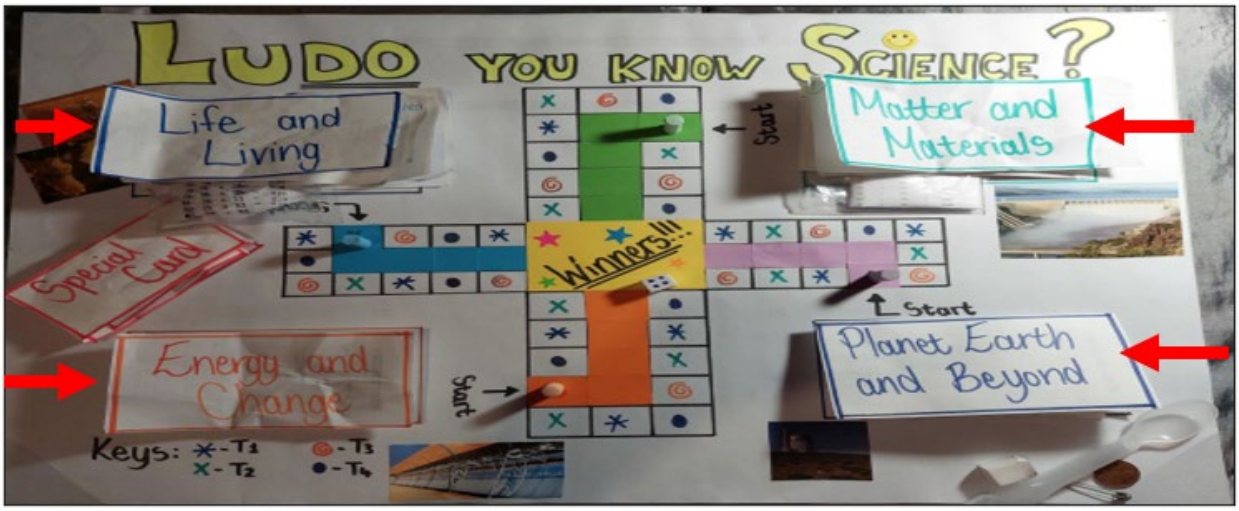

Figure 2. Board game developed by research participant 4

Both the verbal response and the photographic footage provided suggested that the participant was able to strategically integrate content relevant to the subject of natural science into her design of the board game. For example, a closer look at the photographic evidence made it apparent that the suggested topics were categorised under themes identified as "Life and Living", "Matter and Materials", "Earth and Change", and "Planet Earth and Beyond". These themes were visible in the physical footage of the board game provided. Therefore, the participant intentionally integrated content from the natural science school syllabus into the design of her board games. This was done in an effort to test learners' understanding of these topics at a primary school level.

Furthermore, **Figure 3** provided more evidence of how participant 6 creatively integrated content from the natural science school syllabus into the design of her board game.

Figure 3. Board game developed by research participant 6

In particular, level 1 of the board game tested the learners' understanding of the "process of photosynthesis". Level 9, on the other hand, focussed on a topic relevant to "food chains in an ecosystem". Additionally, level 11 dealt with the topic "changing states of matter". Finally, level 21 tested learners' understanding of a "electric circuit diagram in a series connection".

RESPONDING TO SECONDARY RESEARCH QUESTION 2

The second secondary research question sought to determine 'whether the development of educational board games enabled preservice teachers to demonstrate knowledge of instructional strategies'. Knowledge of instructional strategies, as the second knowledge domain that informs the PCK model, focuses on those teaching strategies that actively engage learners in the learning process with a clear lesson goal in mind (Lamon, 2020). In this instance, verbal responses derived from the focus group discussion and physical footage of the board games suggested that the preservice teachers were able to demonstrate knowledge of instructional strategies along two predominant themes. In the first instance, pre-service teachers were able to formulate board game objectives that promoted active and engaged learning. Secondly, the preservice teachers were able to spark learner interest through practical demonstrations and engaged learning experiences. These themes are briefly explored next:

Theme 2.1. Formulating Board Game Objectives That Promoted Active and Engaged Learning

The first theme speaks to the manner in which preservice teachers demonstrated knowledge of instructional strategies. More specifically, the preservice teachers were able to formulate board game objectives that promoted active and engaged learning amongst learners. The objective of the board game informed how the educational activities unfolded during learners' engagement with the board game. One such example of a board game objective can be found in the following verbal response:

> The objective of the board game was that by the time my learners completed the board game, they [learners] would have gained vast knowledge on a variety of topics of natural science, and they [learners] would also be able to see the links between natural science and real life. (Participant 1)

Another participant was able to share his/her board game objective when it was proposed that:

> I wanted to effectively align the board game with my teaching and learning. I wanted to use the board game to promote deep learning, critical, and creative thinking in a collaborative manner. I felt that it was important that my students attempt all the board game questions in preparation for the exam. It was also important to me that my learners communicate effectively using visuals, symbols, and language skills in various modes. (Participant 6)

The verbal responses provided by Participants 1 and 6 were indicative of educational objectives. Phrases such as "align the board game with my teaching and learning" and "learners would also be able to see links between natural science and real life" suggested that they were intentional in using the educational board game as a mechanism to provoke authentic and engaged natural science learning encounters. Furthermore, responses such as "game to promote deep learning, critical and creative thinking in a collaborative manner" suggested that the participants considered "learner-centred" teaching approaches as a means to engage learners in the board games activities. Finally, the reference "learners communicate effectively through using visuals, symbols, and language skills in various modes" indicated that the participant strategically prioritised learners' development of intra- and interpersonal skillsets.

Theme 2.2. Prompting Learner Interest Through Demonstrations and Engaged Learning Experiences

The second theme associated with preservice teachers' knowledge of instructional strategies centred around the inclusion of board game activities that enabled learners to partake in active and cooperative learning experiences. Examples of such activities included small-group work activities, cooperative learning activities, class discussion activities, practical hands-on activities, and modelling activities, to name but a few (van Leeuwen and Janssen, 2019).

For example, participant 2 mentioned that:

> My game requires the students to be hands-on in their group, and these groups will be constantly prompted to provide feedback. What is important to me is that children should not only play, but also learn through play. (Participant 2)

Similarly, participant 5 shared the following sentiment by suggesting that:

> The game uses different graphs that learners will have to interpret and draw. The learners will be exposed to a variety of images and diagrams that they will have to label and draw as well. There are also quiz cards that they will need to complete. Some questions will require them to interpret tables, make

> drawings and even make scientific comparisons. It is important that they learn concepts that I taught them during the term that will be asked in the departmental control test in the future. (Participant 5)

The responses provided by both participants have different meanings. In the first instance, participant 2 claimed that play-based education can promote a joyful, yet meaningful, learning experience. This is supported by phrases such as "kids should not only play but also learn". In addition, participant 2 further made it apparent that his/her board game catered to educational activities such as "hands-on activities and group work activities" that required learners to be actively engaged in cooperative learning. Participant 5, on the other hand, added that his/her board game expected the learners to engage in critical thinking that required them to "interpret visuals and diagrams" and "make visual drawings".

Surprisingly, participant 5 made it apparent that the learning experience offered by her board game was in accordance with the prescribed curriculum and assessment offered by the natural science syllabus. For example, the phrases "learn concepts that I taught during the term" and "learn concepts that would be asked in the departmental control test" suggested that the educational board game provided learners the opportunity to engage with relevant topics offered by the natural science school syllabus.

In addition to these verbal responses, photographic evidence of the "game cards" that were included in participant 5's board game, was indicative of the educational activities that were built into the design of the board game. A closer look at the "game cards" depicted in **Figure 4** suggested that an element of learner engagement and critical thinking were required from the learners.

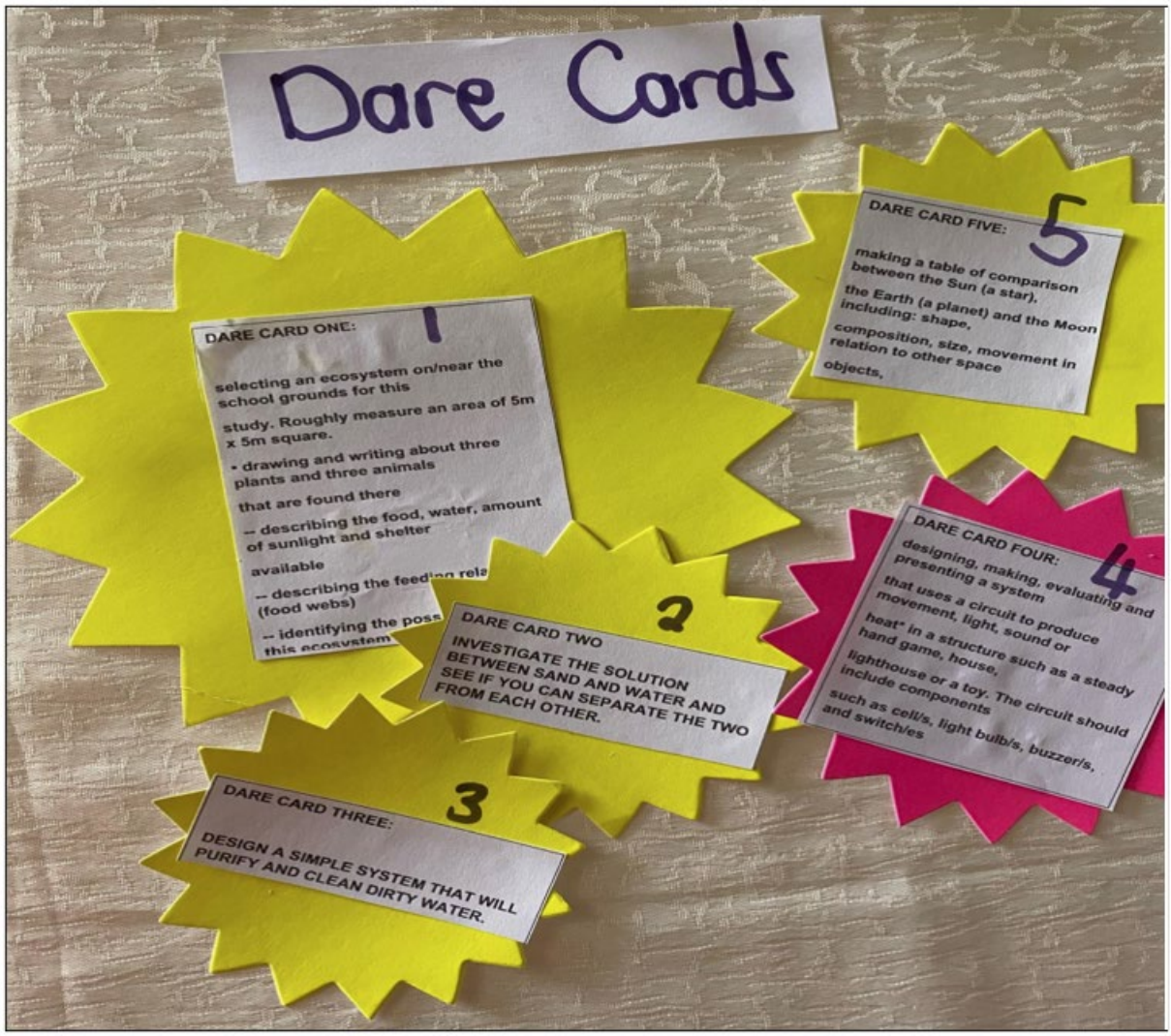

Figure 4. Board game activities that sparked authentic and practical learning

The captured footage provided evidence that the "game cards" developed by participant 5 required the learners to participate in a series of authentic and practical learning activities. Examples of such practical activities included the students "designing a system that will purify water", "developing an electrical circuit" and "mapping out an ecosystem".

RESPONDING TO SECONDARY RESEARCH QUESTION 3

The third secondary research question sought to determine 'whether the development of educational board games enabled preservice teachers to demonstrate knowledge of learner-thinking? Knowledge of learner-thinking, as the third knowledge domain of the PCK model, deals with the manner in which learners approach different educational tasks and activities (Alam, 2022). Given this explanation, learners might approach a learning task through visual (see), auditory (hear), and kinaesthetic (touch), and reflective (think) ways. Drawing from the photographic evidence provided in **Figure 5**, it was found that the preservice teachers demonstrated knowledge of learner-thinking through initiating educational activities within their board game designs that prompted learner engagement through visual, auditory, and kinaesthetic means. This finding is interpreted next.

Theme 3.1. Prompting Learner Thinking Through a Visual and Kinaesthetic Means

A closer look at **Figure 5** resembled photographic evidence of an education board game that has the potential to prompt learner thinking through a visual and kinaesthetic means.

Figure 5. Board game developed by participant 7

The board game portrayed in **Figure 5** revealed how the preservice teacher was strategic in structuring an educational activity in a manner that prompted the learner to think through visual and kinaesthetic means. This educational activity was further grounded in a social learning context where learners were expected to collaborate with their peers. In this instance, the task of accurately fitting the correct puzzle piece in a logical way by studying the creative drawings on the board game will most certainly spark the visual and kinaesthetic thinking of a child. In particular, the educational science board game titled "A Life in a Year" required learners to complete a puzzle board game made from cardboard. This puzzle board game aimed to informally assess learners' prior knowledge and understanding of several topics related to the natural science school syllabus. For example, topics such as "water transport in plants", "the process of photosynthesis", "organic compounds," "process of evaporation", and "solar system" were referenced in the board game. Finally, this educational activity further encouraged the stimulation of the hand-eye coordination and fine motor skills of the learners.

RESPONDING TO SECONDARY RESEARCH QUESTION 4

The fourth and final secondary research question sought to determine 'whether the development of educational board games by preservice teachers enabled them to demonstrate the knowledge of assessment'. Assessment knowledge, as the fourth knowledge domain that informs the PCK model, focusses on the ability of an educator to be equipped with the types of assessment methods that are useful in establishing the learners' understanding of the content taught (Ekiz-Kiran et al., 2021). The use of a focus group discussion and photographic evidence of the board games again served as valuable data collection techniques to determine whether the preservice teachers were able to demonstrate knowledge of assessment. In particular, two predominant themes, namely i) the inclusion of varied written question types in board game designs and ii) aligning questions to the different levels of Bloom's taxonomy, revealed the preservice teachers' knowledge of assessment in this regard. These themes are described next.

Theme 4.1. The Inclusion of Varied Written Question Types in Board Game Designs

The first theme that suggested that the preservice teachers were in fact able to demonstrate knowledge of assessment dealt with the inclusion of varied questioning types in their board game designs. A verbal response from participant 1 confirmed her position on the use of written questions in her board game.

> Okay, so with my board game, I varied my types of questions to include a broad spectrum of the types of questions. I preferred using multiple choice, fill in the missing word, true/false, short answer questions, longer answer questions, and data response questions. I also tried to develop questions that go from lower-order thinking to higher-order thinking. (Participant 1)

In support of this verbal response, participant 1 further shared photographic evidence (see **Figure 6**) of the different type of questions she used in her board game.

Figure 6. Evidence of varied question types

Theme 4.2. Aligning Questions to the Different Levels of Bloom's Taxonomy

In addition to the inclusion of different types of questions by the preservice teacher, it could also be confirmed that some preservice teachers intentionally structured questions that responded to various levels of Bloom's taxonomy. Bloom's taxonomy allows an educator to assess and evaluate learners' thinking at a variety of cognitive levels at different levels of complexity (Pujawan et al., 2022). In the context of this study, a closer look at the question circled in red in **Figure 7** revealed a question that required higher-order thinking on the part of the learner.

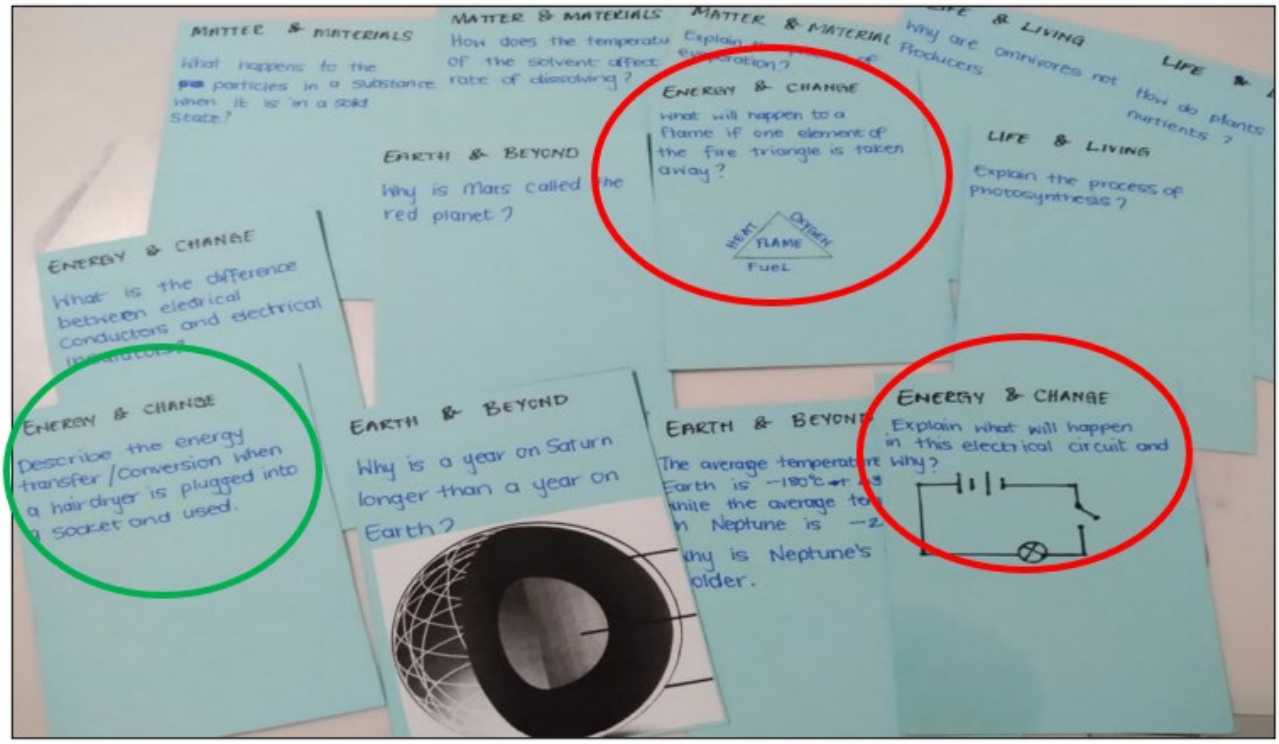

Figure 7. Questions structured at different levels of complexity

In this case, this particular question that dealt with the topic "energy and change" required learners to "predict what would happen to the combustion process when one of the main ingredients of combustion is removed". This kind of question resembled a higher-order question since it required deeper thinking and inner reasoning. Another such example can be found at the bottom right of **Figure 7**. In this case, the learners were asked to "explain what will happen to an electrical current if a circuit is open?".

In addition, **Figure 7** further provided examples of questions that required some form of lower-order thinking on the part of the learner. For example, a closer look at the question circled in green suggested that a simple close-ended response is required from the learner. To be specific, in this instance, learners were asked to "differentiate between electrical conductors and insulators". This type of question requires a single response and constituted lower-level thinking.

DISCUSSION OF FINDINGS

The purpose of the study was to investigate whether the development of educational science board games influenced the ability of preservice teachers to demonstrate pedagogical content knowledge. Rich empirical data derived from the focus group discussion and physical photographic evidence of the board games provided revealed that the task of developing educational board games did, in fact, prompt the demonstration of the four knowledge domains of the PCK model. These four knowledge domains included the preservice teacher's i) knowledge of the subject content, ii) knowledge of instructional strategies applicable to natural science education, iii) knowledge of learners' thinking, and iv) knowledge of assessment applicable to natural science education.

In the first instance, in developing educational boardgames, preservice teachers were able to demonstrate curriculum knowledge that is relevant to the natural science school syllabus. Curriculum knowledge, in the context of natural science education, is broadly defined as the ability of a natural science educator to draw on subject-specific content knowledge that is associated with the planning, implementation, and evaluation of the natural science subject syllabus. Evidence of curriculum knowledge was expressed through themes such as "the use of prior knowledge to promote subject content knowledge", "applicable content selection from the natural science school syllabus", and "content integration within the design of the board game". Photographic evidence on teachers' demonstration of curriculum knowledge can be seen in **Figure 1** and **Figure 2**.

In the second instance, the task to develop educational natural science board games also allowed the preservice teachers to demonstrate knowledge of instructional strategies. Instructional strategies are regarded as specific teaching approaches that are beneficial towards eliciting an effective learning experience in the classroom context (Bizimana et al., 2022.). Examples of instructional strategies in the context of natural science teaching include small-group work activities, cooperative learning activities, class discussion activities, practical hands-on activities,

and modelling activities, to name but a few (Botes, 2022). A characteristic feature of instructional strategies is that it allows for learning to unfold in either visual (see), auditory (hear), and kinaesthetic (touch) and reflective (think) means (Rahayu et al., 2020). With this in mind, the board games developed by the preservice teachers expressed the "development of deep and concrete learning experiences" and "critical, creative, and collaborative thinking in a hands-on way". Finally, in playing the board game, the learners were also challenged to "label, draw, and interpret graphs and tables" and "communicate effectively with their peers". The latter serves as a confirmation that the preservice teachers were intentional to include learning tasks in their board games that catered for the varied learning needs of learners.

In the third instance, in developing educational boardgames, preservice teachers demonstrated knowledge and understanding of learner-thinking. Knowledge of learner-thinking, which serves as the third component of the PCK model (Carlson et al., 2019) suggest that new knowledge is created based on prior knowledge of a learner. With this understanding of learning thinking in mind, multiple references were made to learners engaging in diverse means. For example, references such as "in playing the board game, learners would have gained vast knowledge on a wide range of topics related to natural science" and "they would also be able to see links between the subject of natural science and phenomena" related to science in everyday life. This approach prompts the learner to acquire factual, conceptual, procedural, and metacognitive knowledge (Aivelo and Huovelin, 2020).

Finally, the task to develop educational boardgames further enabled preservice teachers to demonstrate knowledge of assessment that is relevant to the natural science syllabus. The knowledge of assessment, as the fourth component that informs the PCK knowledge model, includes the types of assessment methods used to establish the level and quality of learning that took place in a classroom context (Ekiz-Kiran et al., 2021). With this understanding of "knowledge of assessment" in mind, photographic evidence (see **Figure 4** to **Figure 7**) provided substantial evidence of the ability of preservice teachers to formulate written question types. For example, written question types such as "multiple choice questions", "true and false questions" and "short and long response questions" allowed for the testing of learners' knowledge of several topics related to "matters and materials, energy and change, life and living and earth and beyond". More interestingly, it could also be concluded that the types of written questions that were formulated were strategically aligned with the various levels of Bloom's taxonomy, as seen in **Figure 6** and **Figure 7**. This approach suggested that the intention of composing written questions was categorised according to complexity and specificity.

CONCLUSIONS AND IMPLICATIONS

The study investigated how the development of educational science board games influenced the ability of preservice teachers to demonstrate pedagogical content knowledge. This was done in order to determine whether the task of developing education science board games influenced the pedagogical thinking of preservice teachers. The PCK serves as the type of knowledge that enables an educator to connect content knowledge commonly known as 'what to teach' with pedagogical knowledge also referred to as 'how to teach' (Penso, 2002). The use of a focus group discussion complemented by photo-voice methodology, as data collection techniques, revealed the extent to which "knowledge of the natural science curriculum" was demonstrated since the preservice teachers were able to carefully select content from the natural science school syllabus that was inserted into their board game designs.

Additionally, the development of educational science board games further tested preservice teachers' "knowledge of instructional strategies", as they had to clarify the educational objectives of their board games and also design their board games in a way that involved the learners in a meaningful and engaging learning experience. Furthermore, preservice teachers could also demonstrate "knowledge of learner-thinking" by adding learning instructions and activities to the board game that challenged the varied learning styles of learners. Finally, the task of developing board games triggered the preservice teachers' "knowledge of assessment" due to the fact that different types of questions had to be integrated into their board game designs in order to test learners' knowledge of topics in natural science.

In the future, this study holds a series of implications for future research in the field of initial teacher development and STEM education. For example, it will be interesting to uncover how preservice teachers experience the use of educational board games in their teaching. In addition, it will also be interesting to discover how educational board games can be used in other STEM subjects such as mathematics, technology, and physical science. Ultimately, more research is also required on the learning benefits of educational board games from a learner-perspective.

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