

Using Graphic Organisers to Promote Mathematical and Computational Thinking

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A graphic organiser is an instructional tool students can use to organise and structure information and concepts, and to promote thinking about relationships between concepts and making connections. Furthermore, the spatial arrangement of a graphic organiser allows the student, and the teacher, to identify missing information or gaps in one's thinking. Graphic organisers help students organise and then clarify their thoughts, infer solutions to problems, and communicate their thinking strategies. Thus, in addition to structuring information, graphic organisers can improve students' abilities to comprehend and process information, thus aiding in their mathematical and computational thinking. Over time, graphic organisers help learners become strategic problem solvers. In this paper, we discuss graphic organisers and their potential benefits for students in enhancing their mathematical thinking as well as computational thinking.

Keywords: mathematical thinking, computational thinking, graphic organisers

Introduction

Graphic organisers have been widely used in education in many subject areas, including mathematics. A graphic organiser is an instructional tool that can help to organise and structure information or concepts and to promote thinking about relationships between concepts and mathematical ideas. They have the capability of enhancing learning because visual displays are used to organise knowledge and represent relationships between concepts (Akaeze & Okigbo, 2021).

Research studies have shown that graphic organisers help students in the following areas: (1) brainstorm ideas, (2) develop, organise and communicate ideas, (3) see connections, patterns and relationships (Zollman, 2009), (4) assess and share prior knowledge, (5) classify or categorise concepts, ideas and information, (6) reduce cognitive load (Casteleyn et al., 2013), allowing more of the working memory to attend to learning new material (Chandler & Sweller, 1991), (7) improve social interaction between students and facilitate group work and collaboration, (8) guide review and study (IARE, 2003), and (9) appreciate learning (Casteleyn et al., 2013). Graphic organisers help meaningful learning in several ways. When a student completes a graphic organiser, the student is provided with an opportunity to organise, summarise, analyse and evaluate different ideas, thus promoting the development of critical thinking skills (Brinkerhoff & Booth, 2013; Sharma, 2012).

Figure 1 shows an example of a graphic organiser that helps students process the information in a problem and allows them to have an entry point to solve the problem. The “four corners & a diamond” graphic organiser created by Zollman (2009), embeds Polya’s four step mathematical problem solving (Polya, 1945). The non-linear format implies that students do not fill up the steps in a sequential manner as they can record their ideas as and when it occurs. This helps them to work through the problem and as the ideas flow, they organise their thought processes and make connections. This tool is useful not just when it is used individually but also when students work in groups. Working in groups allow students to understand that there can be more than one way to arrive at the solution.

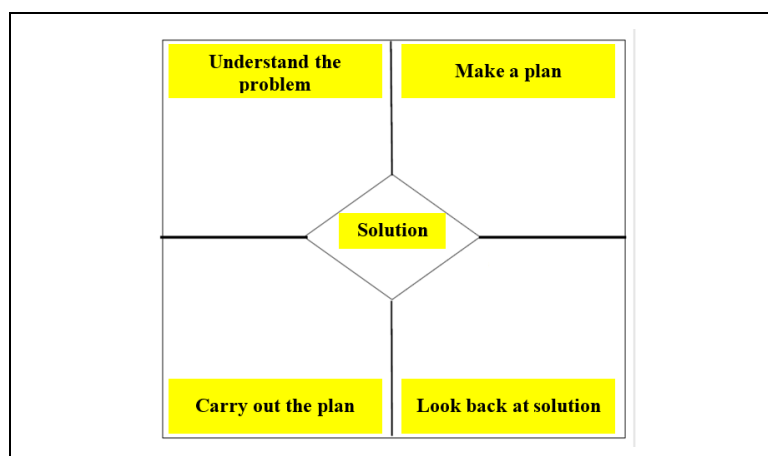


Figure 1. Four corners and a diamond graphic organiser

Mathematical thinking unfolds the processes which lie at the heart of the learning of mathematics. This includes reasoning, abstracting, conjecturing, representing, visualising, deducing, inducing, analysing, synthesising, connecting, generalising and proving (Mason et al., 1982). Graphic organisers can support these processes in several ways:

- Providing the visual representations of concepts to help students develop an understanding of mathematical relationships and structures.
- Organising information in a structured and systematic way so as to be able to identify patterns, synthesise information and make connections.
- Problem-solving as the process that can be broken down into smaller and more doable parts.

This process helps students to be more analytical and strategic.

The graphic organisers could be designed by the teachers, culled from textbooks or designed by students. Other examples of graphic organisers used to visually represent and organise mathematical concepts include:

- Venn diagrams: these are used to display relationships between sets.
- Flowcharts: these are used to represent thought processes in the sequence of steps or algorithm to solve a problem.
- Concept maps: these are used to show connections between mathematical concepts or ideas.

In particular, a flowchart is a useful tool in promoting computational thinking.

Computational thinking is the thought process involved in formulating problems and developing approaches to solving them in a manner that can be implemented with a computer (Wing, 2006). There are parallels between the problem-solving skills learnt in mathematics and the skills in computational thinking, namely, abstraction, generalisation, decomposition and algorithm design (Figure 2). While some aspects like abstraction, generalisation and decomposition are more inherent in the learning of mathematics, algorithm design deserves more focus. By engaging students in designing algorithms to solve a mathematical problem, they will learn how to identify the essential information as input for their algorithm (abstraction), think of a general approach to solve the problem (generalisation) and simplify the algorithm by working on parts of the algorithm (decomposition), if necessary (MOE, 2020).

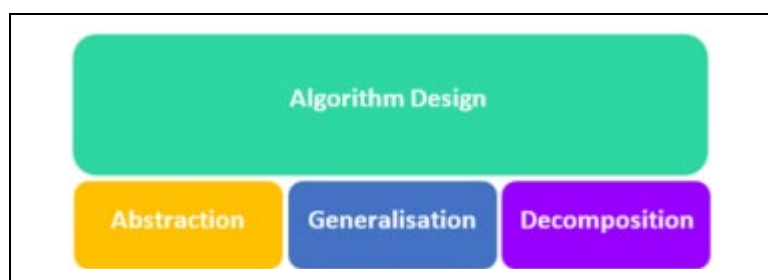


Figure 2. Four skills in computational thinking

We will next discuss how various types of graphic organisers are used to help students (i) see connections, patterns & relationships, (ii) scaffold their thinking and self-assess their learning, (iii) develop algorithmic thinking, (iv) draw a schema for problem-solving, and (v) consolidate their learning and promote metacognition.

Affordances of Graphic Organisers

Cluster diagram for visualising relationships and making connections

The cluster diagram is a graphic organiser that can be used to break down complex concepts into smaller, manageable parts, illustrating the relationships among them. This decomposition not only aids in understanding these components and their interconnections but also enables students to organise information effectively for problem solving.

An example of how a cluster diagram is used to help students visualize relationships and make connections is the lesson on “Hire Purchase”, a real-world application of “Rate” introduced to Secondary One students. While problem solving involving hire purchase builds on students’ prior knowledge of percentages and simple interest, it simultaneously introduces new, contextual terms related to finance such as cash price, down payment, balance, and monthly instalment.

The cluster diagram shown in Figure 3 illustrates how teachers can guide students to understand the concept of hire purchase step-by-step. According to the Dual Coding Theory (Paivio, 2007), processing information through both verbal explanation and visual representation makes the information more memorable. Boaler (2015) also stated that “Visual understanding is incredibly powerful for students, adding a whole new level of understanding ...”. With this structure, students can map out information from any scenario related to hire

purchase to gain an overview, which helps them plan their problem-solving steps more effectively.

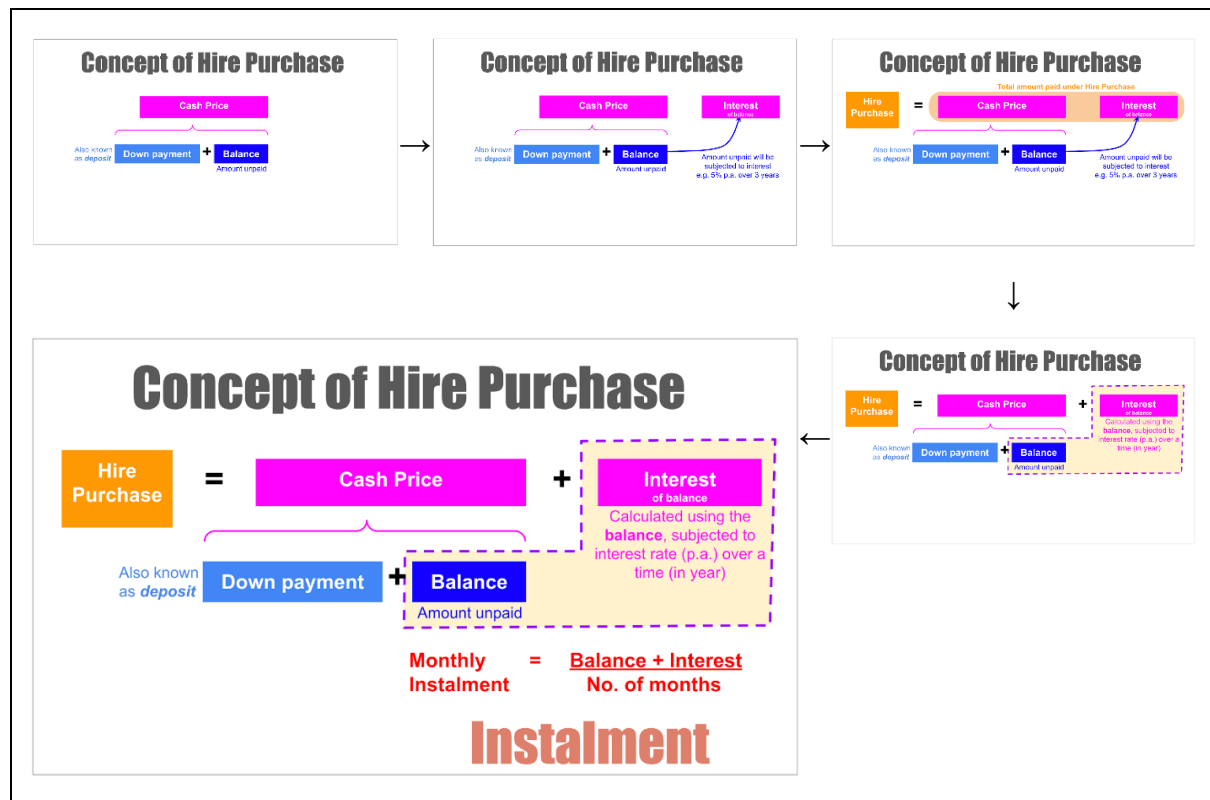


Figure 3. Cluster diagram for hire purchase

This notion of using the cluster diagram is transferable to problem solving when students need to unpack and decompose to see numerous information presented in a word problem. The cluster diagram serves as a visualisation tool to simplify complex relationships at a glance, which addresses common difficult points often faced by students — the confusion over the changes related to rate across different phases over a period of time and handling tiered criteria. Students who took notes in this mindful and thoughtful way found more meaning in, and use for, them. (Liljedahl, 2021, p.200)

Figure 4 shows an application to solve problems involving appreciation or depreciation of goods value over a period of time.

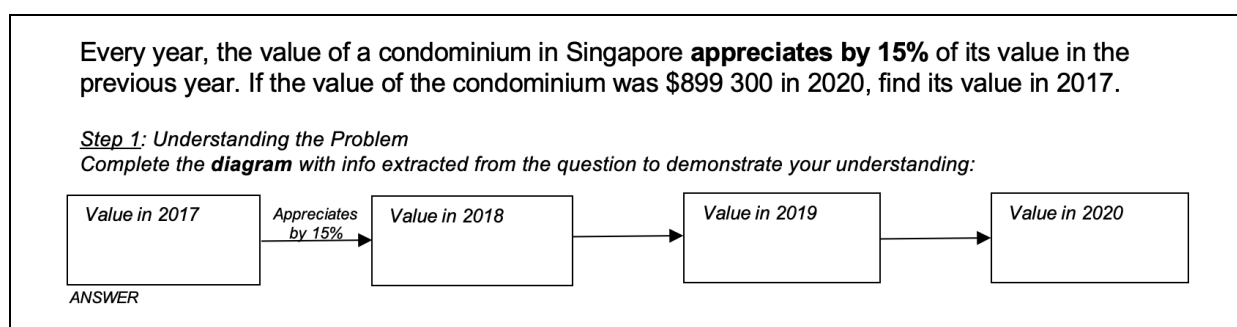


Figure 4. Cluster diagram for word problem involving value appreciation/ depreciation

Figure 5 demonstrates how a problem with tiered information and requirements uses a cluster diagram to decompose and organise the information at a glance. This is commonly seen in questions about discounts, GST, income tax, and commissions.

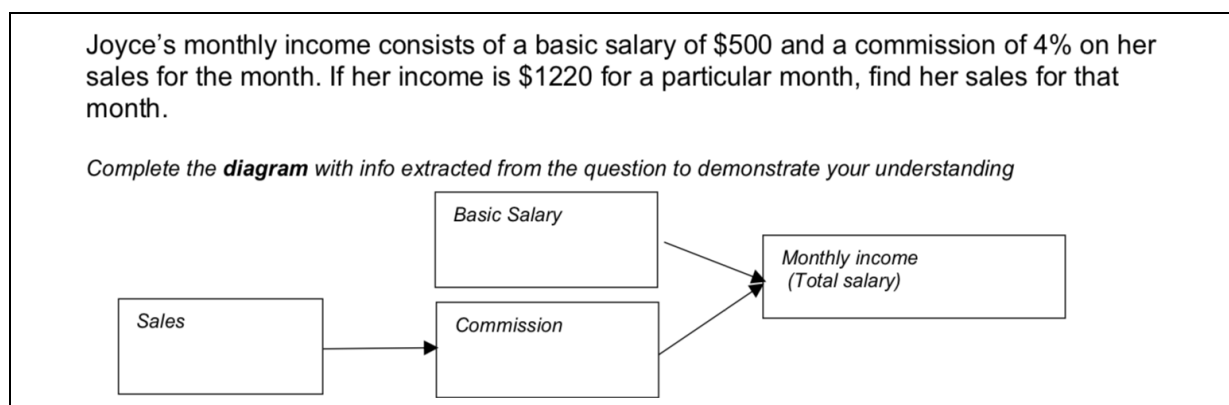


Figure 5. Cluster diagram for word problem involving parts to be handled differently

The above examples illustrate how a cluster diagram helps students unpack and decompose information in word problems effectively, that enhances algorithmic thinking, an essential process in computational thinking.

Checklists for scaffolding and self assessment

A checklist outlines criteria necessary to meet task standards, helping students recognise and remember essential elements required for completion, such as those needed in graph plotting. When these elements are listed sequentially, frequent referencing and practice not only reinforce memory but also help students internalise the process or procedure involved.

An application of a checklist for such purpose is to guide the drawing of number lines (Figure 6a). Instead of presenting students with the checklist, the teacher could first engage students to construct a number line. Participation offers students the opportunity to clarify the approach and suggest considerations. This co-construction process could then be translated into the checklist, promoting co-ownership in the learning process.

S1 Mathematics: Unit 1 Numbers and Their Operations – **NUMBER LINES**

[SELF/ PEER-ASSESSMENT]

Checking my answer before submission/ Giving feedback to others

CHECKLIST for **discrete** values on number line

Examine the “given” numbers

	Numbers in fractions are expressed in decimal [^] ?
	Numbers given in a range with conditions are listed? (if applicable)
	Identified the smallest and biggest numbers [#] ?

[Points to ponder]

[^] Why decimal is preferred? Why not fractions?

[#] Why identify the smallest/ biggest numbers?

The NUMBER LINE

	Equal intervals are marked, with integers written below the line?
	The last number (at each end) is at least one more than the “last” given number?
	Each end of the number line is marked with an arrow?
	Dots are clearly marked above the required number?
	All given numbers are clearly marked below the line?
	Numbers are written in the <u>original</u> form?

Figure 6a. Checklist to construct a number line

To assess students’ understanding of the criteria, error analysis questions (Figure 6b) provide a means to check comprehension and offer students an opportunity to clarify doubts before they begin drawing number lines from scratch.

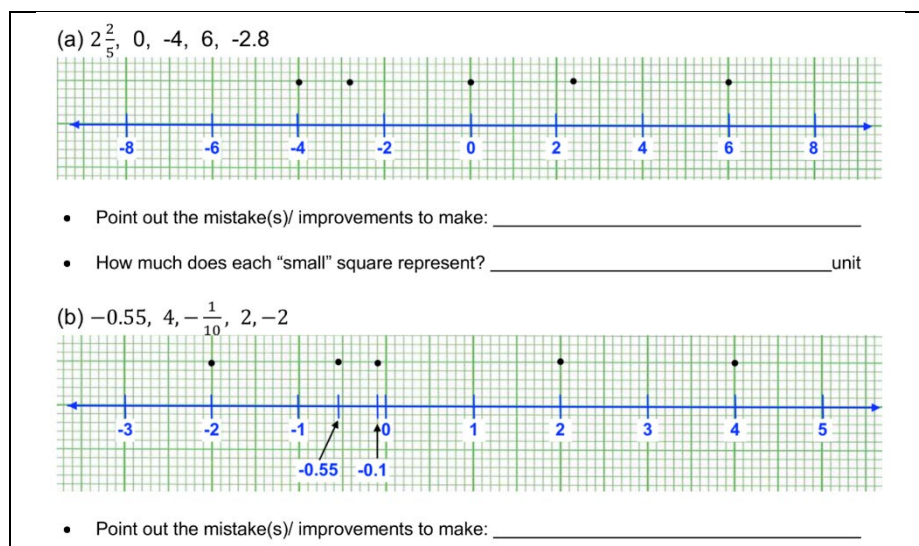


Figure 6b. Scaffold to check students’ understanding using a checklist

The use of checklists extends beyond just procedural tasks. A checklist with key mathematical terms effectively guides students in using precise language consistently across various mathematical activities. It guides students to consciously apply correct terminology, enhancing clarity and boosting confidence. This regular reinforcement of accurate terms not only aids in specific tasks like equation solving but also nurtures deeper understanding and communication in mathematics.

The example in Figure 7 illustrates how a checklist can effectively support students in articulating their conceptual understanding while solving linear equations. Having deconstructed the problem and systematically applying the algorithm, students then select the suitable mathematical terms from the checklist to describe each step accurately. This process helps students to verbalise their thoughts to communicate the mathematical understanding clearly.

PART 2 (estimated: 30 minutes)	To be submitted online by MON 31 JULY																														
You shall CHOOSE ONLY ONE of the following questions to attempt (Q9) - Useful references: (1) Textbook 1A worked examples 1, 2 & 3 (2) YouTube Playlist <u>Instructions</u> - Think through and plan how you would solve the equation. - Record a video to describe how you solve the equation. - Articulate the concepts involving balancing the equations like what you see in the YouTube Playlist - It is important that you use the appropriate vocabulary to articulate your thought processes. - Post your video clip in the Padlet in the Google Classroom/ Maths Blog - The clip should not be longer than 2 minutes																															
9. Solve each of the following equations. (a) $10x - \frac{5x+4}{3} = 7$ (b) $\frac{4x}{3} - \frac{x-1}{2} = 1\frac{1}{4}$ (c) $\frac{x-1}{3} - \frac{x+3}{4} = -1$ (d) $1 - \frac{y+5}{3} = \frac{3(y-1)}{4}$ (e) $\frac{6(y-2)}{7} - 12 = \frac{2(y-7)}{3}$ (f) $\frac{7-2y}{2} - \frac{2}{5}(2-y) = 1\frac{1}{4}$																															
Checklist - Tick on the phrases you have used when articulating the explanation. - You should have used at least 50% of what is listed, i.e. you may not use all these phrases, depending on the question you choose. However, you may also use terms/ phrases not listed below, when relevant. <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top;"> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">To balance the equation...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Add to both sides of the equation...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Subtract from both sides of the equation...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Multiply/ Divide both sides of the equation by....</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Remove..... from LHS/ RHS...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Move the variable term(s) to....</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Move the constant term(s) to...</td></tr> </table> </td> <td style="width: 50%; vertical-align: top;"> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Express as a single fraction...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Common denominator</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Use distributive law to...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Expand the expression....</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Simplify...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Expand...</td></tr> <tr><td colspan="2" style="padding: 2px 5px;">... any other terms/ phrases ...</td></tr> </table> </td> </tr> </table>		<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">To balance the equation...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Add to both sides of the equation...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Subtract from both sides of the equation...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Multiply/ Divide both sides of the equation by....</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Remove..... from LHS/ RHS...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Move the variable term(s) to....</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Move the constant term(s) to...</td></tr> </table>	☐	To balance the equation...	☐	Add to both sides of the equation...	☐	Subtract from both sides of the equation...	☐	Multiply/ Divide both sides of the equation by....	☐	Remove..... from LHS/ RHS...	☐	Move the variable term(s) to....	☐	Move the constant term(s) to...	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Express as a single fraction...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Common denominator</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Use distributive law to...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Expand the expression....</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Simplify...</td></tr> <tr><td style="padding: 2px 5px;">☐</td><td style="padding: 2px 5px;">Expand...</td></tr> <tr><td colspan="2" style="padding: 2px 5px;">... any other terms/ phrases ...</td></tr> </table>	☐	Express as a single fraction...	☐	Common denominator	☐	Use distributive law to...	☐	Expand the expression....	☐	Simplify...	☐	Expand...	... any other terms/ phrases ...	
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Figure 7. The task and the checklist that guides students

Flowchart for promoting algorithmic thinking

Flowcharts are essential tools that support the visualisation and organisation of mathematical processes, serving various functions throughout different stages of mathematical learning. Students use the basic symbols and concepts of flowcharts to develop their understanding,

and subsequently to translate mathematical problems into flowchart diagrams. By breaking down complex tasks into manageable steps, students enhance their problem-solving skills and deepen their understanding of mathematical concepts.

The example in Figure 8 illustrates how a flowchart fosters algorithmic thinking when students follow the guides to consolidate their understanding on the various scenarios when finding Highest Common Factor and Lowest Common Multiple of numbers.

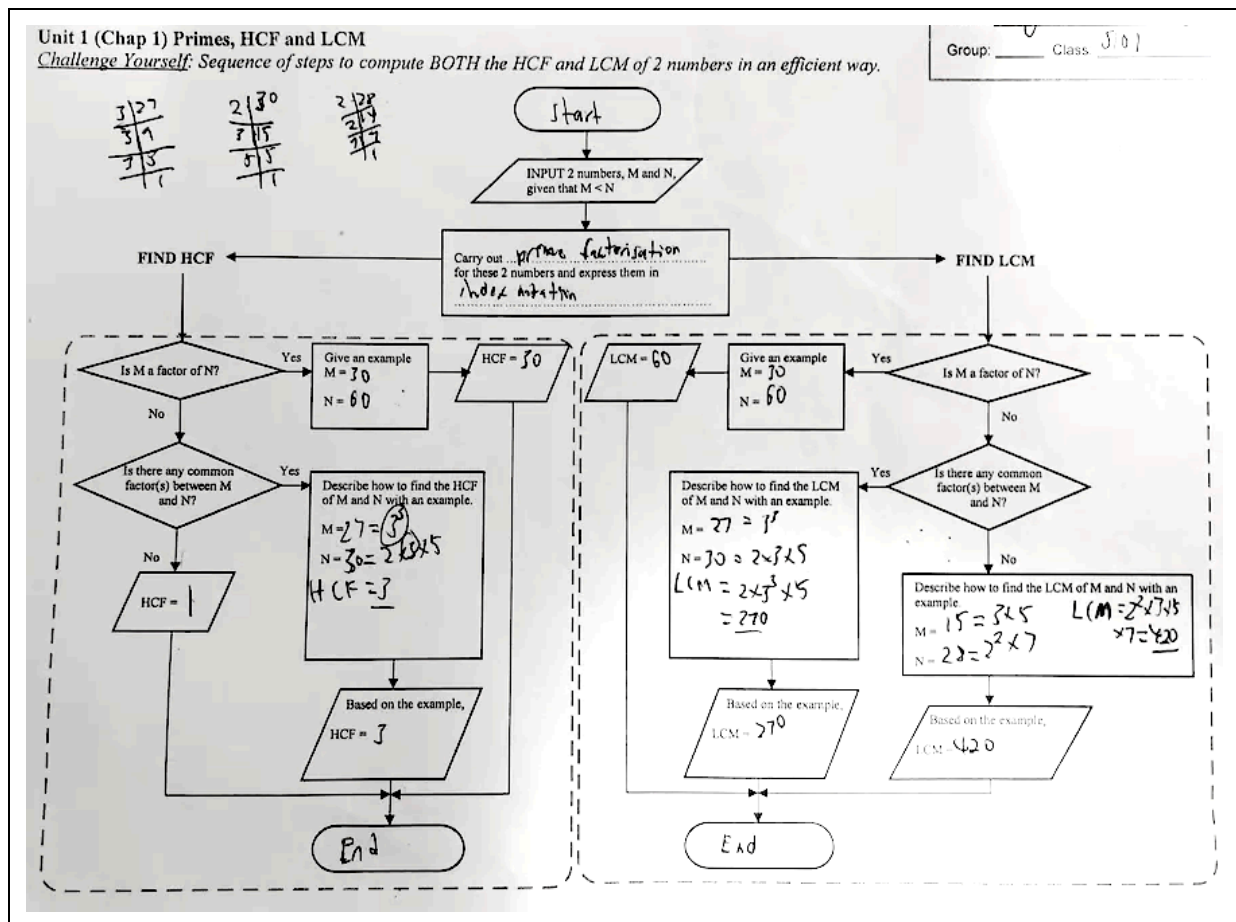


Figure 8. Flowchart to find HCF and LCM

It is common that students apply procedures where they are not suitable just because they have memorised them (DeCaro, 2016). When procedures are taught using flowcharts, students are constantly prompted to pause and think before making decision at every step as “flowcharts represent a sequence of decision making and information processing” (Marzano, 2017, p. 57). The checks and balances provided by the flowchart will enhance students’ abilities to determine relevant procedures that must be applied to solve a problem (Chinofunga et al., 2022).

Flowchart for developing a schema for problem solving

According to Dye (2000), “the graphic organiser has its roots in schema theory”. Studies have also shown that the use of graphic organisers improved the students’ achievement (Owolabi & Adaramati, 2015; Pantziara et al., 2009; Zollman, 2009, 2012). Organising information in a scaffold hierarchy using a flowchart provides a means for students to organise and interpret

information and to make connections between prior knowledge and the procedures relevant to the task (Mortimore & Dickfos, 2014). This helps to reduce students' cognitive effort to understand complex relationships, reduce stress on working memory, and assist students to organise and integrate related elements to see the 'big picture' (Adkins et al., 2012).

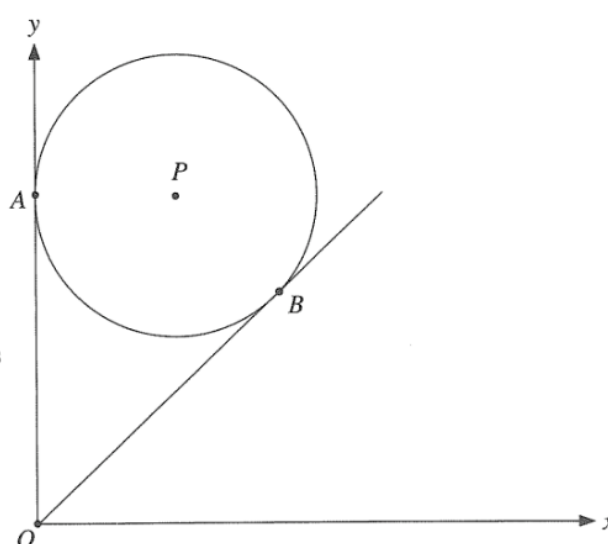
The task shown in Figure 9a is a word problem on the topic "Equations of Circles". The task to find the equation of the line OB proves to be a challenge to most Secondary Three students. Using a flowchart shown in Figure 9b shows how a student may divide the task at hand into smaller related and manageable steps that need to be performed.

The task:

The diagram shows a circle C with centre P and radius 5 units. The circle touches the y -axis at the point $A(0, 8)$ and the line OB is a tangent to the circle at the point B .

Find

- (i) the coordinates of P ,
- (ii) the equation of the circle in the form $x^2 + y^2 + 2gx + 2fy + c = 0$, where g , f and c are constants and state the values of g , f and c ,
- (iii) the equation of the line OB .



Source: *Mentor Additional Mathematics*, Topic 6, Question 46

Figure 9a. A task on equations of circles

Flowcharting gives students an approach to decipher and decode the problems they, at one time, would not attempt. Practice and reinforcement of these skills enable students to achieve success in developing problem-solving techniques and build their confidence in their own problem-solving skills. Computational thinking, or to think like a computer, helps them to approach a task in a logical, sequential order, and subsequently to organise their thinking patterns.

Flowchart for consolidating learning and promoting metacognition

Research (e.g. Zimmermann et al., 2024) shows that the use of flowcharts not only helps students consolidate their learning but also enhances their metacognitive abilities. As students construct their flowcharts, they are actively engaged in metacognitive processes such as planning, monitoring, evaluating understanding and self-explaining. As students engage in creating or interpreting flowcharts, they are prompted to reflect on their own thinking processes, allowing them to identify gaps in their understanding, make connections between ideas, and monitor their own comprehension, thus developing metacognitive skills such as monitoring thinking and self-regulation (Ainsworth & Loizou, 2003). Moreover, the iterative

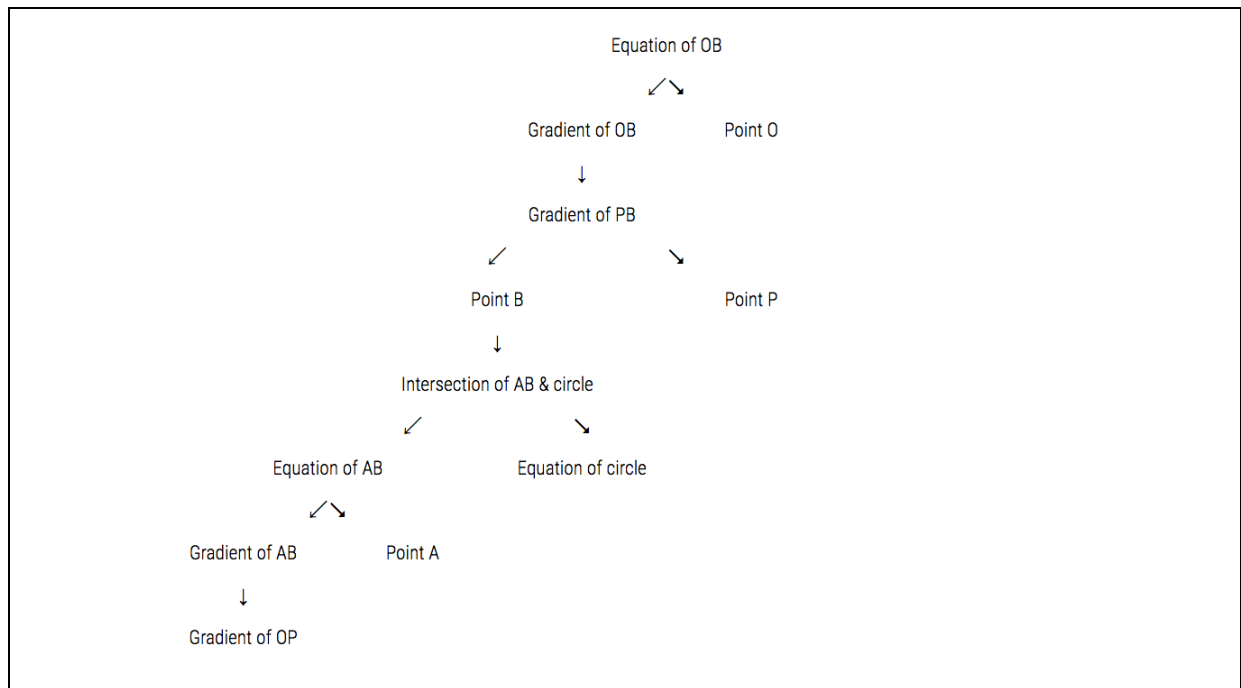


Figure 9b. Flowchart to develop a schema for problem solving

nature of working with flowcharts encourages students to revise and refine their mental models, leading to more robust and deeper understanding of the mathematical concepts.

The task shown in Figure 10a is a computational thinking task for the topic “Trigonometry”. The students are tasked to write a program that solves a triangle given any three measures of its angles or sides, after they have learnt concepts such as the Sine Rule and the Cosine Rule. Figure 10b shows a sample of student work.

S3MA05 Computational Thinking Task: Solving a Triangle [Pair work]

Wong Lai Fong • Jul 15 (Edited Jul 17)

100 points Due Jul 24

You are to write a program that solves a triangle given any three measures of its angles (A, B, C) or sides (a, b, c). Draw a flow-chart for this program using Flowgorithm or any other app.

You may use to make reference to Q2 in WS5.4a. Solutions to WS5.4a have been uploaded: https://drive.google.com/file/d/15VD59gL3KdcDqfdoX644NNbgSU8sxBCq/view?usp=drive_web&authuser=0

Deadline: Monday 24 July

S3MA05 Trigonometry WS5....
PDF

CT Trigonometry
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Figure 10a. Computational thinking task: Solving a triangle

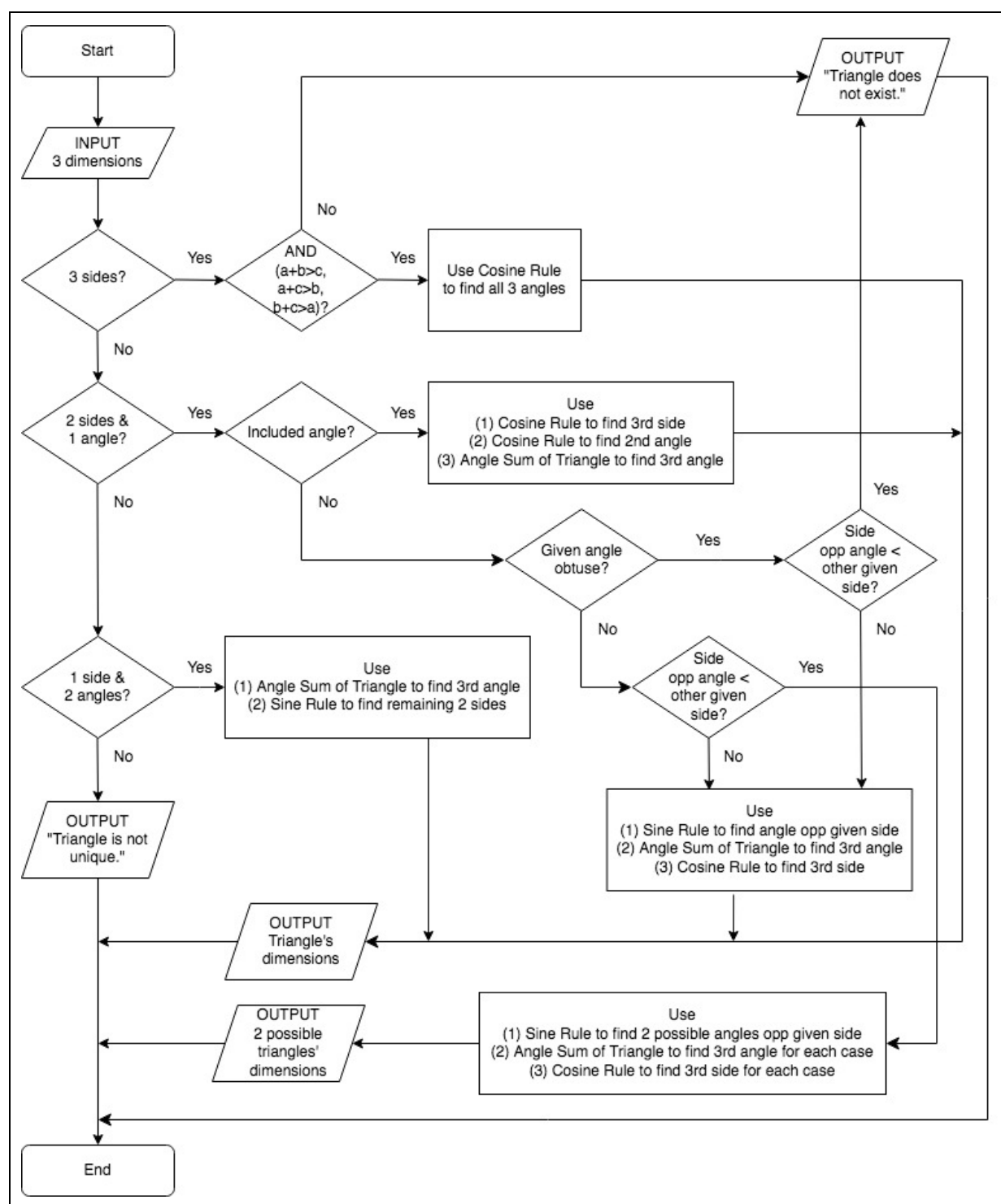


Figure 10b. A sample flowchart of a program to solve a triangle

The use of flowcharts helps students to develop the ability to identify suitable methods for solving mathematical problems, while also fostering their adeptness when handling more complex problems (Newton et al., 2020). The use of flowcharts to represent multiple ways or choices to a solution not only helps students to consolidate their learning but also to enhance their metacognitive skills. The construction of the flowcharts guide students through

processes, steps and decision making which is critical for procedural fluency and deep understanding, and “when students achieve procedural fluency, they carry out procedures flexibly, accurately and efficiently” (Queensland Curriculum and Assessment Authority, 2018, p.1). Furthermore, as students go through all stages of evaluation and alternative paths of a solution to a desired result, they also go through the metacognitive processes of monitoring and self-regulating of their thinking.

Other affordances of graphic organisers

While graphic organisers support mathematical and computational thinking which enhance the critical, adaptive and inventive thinking of the students, other affordances include supporting differentiated instruction. The use of graphic organisers provides a starting point for low progress students, helps average students organise their thoughts, and encourages high progress students improve their communication skills (Zollman, 2009). Allan & Tomlinson (2000) mentioned the use of visual supports, for example, visual organisers, to meet the diverse learning needs of the students. This will help students to access learning and be engaged in the mathematics content. Students can express their thinking visually and communicate mathematical ideas.

Conclusion

As with any other novel tools employed in the classroom, challenges are inevitable, and opportunities are forthcoming. From our classroom experiences, graphic organisers do help promote students’ mathematical and computational thinking. Furthermore, it is a useful tool to assess students’ mathematical understanding in the process stage and focuses less on the final product of problem solving. However, the graphic organisers can only be a powerful tool in the presence of teachers’ effective lesson design and instructions. When designing a lesson incorporating the use of graphic organisers, teachers may wish to make the following considerations:

- How would I introduce this task to my class?
- What are the learning objectives/outcomes?
- What challenges do I anticipate?
- How would I facilitate the lesson?
- What level of scaffolding/guidance would be appropriate for my class?
- What are some facilitation questions? How are the questions posed?
- How would I assess students’ learning via their graphic organisers?
- What are some other lesson design considerations?

Graphic organisers can serve to be an invaluable tool in the various learning contexts mentioned. It facilitates clarity, organisation and retention of mathematical concepts through visual representations. When breaking down complex problems into simpler components, it supports students in problem solving and fosters critical and inventive thinking skills. As we strive to meet the diverse learning needs of the learners, the use of graphic organisers offer a practical approach to support their learning, in particular, to visualise mathematical relationships or promote computational thinking skills. Not only are we creating active learning through the learning experiences provided to our learners, we are also empowering them to be confident problem solvers, with a deeper appreciation for the beauty of mathematics.

References

- Adkins, N., Henderson, B. C., & Key, K. G. (2012). Graphical organisers in tax education. *Journal of Accounting Education*, 30(1), 2–21.
- Ainsworth, S., & Loizou, A. T. (2003). The effects of self-explaining when learning with text or diagrams. *Cognitive Science*, 27(4), 669–681.
- Akaze, J. U., & Okigbo, E. C. (2021). Effect of metacognitive reading strategy and graphic organizer on students' retention of mathematics concepts in junior secondary schools of Onitsha education zone. *South Eastern Journal Of Research And Sustainable Development (SEJRSD)*, 4(1), 108–117.
- Allan, S. D., & Tomlinson, C. A. (2000). *Leadership for differentiating schools and classrooms*. Alexandria, VA: Association for Supervision and Curriculum Development.
- Boaler, J. (2015). *Mathematical mindsets: Unleashing students' potential through creative math, inspiring messages and innovative teaching*. John Wiley & Sons.
- Brinkerhoff L. J., & Booth M. G. (2013): The effect of concept mapping on student achievement in an introductory non-majors biology class. *European International Journal of Science and Technology*. ISSN: 2304-9693, 2(8). 43–72.
- Casteleyn, J., Mottart, A., & Valcke, M. (2013). The impact of graphic organisers on learning from presentations. *Technology, Pedagogy and Education*, 22(3), 283–301.
- Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, 8(4), 293–332.
- Chinofunga, M. D., Chigeza, P., & Taylor, S. (2022). Procedural Flowcharts Can Enhance Senior Secondary Mathematics. In N. Fitzallen, C. Murphy, & V. Hatisaru (Eds.), *Proceedings of the 44th Annual Conference of the Mathematics Education Research Group of Australasia*, July 3-7 (pp. 130–137). Launceston: MERGA.
- DeCaro, M. S. (2016). Inducing mental set constrains procedural flexibility and conceptual understanding in mathematics. *Memory & Cognition*, 44(7), 1138–1148. <https://doi.org/10.3758/s13421-016-0614-y>
- Dye, G. A. (2000). Graphic organisers to the rescue! Helping students link—and remember—information. *Teaching Exceptional Children*, 32(3), 72–76.
- Liljedahl, P. (2020). *Building thinking classrooms in mathematics, grades K-12: 14 teaching practices for enhancing learning*. Corwin press.
- Marzano, R. J. (2017). *The new art and science of teaching: More than fifty new instructional strategies for academic success*. Solution Tree.
- Mason, J., Burton, L., & Stacey, K. (1982). *Thinking Mathematically*. Addison Wesley, London.
- Ministry of Education, Curriculum Planning & Development Division. (2020). A Starter Guide to 'Developing Computational Thinking in the Mathematics Classroom'. Retrieved 18 April, 2024, from <https://www.opal2.moe.edu.sg/csl/s/cpdd-sec-math/wiki/page/>.
- Mortimore, A., & Dickfos, J. (2014). Using schemas to demonstrate the methodology of solving complex tax problems: A case study. *Journal of the Australasian Tax Teachers Association*, 9(1), 230–246.

- Newton, K. J., Lange, K., & Booth, J. L. (2020). Mathematical flexibility: Aspects of a continuum and the role of prior knowledge. *The Journal of Experimental Education*, 88(4), 503–515. <https://doi.org/10.1080/00220973.2019.1586629>
- Owolabi, J., & Adaramati, T.F. (2015). Effects of graphic organiser on students' achievement in algebraic word problems. *Journal of Education and Practice*, 6(5), 39–44.
- Paivio, A. (2007). *Mind and its evolution: A dual coding theoretical approach*. Lawrence Erlbaum Associates Publishers.
- Pantziara, M., Gagatsis, A., & Elia, I. (2009). Using diagram as tools for the solution of non-routine mathematical problems. *Educational Studies in Mathematics* (72), pp. 39–60.
- Polya, G. (1945). *How to solve it?* Princeton, NJ: Princeton University Press.
- Queensland Curriculum and Assessment Authority. (2018). Mathematical methods 2019 v1.2: General senior syllabus. https://www.qcaa.qld.edu.au/downloads/senior-qce/syllabuses/snr_maths_methods_19_syll.pdf
- Sharma, S. (2012). Effect of concept mapping strategy on the learning outcome in relation to intelligence and study habits. *International Multidisciplinary e-Journal*. 1(7): 44–52.
- The Institute for the Advancement of Research in Education (IARE) at AEL. (2003). Graphic organisers: a review of scientifically based research. Retrieved 18 April, 2024, from https://www.academia.edu/9501576/Graphic_Organisers_A_Review_of_Scientifically_Based_Research_The_Institute_for_the_Advancement_of_Research_in_Education_IARE_at_AEL.
- Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33–35. doi:10.1145/1118178.1118215
- Zimmermann, A. E., King, E. E., & Bose, D. D. (2024). Effectiveness and Utility of Flowcharts on Learning in a Classroom Setting: A Mixed-Methods Study. *American Journal of Pharmaceutical Education*, 88(1), 100591.
- Zollman, A. (2009). Students use graphic organisers to improve mathematical problem-solving communications. *Middle School Journal*, 41(2), 4–12.
- Zollman, A. (2012). Write Is Right: Using Graphic Organisers to Improve Student Mathematical Problem Solving. *Investigations in Mathematics Learning*, 4(3), 50–60. <https://doi.org/10.1080/24727466.2012.11790316>

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