Concept Maps as a Resource to Enhance Teaching and Learning of Mathematics at Senior Secondary Level

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Keywords: Concept maps, conceptual knowledge, prior knowledge, visual representations

Abstract

Research has identified conceptual understanding as central to students' mathematics comprehension. However, limited research is available to help teachers link mathematics concepts from junior to senior subjects during teaching and learning in Queensland. This mixed methods study is underpinned by constructivism. It explores teachers' perceptions on how visual representations such as concept maps that link junior concepts (years 7 to 10) to senior concepts (year 11 and 12) can enhance the teaching and learning of conceptual knowledge at senior secondary mathematics. Surveys that include Likert scale items and open-ended questions were conducted with sixteen senior secondary mathematics teachers. To gain deeper understanding, eight semi-structured interviews were also conducted. Results show teachers hold the perception that when concept maps are used to link junior (years 7 to 10) to secondary concepts (year 11 and 12) they can be a resource that enhances conceptual knowledge, consolidation, and assessment of students' mathematical knowledge. The role of visual representations in mathematics teaching and learning that is enhanced by concept maps is an area that needs more attention to help improve students' participation and achievement.

Introduction

Schools are facing challenges in developing students' conceptual knowledge in mathematics (Richland, Stigler, & Holyoak, 2012). Conceptual knowledge is defined as the knowledge of the interconnection of fundamental concepts in a domain (Schneider & Stern, 2010). Students lack the deeper understanding of mathematics that facilitates reasoning, flexibility and generalisations (Richland et al., 2012). Richland and colleagues noted, high school graduates who enter the community college system in USA end up in mathematics bridging courses because they lack conceptual knowledge. Similarly, in Australia, limited conceptual knowledge focus has been identified as the main factor influencing students' participation in mathematics (Smith, Ladewig, & Prinsley, 2018). Mathematics teaching and learning can be enhanced when students learn "*with understanding, actively building new knowledge from experience and previous knowledge*" (National Council of Teachers of Mathematics [NCTM], 2000, p. 2). Australian teachers believe conceptual knowledge is essential in making students understand mathematics (Hurrell, 2021). The understanding that conceptual knowledge plays a key role in mathematics knowledge development highlights the importance of interlinking mathematics concepts.

Conceptual knowledge is built through defining and understanding the interconnection of concepts. It is a network of concepts that constitute a bigger unit of knowledge (Österman & Bråting, 2019). In fact, complex unfamiliar problems that require deeper understanding of mathematics in most cases require students to make connections of knowledge within or across the domain (Queensland Curriculum and Assessment Authority [QCAA], 2018). Awareness of the connectedness and coherence of mathematics concepts is often overlooked by mathematics teachers, however, it is an important goal that has reshaped instruction during teaching and learning of mathematics (Novak, 2010). This is because, "*Mathematics is a field of continuous inquiry about new relationships and of proving these relationships.*" (Bingölbali & Coşkun, 2016, p. 236). Moreover, coherent instruction in mathematics connects prior and fundamental concepts to new knowledge and provide the opportunity to deepen the understanding to complex concepts (Doabler, Fien, Nelson-Walker, & Baker, 2012). Mathematical understanding is enhanced when students are presented with the opportunity to adapt or reflect on their experience and knowledge and make connections between prior knowledge and new knowledge, resulting in gradually developing new knowledge (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2013). "*Well-constructed knowledge is interconnected, so that when one part of a network of ideas is recalled for use at some future time, the other parts are also recalled*" (Sullivan, 2011, p. 6). Thus, this study's focus is on exploring a visual representation that teachers can use to enhance students' development of mathematical knowledge through the ability to link junior to senior concepts as learning progresses.

Students learn better when exposed to information in visual form (Raiyn, 2016). In fact, students retain visual formats better and longer in their minds, as it is easy to understand and show connections (Raiyn, 2016). Similarly, visuals not only provide teachers and students with the opportunity to identify and visualise concepts and procedures but also to realise and illustrate relationships, making recalling easier (Birbili, 2006). Indeed, visuals are "*the best tool for making teaching effective and the best dissemination of knowledge*" (Shabiralyani, 2015, p. 226). Moreover, they can represent a large amount of information, reducing the time required to go through the information (Raiyn, 2016). As a result, visuals such as concept maps that can link junior concepts (years 7 to 10) to senior concepts (year 11 and 12) can enhance teaching and learning of mathematics.

Concept maps

The use of concept maps in teaching conceptual knowledge has been highly recommended. Novak (1990) introduced concept maps in science and mathematics to organise and link concepts. Research on use of concept maps in mathematics has focused mostly on middle school and teacher training level with very limited research at the senior secondary level (Schroeder, Nesbit, Anguiano, & Adesope, 2018). Importantly, a metanalysis by Schroeder and colleagues concluded that research has focused more on explaining the benefits of using concept maps without collecting evidence to support such assertions. This study reports on teachers' perceptions of the benefits of concept maps for mathematics teaching at the senior secondary level.

Concept maps show concepts and how they are connected, thus giving a representation of conceptual understanding. They are a resource that can be used to represent and demonstrate conceptual understanding (Watson, Pelkey, Noyes, & Rodgers, 2016). Moreover, they can be a tool to demonstrate concept cohesion within or across a domain (Hartsell, 2021), which is key to mathematics content sequencing during planning (Chinofunga, Chigeza, & Taylor, 2022). In this view, conceptual understanding is represented by concept nodes that are connected by single or bidirectional arrows labelled with verbs to specify the relationship between and among them (Birbili, 2006; Novak, 2010). They may be hierarchical in nature and low-ranking concepts can be more elaborative and specific (Llinas, Macias, & Marquez, 2018), which blends well with the hierarchical structure of mathematics.

Concept maps promote higher order thinking (Cañas, Priit, & Aet, 2017), facilitate integration of complex ideas (Beat, 2015) and promote problem solving (Watson et al., 2016). Their ability to provide opportunities to present conceptual interconnections and relationships that include the main concepts and other related prior or sub-concepts promotes critical thinking (Groffman & Wolfe, 2019). Similarly, use of visual representations to show relationships of mathematics concepts encourages critical thinking and enhances teaching and learning of mathematics (Bay-Williams & SanGiovanni, 2021). It follows that, "*concept mapping promotes students' understanding of complex constructs and complicated relationships, while stimulating critical analysis and improving critical thinking*" (Fonteyn, 2007, p. 200). Furthermore, they enhance the quality of students' learning by facilitating connection of ideas and providing a solid foundation to add and understand new knowledge, which is valuable for problem solving (Kinchin, Möllits, & Reiska, 2019). Being able to break down complex phenomenon into familiar concepts is central in solving complex questions that might require integration of different concepts, which is expected in mathematics at senior secondary (QCAA, 2018). Moreover, linking as much prior knowledge as possible to new knowledge enhances cohesion of concepts and understanding (Mai, George-Williams, & Pullen, 2021). At senior secondary level, students' ability to link relevant prior knowledge at junior level to senior level concepts enhances participation and understanding.

Broadly, concept maps have several benefits to teaching and learning. They are beneficial "*in activating students' prior knowledge, identifying misconceptions, focusing discussions, facilitating collaborative learning and as revision and assessment tools*" (Kinchin, 2011, p. 183). Concept maps help teachers in focusing students on what they need to learn and the main concepts they need to retain (Hartsell, 2021). They also facilitate a meaningful and consolidated understanding of mathematics, as well as help to show the differences in knowledge and understanding among students (Ho, Harris, Kumar, & Velan, 2018). As a result, they can be used in mathematics formative assessments which do not require students to recall facts and procedures (Bell, 2017). Importantly, they provide an overall picture of the phenomenon in question rather than just focusing on facts (Vasconcelos et al., 2019). Mapping concepts provide opportunities of multiple representation which enhances deeper understanding (Gokalp & Bulut, 2018). Similarly, they can be used to identify students' misconceptions in their conceptual understanding (Watson et al., 2016). Moreover, they enhance integration and clarity of concepts and motivate students to learn (Chiou, 2008). Concept maps support student centred learning by making them active participants in the learning process (Groffman & Wolfe, 2019). Thus, teaching and learning of mathematics that involves concept maps is superior to other instructional models (Schroeder et al., 2018).

Teachers as classroom practitioners are well placed to evaluate resources. Thus, this study investigated teachers' perceptions of the impact of concept maps that link junior to senior concepts on the teaching and learning of mathematics at senior secondary school. The study addressed the following research question:

> What are senior secondary teachers' perceptions of the impact of concept maps that link junior to senior concepts on the teaching and learning of mathematics at senior secondary school?

Method

This mixed methods study explored the impact of concepts maps in the teaching and learning of mathematics. The mixed methods approach is ideal because it provides an opportunity for consolidating results from both quantitative and qualitative research methods (Creswell, 2015).

Quantitative and qualitative data are analysed and then integrated in order to cross validate findings (Creswell, 2015). The purpose of the study was to investigate secondary mathematics teachers' perspectives on the effectiveness of using concept maps that link junior to senior concepts as tools that mathematics teachers can use in developing students' conceptual knowledge.

Purposive sampling was used to select 16 high school mathematics teachers in Queensland, Australia. The inclusion criteria were teachers who are currently teaching or who have taught mathematics, especially calculus-based options at senior high school level that is Year 11 and 12 in Queensland. Ethical approval was gained from the Department of Education, Queensland: Reference number: 550/27/2383 and James Cook University Human Research Ethics Committee: Approval number: H8201.

Sixteen research participants took part in a 10-minute video presentation where they were provided with information on how concept maps that link junior to senior concepts could be used in teaching and learning of mathematics. The video presentation included how to develop the concept maps and the possible stages where they could be used during teaching and learning. They were given a full school term (10 weeks) to respond after including concept maps that link junior to senior concepts in their teaching. During the implementation period, fortnightly after-hours Microsoft Teams check-in meetings with all participants were organised to check on progress and offer support. When and how to employ such concept maps during teaching and learning was left for teachers to decide considering class dynamics. The concept maps could be teacher developed, student developed and/or class developed depending on the pedagogy employed by the teacher. This provided teachers with the opportunity to be innovative resulting in diverse experiences and perceptions. The concept map tools that link junior to senior concepts were developed using a Content Sequencing framework developed by Chinofunga and colleagues (2022). The mathematics content presented in the concept map presented to teachers was drawn from Unit 1 in Mathematical Methods (Figure 1), with functions as a focus.

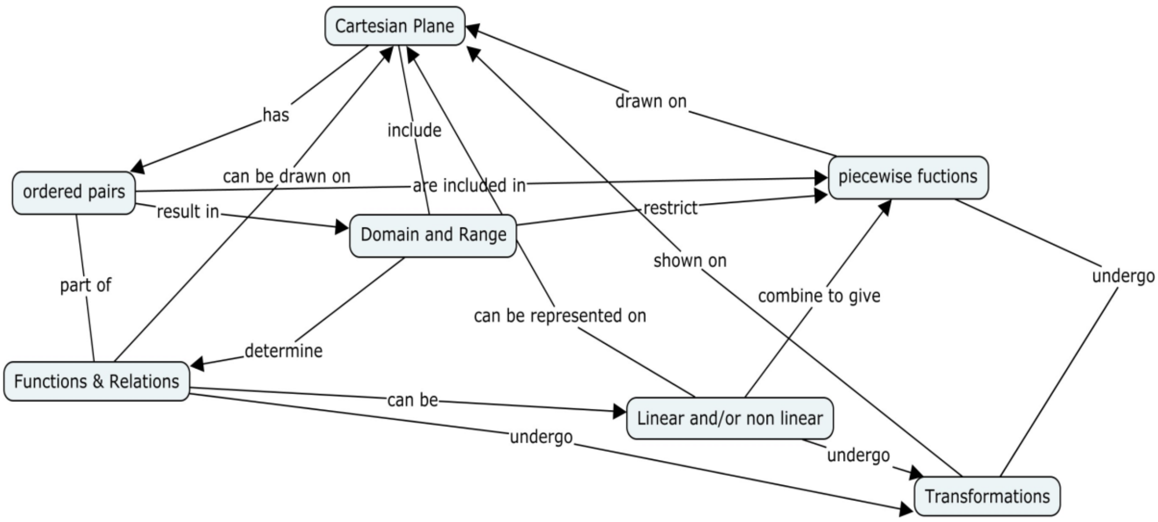

Figure 1: Concept map that links junior to senior concepts: Functions

The concept map above links the concepts on a section of functions in Unit 1 Mathematical Methods. It includes phrases that help explain how the concepts link. To and from arrows demonstrate that some connections are bi-directional. Thus, concept maps help to construct meaning and relationship between concepts.

Data Collection

Data collection was conducted through a survey and semi-structured interviews. The survey with a five-point Likert scale and five open-ended questions was shared with the participants. The scaled survey questions required teachers to rate their level of agreement on a scale from 1 to 5 on questions based on use of concept maps that link junior to senior concepts in developing students' mathematics knowledge.

Semi-structured interviews were conducted to gain knowledge of how teachers used the concept maps in their teaching of mathematics. Semi-structured interviews are adjustable and adaptable, because they provide opportunities for the interviewer to ask follow-up questions based on the interviewee's responses (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). Interviews were conducted with only eight out of the 16 participants who completed the survey due to competing schedules. The interviews averaged about 25 minutes.

Data Analysis

Quantitative data from the 5-point Likert scale were collated in Excel. Rows were allocated to participants and columns to questions. From the initial results tabulation, the mode and median responses for each question were determined. This is because Likert data are generally ordinal in nature and are best analysed using modes and medians (Stratton, 2018). Thereafter a table of questions and percentage responses was created to summarise results.

This study involves two types of qualitative data which were open-ended survey questions and semi-structured interviews. After transcribing the semi-structured interviews, member check was done with two participants to verify accuracy of the transcribed scripts. Data analysis of survey open-ended questions and interviews followed a thematic analysis. Thematic analysis aims to identify, investigate, and reveal patterns found in a data set (Braun & Clarke, 2006). To ensure validity, the study used theory triangulation. It involves sharing qualitative responses among colleagues at different status positions in the field, then comparing findings and conclusions (Guion, Diehl, & McDonald, 2011). Survey open-ended responses and interview transcripts of participants were shared among the principal researcher and his two supervisors for independent analysis. Analysis was informed by the research questions. Coding was independently undertaken by the principal researcher and his two supervisors. This included initial identification of themes and data related to the themes independently. The findings were collaboratively reviewed, and themes were discussed and revised. The following themes were agreed upon which captured the views of participants on:

- the utility of concept maps that link junior to senior concepts in creating an environment that creates awareness of the interconnection of mathematical concepts.
- the utility of concept maps that link junior to senior concepts in creating an environment that enhances consolidation and assessment of teaching and learning of mathematics.

Semi- structured interviews gave participants an opportunity to explain their experiences after using such concept maps in teaching and learning of mathematics. Quantitative and qualitative data were integrated to answer the research question. Combining the two data sets may result in validated and well justified findings (Creswell, 2015).

Results

The teachers' responses suggested that use of concept maps that link junior to senior concepts can enrich mathematics classrooms. Table 1 represents the Likert scale items that captured the teachers' perceptions on the utility of concept maps in the teaching and learning of mathematics.

Table 1: Likert scale responses in percentage

Questions	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
1. Concept maps help students understand how mathematical concepts are related.	88%	13%	0%	0%	0%
2. Student or teacher developed concept maps can be used to link prior knowledge to new knowledge.	81%	19%	0%	0%	0%
3. Concept maps facilitate consolidation of learning.	69%	31%	0%	0%	0%
4. Concept maps facilitate a visual evaluation of students learning.	75%	25%	0%	0%	0%
5. Concept maps give an overview of a topic.	81%	19%	0%	0%	0%
6. Concept maps helps identify key concepts in a topic.	81%	19%	0%	0%	0%
7. Concept maps promote integration of concepts that deepen mathematical understanding.	69%	19%	6%	6%	0%
8. The hierarchical nature of mathematics make concept mapping central to teaching and learning of mathematics.	56%	25%	19%	0%	0%

The research question is centred on teachers' views on how concept maps that link junior to senior concepts can strengthen the teaching and learning of the interconnection of concepts. The mode and median of all the questions under consideration shows strong agreement. Similarly, all participants agreed or strongly agreed that concept maps enhance conceptual understanding, facilitate consolidation, are a visual representation of mathematical knowledge, provide overviews and help identify key concepts. Moreover, at least 81% of participants agreed or strongly agreed that concept maps play an important role in enhancing the teaching and learning of mathematics especially through connecting concepts.

Theme 1: The utility of concept maps that link junior to senior concepts in creating an environment that stimulates awareness of the interconnection of mathematical concepts.
The theme focuses on use of concept maps in developing knowledge of the interconnection of mathematics concepts. Results from survey open-ended questions indicated participants' views on the usefulness of concept maps in enhancing students' knowledge of conceptual connections. Participants identified the following benefits of using concept maps to create an awareness of the interconnection of mathematical concepts:

- providing concept maps for students helps them to visualise the links between concepts
- developing concept maps in class for students helps them make conceptual connections
- students can also develop their concept maps to represent their knowledge development
- concept maps allow students to link prior knowledge or foundational concepts with new knowledge
- concept maps show students how simple familiar procedures develop into complex problem solving

The participants' views demonstrate the critical role concept maps can play in developing students' mathematics conceptual knowledge.

Semi-structured interview data further explored feedback from participants on the role of concept maps in the teaching and learning of conceptual knowledge. The value of linking concepts to students' learning was made clear. Participants observed that it helped students value current learning as they realise it is connected to future understanding. For example, Participant 1 combined the importance of visuals and conceptual connection when she said, *"they can see the relevance of what they have learnt in the past and how it links to something you are trying to teach them now and something that you will teach them in the future".* Participant 2 had similar experiences when she stated that, *"so that definitely help in terms of helping the students make that link between concepts and why they need to actually learn those concepts".* Participant 8 was more specific when he said, "*have since included concept maps in conceptual teaching and students seems to understand the linking of concepts much clear"*. Concept maps can play a vital role in helping students understand the interconnection of mathematics concepts and value that current knowledge is critical to future knowledge and thereby enhance students' learning.

Concept maps can also be used to link prior experience to new knowledge or to link concepts within or across domains which is key to effective mathematics teaching. During the interview, Participant 4 stressed that concept maps can show, "*connections between prior and current learning, that's one purpose of using a concept map".* The same observation was also put forward by participant 8 who said, *"concept maps also emphasise the importance of prior knowledge to new content."* It is interesting that the linking arrows' directions found in concept maps was also a key focus for participants. Participant 3 said, *"conceptual maps actually allow students to have something to hang on and they can go backwards and forwards".* The arrows emphasise the fact that mathematics is spiral and hierarchical in nature thus concepts can be integrated. This observation was also shared by participant 8 who mentioned, *"two-way linking".* Moreover, the importance of backward arrows was also noticed by Participant 5 when he said, *"forward and backwards arrows that can help your concept map".* Furthermore, the use of arrows in facilitating integration of concepts was noted by Participant 2 who said arrows can help in: *"showing how they can actually link concepts together and use it for example, in problem solving where you've got to use multiple concepts at a time".* This indicates that complex problems are a combination of concepts, and a concept map is useful in building that understanding. These findings show that concept maps can be very effective in teaching and learning of conceptual knowledge.

Theme 2: The utility of concept maps that link junior to senior concepts in creating an environment that enhances consolidation and assessment of mathematics knowledge.

The theme focuses on how concept maps can enhance consolidation and assessment in mathematics. The following participant responses identified the important role of concept maps in the consolidation and assessment of mathematics knowledge:

- students can develop concept maps for consolidation of a topic or unit
- students can be asked to develop a concept map at the end of a lesson, topic, or unit as part of assessment
- uncompleted concept maps can be used as a task for students to fill in the gaps
- concept maps developed in class can be used to expose misconceptions or common mistakes

Student-developed concept maps represent their mathematics knowledge and thus, can be used as an assessment tool to measure students' understanding. Participant 7 pointed out that, *"would give me a better way to checklist how each individual student is acquiring knowledge".* Participant 8 went further when he said, "*used it in a lesson for students to show me how their knowledge has developed".* Moreover, Participant 2 was more focused on visual learners' representations when she said, *"it helps those visual learners and organizing their thoughts".* The results show that concept maps, when developed by students, can be used to evaluate students' mathematics understanding hence can be an assessment tool that requires teacher feedback.

The importance of this feedback was emphasised by Participant 7 when she said, *"if kids miss concepts, you will never get them to be able to progress until you go back, by having a map, we know where to go back to and we can trace back until we find the gap."* Student-developed concept maps might also open an opportunity to identify students' misconceptions and evaluate their understanding and take corrective action. This is supported by Participant 8 who said, "*Misconceptions can also be identified as students develop concepts that give the teacher the opportunity to reteach or redirect."* Importantly opportunities for effective consolidation arises at the end of a topic or unit when teachers take into consideration students' knowledge representations and sum up everything that they have learnt.

Discussion

Analysis of both qualitative and quantitative data indicate that teachers have a perception that concept maps that link junior to senior concepts can enhance the teaching and learning of mathematics at the senior secondary level. In particular, participants' views provide supporting evidence that such concept maps can enhance students' knowledge of conceptual connections which is critical in making students aware of how mathematics concepts relate to each other. During semi-structured interviews, participants noted that students' understanding of mathematics as a web of concepts was enhanced. The findings are consistent with previous research by Watson and colleagues (2016) who noted that concept maps enhance conceptual understanding. Thus, promoting the interlinking of mathematics concepts is a more effective teaching and learning strategy in senior school mathematics compared to other instructional models (Novak, 2010). It is because it promotes coherent instructions that foster the development of new knowledge from prior knowledge (fundamental concepts) and then provide opportunities to include more complex concepts as teaching and learning progresses (Doabler et al., 2012). These results support the idea that concept maps can also be used to show the cohesion of concepts (Hartsell, 2021), which can promote content sequencing in mathematics. The nature and structure of concept maps, that is the nodes, arrows and linking words, might be key in deepening students' understanding of mathematics.

The uni- or bi-directional arrows on concept maps show links between concepts which can enhance integration and help identify key concepts. Quantitative results show that 88% of participants agreed that concept maps enhance integration of concepts while all participants agreed that they can be used to identify key concepts. During interviews, participants further emphasised that concept maps provide evidence on how solving a problem may involve several concepts. Similarly, during open-ended survey responses, participants noted that concept maps may demonstrate how simple familiar concepts integrate to complex unfamiliar concepts as concepts integrate. These views support the position that complex problems require students to integrate different concepts (QCAA, 2018). Similarly, Fonteyn (2007) suggests that concept maps may demonstrate how concepts evolve from simple familiar to complex unfamiliar as concepts integrate and relationships get more complex. Importantly, the findings may also indicate that concept maps can help students understand and integrate concepts (Beat, 2015; Kinchin et al., 2019). Concept maps show relationships of mathematics concepts which will help students to understand mathematics as a web of concepts.

The interconnection of concepts is not only important in understanding the nature of mathematics but can also inform how it is effectively taught. Teachers' views from both quantitative and qualitative results show that concept maps can facilitate the linking of prior knowledge to new knowledge. Semi-structured interview data provided an in depth understanding as participants explained that the concept maps promoted and enabled connections to be made between junior and senior concepts. This supports the hierarchical nature of mathematics and underscores the importance of content sequencing from prior to new knowledge since this is critical to students' understanding of new concepts. The results may provide supporting evidence to Kinchin (2019) who posited that by identifying connections and underlying links between prior knowledge and new knowledge, students have a better chance to learn effectively. This is because mathematics is all about exploring new and existing relationships among concepts (Bingölbali & Coşkun, 2016). Therefore, concept maps that link junior to senior concepts can be a critical resource in enhancing teaching and learning of mathematics as connections between prior knowledge and new knowledge play a key role in comprehension.

The views of participants in this research may provide supporting evidence that conceptual maps can be a tool for consolidation and assessment. Consolidating a topic or a unit requires students to have a general understanding of the interlinking of concepts that are involved because topics in a unit or topic are closely connected. During semi-structured interviews participants went further to point out that concept maps can help identify gaps in knowledge and also show connections of concepts within a topic or subject matter together. The gaps might indicate misconceptions. These results may point to the effectiveness of concept maps in facilitating consolidation, as well as identifying and addressing misconceptions. The results support Kinchin (2011) whose works determined that concept maps can expose students' conceptual misconceptions and also enhance consolidation. The findings may also indicate that concept maps that link junior to senior concepts made by students represent their conceptual understanding and thus can be used as an assessment tool.

Concept maps may be considered as a visual representation of students' conceptual understanding. Quantitative results show that all participants agreed that they can be a representation of students' knowledge of the interconnection of concepts. In open-ended survey question responses, participants noted that students can develop concept maps during or at the end of a learning session or a topic or unit. Interviews provided an in depth understanding that concept maps can represent students' thoughts. Results may demonstrate concept maps developed by students can be used to check for understanding which in turn provide an opportunity for teachers to give feedback. The results align with Ho and colleagues' (2017) work which noted that concept maps represent a visual display of an individual's conceptual understanding. The results are also in line with Bell (2017) who posited that concept maps may be used as an assessment task during formative evaluation to assess knowledge beyond facts and procedures. Furthermore, participants highlighted that incomplete concept maps can be used as assessment pieces for students to complete. Therefore, effective use of concept maps that link junior to senior concepts may play an important role in improving students' participation and achievement in mathematics.

Implications for practice

Concept maps that link junior to senior concepts can be a resource that teachers can use to enhance teaching and learning of mathematics at senior secondary school. Linking prior to senior concepts can facilitate gradual development of knowledge and deeper understanding. The linking of junior to senior concepts is critical to teaching and learning as it shows mathematics is a web of concepts that build on each other. Moreover, it represents continuity especially in jurisdictions where students choose mathematics subjects at senior secondary level. Similarly, concept maps are visual representations that research has identified as easy to recall and an effective teaching and learning tool. The use of concept maps at senior secondary level needs to be encouraged and their inclusion in resources such as textbooks and assessments can be a starting point.

Conclusion

In conclusion, teachers have a perception that concept maps that link junior to senior concepts can play a central role as a key resource of choice in deepening senior secondary students' mathematics knowledge. The results from this study can support concept maps as a resource that can create a rich learning environment beyond developing conceptual knowledge in mathematics teaching and learning at senior secondary level. However, the main limitations of this study are that a small number of participants was used, and senior secondary students' views and experiences as key stakeholders were not solicitated. Furthermore, this study did not include evidence of impact on students' learning outcomes. Despite these limitations, the present study has contributed important insights into our understanding of the role of concept maps in the teaching and learning of mathematics at senior secondary level. We hope this study will stimulate further investigation on the importance and role of visuals in mathematics teaching and learning especially at senior secondary level.

Future Direction

Teacher's perceptions provide useful insights into how resources such as concept maps can be used to enhance teaching and learning of mathematics. However, the impact of such resources on student learning outcomes would provide strong evidence of the utility of concept maps in teaching and learning of mathematics. Further research that focuses on how students' mathematics understanding develops when they apply concept maps that link junior to senior concepts would be useful.

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