RESEARCH PAPER

Procedural Flowcharts Can Enhance Senior Secondary Mathematics

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The senior secondary Mathematical Methods subject was introduced in Queensland in 2019 and parents were concerned with the low grades attained. Students in the subject need to develop extensive procedural knowledge and fluency to participate and engage successfully. This mixed methods study informed by constructivism investigated teachers' perceptions on how procedural flowcharts can enhance procedural fluency in the subject. Data were collected through a survey and semi structured interviews with the subject teachers. The study found that procedural flowcharts can foster a classroom environment that stimulates procedural fluency and student-centred teaching and learning of mathematics. The study suggests the potential for using procedural flowcharts in other mathematics subjects at different levels of study.

When the senior secondary Mathematical Methods subject was introduced by the Queensland Curriculum and Assessment Authority (QCAA) in 2019, parents raised the issue that students who used to obtain 'As' at junior level were now getting lower grades at senior level (Bennett, 2019). In Queensland, trends have shown student decline in participation and achievement in calculus-based senior secondary mathematics options (Chinofunga et al., 2022). Internationally, trends have shown a decline in participation in advanced mathematics subjects at senior secondary level in most countries (Hodgen et al., 2010). Researchers have pointed to pedagogy and classroom practices that are disengaging (Tytler et al., 2011) as one of the causes of the decline in participation and achievement in the advanced mathematics subjects. Additionally, students' limited procedural fluency has been highlighted as one of the causes that limits their understanding of mathematics ideas and solving mathematics problems (Kilpatrick et al., 2001), hence affecting participation and achievement.

Procedural Fluency

Procedural knowledge is a part of procedural fluency in mathematics education. Procedural knowledge is defined as knowledge of procedures and steps to a solution (Braithwaite & Sprague, 2021). Procedural fluency, on the other hand, is more than just being able to perform a procedure as it involves conception of the problem, choosing the appropriate method and adaptability in applying the chosen method (Bay-Williams, 2020). Moreover, procedural fluency involves "using procedures efficiently, flexibly, and accurately" (Bay-Williams et al., 2022, p. 178). Bay-Williams and SanGiovanni (2021) define "efficiency" as selecting the best method and using it to solve a mathematics problem within a set time and "accurately" as using a procedure correctly. While "flexibility" is conceptualised as knowing more than one procedure and being able to modify procedures when solving a mathematics problem (Star, 2005). "To support flexibility, teaching standards in numerous countries recommend that students be introduced to multiple procedures early in instruction and be encouraged to compare the procedures" (Rittle-Johnson et al., 2012, p. 437). Importantly, students demonstrate procedural fluency when they exhibit flexibility in using a skill, obtain the correct solution and are able to effectively communicate the method used (McClure, 2014). Therefore, procedural knowledge is part of procedural fluency and teachers are expected to help students build procedural fluency using different strategies and teaching styles.

2022. N. Fitzallen, C. Murphy, V. Hatisaru, & N. Maher (Eds.), *Mathematical confluences and journeys* (Proceedings of the 44th Annual Conference of the Mathematics Education Research Group of Australasia, July 3–7), pp. 130–137. Launceston: MERGA.

Teachers in Queensland use explicit teaching approaches to help students execute procedures accurately and to select the optimal method to solve a given problem while further practice brings flexibility and efficiency. In this approach, teachers demonstrate the skill, then guide students' practice and finally provide the opportunity for unprompted practice (Archer & Hughes, 2010). Thus, after the students have been explicitly taught a method to solve a mathematics problem, they must be given an opportunity to practice when and how to use the method (Bay-Williams et al., 2022). When students can identify the context where the procedure can be suitably applied, it provides the opportunity for procedure modification (National Council of Teachers of Mathematics [NCTM], 2014), resulting in deeper knowledge. Similarly, "procedural fluency, is a comprehensive way of navigating mathematical procedures; it includes mastery of algorithms and strategies, but it also includes knowing when to use them" (Bay-Williams & SanGiovanni, 2021, p. 25). However, procedural knowledge is perfected through "practice, and thus is tied to particular problem types" (Rittle-Johnson et al., 2015, p. 119), as mastery of procedures is key to developing this knowledge. As a result, repeated practice and guidance is one critical part of building procedural knowledge (Rittle-Johnson, 2015). Hence, procedural knowledge development is characterised by firstly being guided, mimicking and then through experience, adapting procedures to other complex familiar problems as part of procedural fluency.

Students who operate at high levels of procedural fluency are more likely to integrate and modify familiar procedures to solve complex unfamiliar problems (Blöte et al., 2001). However, in Queensland, simple familiar problems constitute 60% of examination questions and require use of procedures identified in the questions (QCAA, 2018). In this case, students have to identify the most appropriate procedure, apply it correctly and efficiently to pass the examination. Therefore, procedural fluency plays a key role in being successful in mathematics. This study focuses on how procedural flowcharts can enhance students' procedural fluency in the Mathematical Methods subject.

Procedural Flowcharts

A flowchart is the most efficient and concrete method to illustrate a procedure or multiple procedures to solve a problem (Toyib et al., 2017). The importance of flowcharts in developing procedural knowledge is supported by the definition of procedure established by Rittle-Johnson et al. (2015), that it is "a series of steps, or actions, done to accomplish a goal" (p. 588). In addition, they are effective in a class with students operating at different levels of prior knowledge; being more advantageous to those at the very low level as they help in decision making and provide problem solving skills (Hooshyar et al., 2015). Importantly, flowcharts play a significant role in promoting independent learning as students can refer to them after encountering a familiar mathematics problem (Marzano, 2017). Apart from showing contradictions and contrasting procedures, they promote representations of steps and procedures from different perspectives (Andrej, 2018). In procedural knowledge, relationships are sequential that is, steps follow each other (Hiebert & Leferve, 1986). Consequently, flowcharts are an important tool that a mathematics teacher can use to teach procedural knowledge as they guide students through the process allowing learning to be student centred and accommodative of different students' understanding.

It is a common experience for mathematics teachers to witness students applying procedures where they are not suitable just because they have memorised them (DeCaro, 2016). Minimising this common problem will improve students' participation and achievement. When procedures are taught using flowcharts, decisions are taken at every step. This is because, "flowcharts represent a sequence of decision making and information processing" (Marzano, 2017, p. 57). They are an "aid to thought" that help in analysing a problem and planning the solution (Ensmenger, 2016, p. 328). Consistent use of flowcharts helps students to develop the ability to identify suitable methods for solving mathematical problems, as well as helping them to gain sophistication in approaching complex problems (Newton et al., 2020). Superficial procedural knowledge might be limited to accurate and efficient use of one procedure, but deep procedural knowledge involves several approaches and knowing when to apply a particular strategy (Bay-Williams, 2020). As students apply a flowchart, decisions are made depending on how the solution, the processes, and steps being followed align with the flowchart. Due to the checks and balances provided by the flowchart, students will be able to determine relevant procedures that must be applied to solve a particular problem.

Applying tools that promote multi-solution strategies enhance students' capacity to solve a variety of problems. Teachers can use flowcharts to represent multiple ways or choices to a solution (Marzano, 2017), thus promoting procedural flexibility. Marzano noted flowcharts guide students through processes, steps and decision making which is critical for procedural fluency. "When students achieve procedural fluency, they carry out procedures flexibly, accurately and efficiently" (QCAA, 2018 p. 1). Thus, procedural flowcharts are a visual representation of available procedures and corresponding steps, showing all stages of evaluation and alternative paths of a solution to a desired result. This study explored teachers' perceptions on the use of procedural flowcharts. The research question was: What are teachers' perceptions on how flowcharts impact teaching and learning of procedural fluency in the Mathematical Methods subject?

Method

The mixed methods study informed by constructivism focused on teachers' perceptions on how procedural flowcharts can enhance the Mathematical Methods subject. Quantitative and qualitative data were collected and analysed to gain further insights into participating teachers' perspectives (Creswell, 2015). Ethical approvals were obtained from the Department of Education, Queensland: Reference number: 550/27/2383 and James Cook University Human Research Ethics Committee: Approval number: H8201. Sixteen senior secondary mathematical methods teachers participated in the study. The participants took part in a 10-minute video presentation based on procedural flowchart tools developed from a section on Functions in Unit 1 of the Mathematical Methods syllabus. Figure 1 below is an example of one of the procedural flowcharts developed from the Content Sequencing framework and used in the presentation.

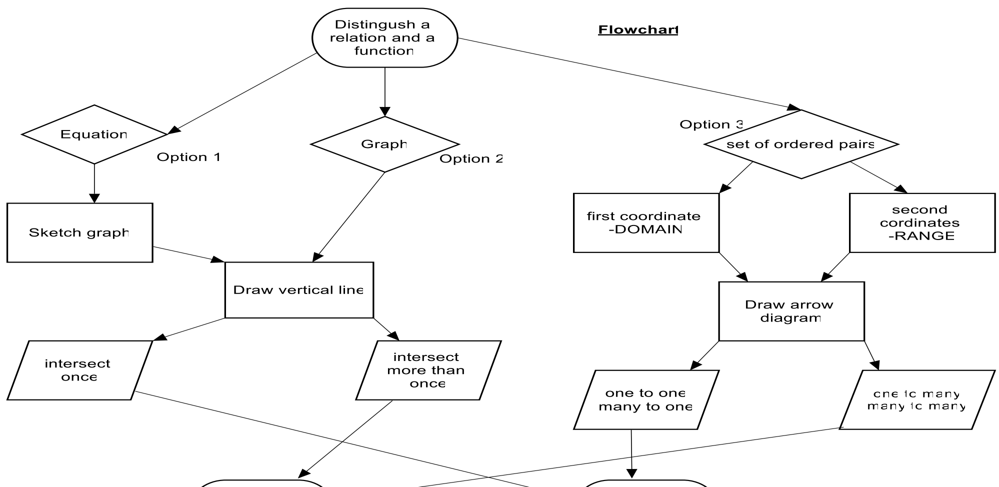

Figure 1: Procedural flowchart on distinguishing functions and relations.

Using Figure 1, students are asked to determine if a polynomial, graph or set of ordered pairs is a function or a relation. The decision is reached after applying the mathematical procedures. As the mathematical procedures are being implemented, they provide room for justification of choices given in the flowchart. This allows students to work through independently and be reminded of the steps and procedures that are critical in solving the problem. Students are also expected to learn about features of quadratic functions.

A procedural flowchart on features of quadratic functions that shows procedures of determining different features that students are expected to learn at Year 11 is also presented to students. Effective teaching of quadratic functions promotes students' comprehension of how different forms of algebraic representations relate to how features of the functions are determined, which is also included in the flowchart on quadratic functions. Equally, the relationships between these features also shown in the flowchart help students to build and broaden their understanding of the concept. The students are also reminded of key mathematical steps and procedures to solve problems related to the concept. Thus, procedural flowcharts are key in highlighting vocabulary expected in a concept such as intercepts, turning points and discriminant which is important in developing mathematical fluency.

Data Collection and Analysis

Participants were given a school term to embed the procedural flowcharts in teaching and learning of mathematics. They were then asked to complete a survey comprised of five-point Likert scale items and open-ended questions to gain a deeper understanding of participants' insight into the use of procedural flowcharts in the teaching and learning of mathematical methods. The 20-minute semi structured interviews were conducted with eight participants who completed the surveys. The thematic analysis and coding of survey open ended questions and semi structured interviews was done independently among the authors (Creswell, 2015).

Results

The survey data collected using the five-point Likert scale were analysed (see Table 1).

Table 1
Responses to Likert Scale Questions: Teacher Perceptions of Using Procedural Flowcharts

Questions	Strongly Agree	Agree	Not Sure	Disagree	Strongly disagree
1. Visual representation of mathematical knowledge enhances teaching and learning of mathematics.	94%	6%	0%	0%	0%
2. Procedural flowcharts (showing steps and procedures) plays an important role in developing students' mathematical skills.	56%	31%	6%	6%	0%
3. Procedural flowcharts promote fluency and recall.	69%	13%	19%	0%	0%
4. Procedural flowcharts can be used to highlight critical vocabulary	69%	19%	13%	0%	0%
5. Procedural flowcharts are a reference resources that can also be used for revision.	81%	19%	0%	0%	0%
6. Procedural flowcharts focus on students learning.	69%	19%	13%	0%	0%
7. Procedural flowcharts promote independent or collaborative learning.	69%	13%	19%	0%	0%
8. Procedural flowcharts can help evaluate or give feedback to students on their understanding and correct use of a procedure.	63%	31%	6%	0%	0%

The following themes were agreed upon after the independent thematic analysis, collaborative reviewing and revision: (1) procedural flowcharts can foster a classroom environment that stimulates procedural fluency when learning mathematics, and (2) procedural flowcharts can enhance student centred teaching and learning of mathematics procedures.

Theme 1: Procedural Flowcharts Can Foster a Classroom Environment That Stimulates Procedural Fluency When Learning Mathematics

The participants agreed that procedural flowcharts stimulate procedural fluency. The open-ended survey questions showed that participants supported the use of procedural flowcharts in enhancing procedural fluency. These included: (i) teacher created procedural flowcharts for students to use during explicit teaching phases or targeting students who have not achieved fluency or for students with identified learning needs, (ii) class generated procedural flowcharts during collaborative teaching phases to show the processes that were applied, and (iii) student generated procedural flowcharts to show common mistakes or misconceptions. These results demonstrate the flexibility of procedural flowcharts in enhancing fluency.

Feedback from semi structured interviews gave greater detail on how procedural flowcharts create a wide range of opportunities for developing procedural fluency in mathematics. Participants' perceptions after applying them as a teaching and learning resource provided some insight into how this resource can help develop students' procedural knowledge and skills. Participants noted that students are comfortable with visual representations more than just worded steps. In fact, they appreciated that most students are visual learners who respond well to diagrammatical representations than written steps. For example, Participant 8 said, "*Because it's a diagrammatic representation, students look at it favourably because it's easier to process and like I said most students are visual learners."* Participant 7 went further to give an advantage of a procedural flowchart by saying, "*it is steps in diagrammatic form which is easy to process and easy to understand*." Thus, students can follow easily and use the steps to answer problems with minimum help. Participant 2 noted that, "*if you had steps just written down in the book, it's hard to flip back through and find the information you're looking for, whereas if it's a diagram, it's easy to find."* Participant 2 went further and said, "*they enhance students' memory*". Therefore, flowcharts that are easy to navigate and use provide a better opportunity to recall and accurately apply information, which enhances procedural fluency. This will help in solving most problems in mathematical methods examinations as indicated by Participant 8 when he said, *"It is very handy for simple familiar questions which are mostly recall and fluency questions, but which are the majority in mathematics examinations."*

As students follow the steps on the procedural flowchart, they enhance their procedural knowledge and fluency. Participant 2 made this point when she said, *"really good how it organizes the steps and explains where you need to go if you're at a certain part in a procedure."* In addition, Participant 7 mentioned, "*the cycle approach, the feeding back in, feeding back out, that type of stuff, that's when we are starting to teach students how to think.*" Likewise, Participant 8 observed that, "*Complex procedural flowcharts like the one you provided guide students in making key decisions as they work through solutions which is key to critical thinking and judgement and these two are very important in maths.*" Procedural flowcharts enhance students' efficiency and flexibility in solving problems, deepening their understanding through reasoning and justification, which are mathematics proficiencies.

Procedural flowcharts provide teachers with the opportunity to determine students' procedural competences and misconceptions. Participant 8 emphasised that, "*I went further to ask my students to create their own procedural flowcharts … so that I can evaluate if they understand and represent their fluency on the chart."* Participant 1 went further to include procedural misconceptions, "*I use it to identify the potential students' misconceptions and I'll use it to identify student's competences."* Therefore, enhancing procedural fluency.

Theme 2: Procedural Flowcharts Can Enhance Student Centred Teaching and Learning of Mathematics Procedures

The participants agreed that the use of procedural flowcharts encourages and facilitates independent and student-centred learning. Open-ended survey responses highlighted use of: (i) students generated procedural flowcharts after explicit teaching, and (ii) student generated procedural flowcharts at the end of the lesson as part of lesson consolidation.

The use of procedural flowcharts by participants in the teaching and learning of mathematical methods made them realise that they promoted independent and student-centred learning. The response from Participant 8 was, "*they promote individual learning and learning which is student centred*." Moreover Participant 6 further alluded that a capable student, "*can teach themselves without even a teacher.*" Importantly, independent learning of students can provide a teacher with the opportunity to help struggling students. This view is supported by Participant 5 when he said, "*it gave me the opportunity to work with slower kids as they promote individual learning*."

Participant responses also indicated that procedural flowcharts enhanced students' engagement. When asked about how procedural flowcharts enhance students' development of procedural knowledge, Participant 8 said, "*I have witnessed more students engaging more in the YOU DO (student centred) phase*." The participant went further to say, "*I was so impressed because students engaged more with the task.*" A similar but more detailed observation was also witnessed by Participant 7 who said, *"mathematics goes from being very dry and dusty to being something which is actually creative and interesting and evolving, starting to get kids actually engaging and having to back themselves, and having to be less passive and more active as learners."*

Moreover, participants noted they help students to understand the importance of understanding procedures if they want to engage effectively with mathematics. Participant 3 shared her observation that procedural flow charts *"allow the students to move in both directions and it makes them see that the actual responses that they have to give are minimized rather than seeing every question as separate."* This is very important especially for questions which require procedural steps not in their most usual form or representation. The participants agreed that procedural flowcharts play an important role in enhancing procedural fluency and engagement in mathematics.

Discussion

One interpretation of these findings is that participants noted procedural flowcharts can enhance development of procedural knowledge and fluency. As highlighted previously, procedural knowledge is knowledge of steps and procedures to a solution (Braithwaite & Sprague, 2021). Thus, procedural flowcharts represent a series of steps and procedures that may include several approaches to reach a desired solution to a particular type of mathematics problem. Results show at least 80% of participants agreed or strongly agreed that procedural flowcharts enhance development of mathematics skills and promote fluency and recall. Fluency includes an understanding of vocabulary and 87% of participants acknowledged procedural flowcharts highlight critical vocabulary. Participants concurred that they do not only provide steps to be followed but facilitate decision making through reasoning as students evaluate the correct procedures to follow. Kilpatrick (2001) posited that procedural skills are central to students' learning of mathematics. Thus, practice in solving problems using sequenced steps and procedures promotes accuracy. Additionally, information processing and decision-making help in evaluating how the path to the solution aligns with the available procedures, thus enhancing "efficiency." This study highlighted that multi-solution procedural flowcharts provided an option for students to know more than one solution, thus enhancing "flexibility." Using mathematics steps accurately, effectively and efficiently develops fluency (Bay-Williams et al., 2022). Therefore, efficient use of procedural flowcharts helps students develop procedural knowledge and enhances procedural fluency. As a resource, it can also support explicit teaching which is one of the main pedagogies in Queensland.

Results show participants appreciated that developing the procedural flowchart during any of the stages of explicit teaching is beneficial. Firstly, teachers can develop the charts during I DO (teacher centred stage) by teaching students how to organise the steps, processes and loops for decision making. Secondly, the charts can be developed as a class during WE DO (collaborative stage) and lastly students can develop them during YOU DO (student centred stage). Participants perceptions show that having students develop their procedural flowcharts can be an efficient way of checking students' procedural understanding, misconceptions and evaluating learning. These results are consistent with Raiyn (2016), whose work concluded that visual representations require less time and are easier to process. Furthermore, presenting information in different forms such as verbal, numerical and diagrammatical helps students comprehend the phenomenon (Murphy, 2011). When students are given the opportunity to create their own procedural flowcharts, they represent their procedural knowledge and fluency diagrammatically. Moreover, procedural flowcharts are a tool that can also be used to promote engagement and student-centred learning.

Quantitative data analysis indicated that at least 81% of participants agreed or strongly agreed that procedural flowcharts enhance independent and student-centred learning. Qualitative data highlighted the importance of procedural flowcharts during YOU DO stage when using the explicit teaching approach. This is the stage where students are expected to interact and solve familiar problems to what they were taught and practiced as a class in the I DO and WE DO phases. This is because "routine practice is an extremely powerful instructional tool that not only helps students learn and retain basic skills and facts in a fluent fashion, but has positive outcomes when students attempt higher-order strategies" (Archer & Hughes, 2010, p. 21). Importantly consistent use of flowcharts helps develop mastery as they are an aid to thinking (Ensmenger, 2016). The participants perceptions are consistent with Marzano's (2017) work that concluded that when students come across familiar problems, they can refer to procedural flowcharts as they independently solve the problem. Likewise, in student centred learning, students develop knowledge and experiences they have acquired by further exploring using tools and resources as scaffolds (Marzano, 2017). When answering open ended and interview questions, participants emphasised that students could use procedural flowcharts during YOU DO stage. This provides students with an opportunity to engage with learning using the procedural flowchart as a scaffolding resource and minimum teacher assistance.

Conclusion

The study highlighted that teachers view the use of procedural flowcharts as a resource that can help to develop students' procedural fluency and participation in mathematics. The study suggests that this approach can be extended to other mathematics subjects at different levels of study. The present research, therefore, contributes to a growing body of evidence suggesting that representation of knowledge and processes in non-linguistic forms such as diagrams enhances participation and achievement. However, the main limitation of this study is the small number of mathematical methods teachers that was used. In terms of future research, we hope this study has provided a basis for further research in use of procedural flowcharts in mathematics teaching and learning.

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