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Reimagining Pedagogic Interventions in Mathematics for Enhancing Mathematical Modelling Competency of Secondary School Students

Kripa Anna Saj[1], Dr. Bindu T.V.[2]

[1]Research Scholar, Department of Education, University of Kerala, Thiruvananthapuram, Kerala
[2]Professor& Head, Department of Education, University of Kerala, Thiruvananthapuram, Kerala

ABSTRACT

Mathematical modelling competency is the ability to apply mathematical concepts, to analyze and solve the real-world problems. Mathematical modelling is one of the important competencies for secondary school students as it enables them to apply mathematical concepts to real-world problems. Developing mathematical modelling competency among secondary school students enables them to address real-world challenges through mathematics, and it also fosters problem solving ability, analytical thinking, critical thinking, meta-cognitive ability, spatial ability, creativity etc. Mathematical modelling competency can be enhanced by different means, among them innovative pedagogic interventions can be highly effective. By incorporating the different pedagogic interventions into the curriculum, educators can significantly enhance secondary school students' mathematical modelling competency, equipping them with essential skills for both academic success and real-life problem-solving. This paper explains different pedagogic interventions such as Design-Thinking Process, Crossover teaching, Digital escape room, Scavenger hunt, Pause procedure and Model Eliciting Activities that aim to enhance mathematical modelling competency among secondary school students.

Keywords: Pedagogic interventions, Mathematical modelling competency, Secondary school students.

INTRODUCTION

Education is the foundation on which societies thrive. It strengthens the individual, encourages critical thinking and arouses curiosity. Among the various disciplines taught in schools, mathematics holds a unique and important position. Mathematics plays an important role in the paradigm shift in education. It is more than just a subject taught in the classroom; rather, it is an important tool that shapes our understanding of the world. Learning mathematics can bring about changes in all three domains (cognitive, psychomotor and affective) of students. It can promote logical thinking, analytical skills, metacognition, problem-solving skills, spatial reasoning, mathematical modelling competency, etc., all of which are essential for success in various fields such as science, engineering, business, and technology. In addition, learning mathematics improves an individual's precision, accuracy, generalisation, classification, abstraction skills, and symbolism.

Mathematics is a foundational discipline that underpins many aspects of our daily lives and various fields, including science, engineering, economics, and technology. It encompasses a broad range of topics, including arithmetic, algebra, geometry, calculus, and statistics. The study of mathematics not only enhances logical reasoning and analytical skills but also fosters problem-solving abilities that are essential in both academic and real-world contexts. Within the realm of mathematics education, mathematical modelling emerges as an essential competency that enables students to apply mathematical concepts to solve real-world problems.

Mathematical modelling is a powerful tool that allows individuals to represent real-world situations using mathematical concepts and language. This competency involves the ability to translate complex problems into mathematical terms, analyze them, and derive meaningful conclusions or predictions. By engaging in mathematical modelling, secondary school students can bridge the gap between theoretical mathematics and practical application, developing skills that are vital for their future academic pursuits and careers. In this context, enhancing mathematical modelling competency among secondary school students becomes imperative. It equips them with the tools to approach real-life challenges systematically and creatively. Enhancing mathematical modelling competency among secondary school students is

vital for several reasons. First, it prepares students to approach real-world problems systematically and creatively. Second, it encourages critical thinking and promotes the application of mathematical knowledge beyond the classroom. The significance of mathematical modelling in fostering these competencies is becoming more widely acknowledged by educators, innovative pedagogic interventions become essential for effectively integrating this skill into the curriculum.

Mathematical modelling competency is the ability to analyze real-world problems, represent them mathematically, solve those using appropriate tools and techniques, and interpret the results in context. It plays a critical role in applying mathematics to practical situations across various fields such as science, engineering, and economics. The sub-competencies of mathematical modelling competency are simplifying, mathematising, working mathematically, interpreting and validating. Simplifying is the competency to recognize and define the real-world problem to be solved.; mathematising is the competency to translate the real-world problem into a mathematical model using symbols, equations, or other representations ; working mathematically is the competency to solve the formulated mathematical model using appropriate techniques.; interpreting is the ability to relate the mathematical solution back to the real-world problem.; and validating is the competency to check the accuracy of the model and revising, it if necessary (Wang, Zhang , Xie &Liu,2023). The competency in mathematical modelling is increasingly important across various fields such as engineering, economics, biology, and environmental science.

Pedagogic interventions are the systematic procedure employed by educators to facilitate learning and enhance student engagement. These pedagogic interventions encompass a range of techniques, approaches, and practices designed to meet diverse learning needs and improve educational outcomes. Effective pedagogic interventions are essential in secondary education, where students are often preparing for higher education or vocational paths. This paper explores various innovative pedagogic interventions aimed at fostering mathematical modelling competency of secondary school students. By examining these strategies, we aim to highlight their effectiveness in enhancing students' understanding and application of mathematical concepts in real-world contexts.

PEDAGOGIC INTERVENTIONS

Mathematical modelling is a crucial skill for secondary school students, enabling them to apply mathematical concepts to real-world problems. Innovative pedagogic interventions can significantly enhance students' competency in mathematical modelling by promoting engagement, critical thinking, and problem-solving skills. Some of the strategies are given below:

- Design-Thinking Process
- Crossover teaching
- Digital escape room
- Scavenger hunt
- Pause procedure
- Model Eliciting Activities

Design-Thinking Process

The Design Thinking Process is an innovative, human-centered, and iterative approach to problem-solving that fosters creativity, collaboration, and critical thinking in students. In education, it encourages learners to actively engage in identifying problems and developing solutions, making learning meaningful and applicable to real-world contexts (Razzouk & Shute, 2012).

The Design Thinking process involves five key stages:

1. Empathize: Understand the needs and perspectives of the users or stakeholders.
2. Define: Clearly articulate the problem based on insights gathered during the empathize stage.
3. Ideate: Generate a wide range of creative ideas and possible solutions.
4. Prototype: Develop tangible models or representations of the solutions.
5. Test: Implement the solution and refine it based on feedback.

For example, the teacher is teaching about geometry such as different shape, area perimeter etc. then teacher assigns students to design a school playground

1. Empathize: Students research and interview peers to identify issues with the current playground design (e.g., lack of space, no shaded areas). They note the preferences of different groups (e.g., younger students might want swings, elder students might prefer sports areas).
2. Define: Frame the problem: "How can we redesign our school playground to optimize space and meet the needs of all students?"

3. Ideate: Students brainstorm different designs using geometric shapes to represent various playground elements (e.g., rectangular fields, circular sandpits). Encourage them to consider constraints such as area, perimeter, and budget.
4. Prototype: Students create scale models or diagrams of their proposed playground using graph paper or software tools like GeoGebra. They calculate areas and perimeters to ensure efficient use of space.
5. Test: Present the designs to peers and gather feedback. Revise the designs based on suggestions, refining dimensions and adding features.

Design thinking process when used for teaching mathematics help student's to develop spatial reasoning, collaboration, and problem-solving skills which will aligns mathematical learning with real-life applications, making the subject more engaging and meaningful.

Crossover Teaching

Crossover teaching is an instructional approach that integrates learning experiences from formal educational settings (like classrooms) with informal settings (such as real-world environments, museums, or online communities). It aims to bridge the gap between theoretical knowledge and practical application, fostering deeper understanding and engagement. In mathematics, this strategy can be used to relate abstract concepts to everyday situations, encouraging students to apply what they learn in class to solve real-world problems.

For example, in classroom teacher taught the concepts of ratios and proportion.

Formal Setting: Teach the concepts of ratios and proportions using textbook examples and exercises. Discuss their importance in real-life situations, such as cooking, map reading, and scale models.

Informal Setting Activity: The assigned topic is to Redesigning a School Garden. Take students to the school garden and provide real-world measurements of the space. Assign the task: "Plan the garden layout by dividing the space into areas for flowers, vegetables, and pathways using specific ratios (e.g., 2:3:1)." Students must use their knowledge of ratios and proportions to calculate the areas for each section and create a scale drawing of the garden.

Crossover teaching stress on connecting mathematical concepts to real-world experiences and thereby students understand the relevance of various concepts in Mathematics for enhancing analytical and modelling skills of students.

Digital Escape Room

A digital escape room strategy is an instructional approach that gamifies learning by presenting students with virtual puzzles, challenges, and clues that they must solve collaboratively or individually to "escape" from a fictional scenario. This strategy is designed to engage students, promote critical thinking, and foster problem-solving skills. Digital escape rooms typically incorporate interactive elements like videos, digital locks, and online tools, making them particularly suitable for secondary school students who are accustomed to technology.

For example, the teacher taught the concepts of linear equation and how to solve the linear equation. First, we give a situation and then we give so many challenges they have to tackle these challenges by solving the problem and find out the solution for the given situation.

Situation: Students are trapped in a mysterious laboratory where scientist has locked them in. The only way to escape is to solve a series of mathematical puzzles related to linear equations, which reveal the access codes to unlock the doors.

Challenge 1: Equation Decoder*
Students are given clues in the form of word problems. For example:
"If twice a number is decreased by 4, the result is 10. What is the number?"
Students solve the equation $2x - 4 = 10$ to find x. The solution reveals a piece of the escape code.
Challenge 2: Matching Game
Students match equivalent forms of linear equations (e.g., $y = 2x + 3$) matches with ($2x - y + 3 = 0$) to unlock a hidden compartment in the lab.
Challenge 3: Graph the Secret Message
Students are tasked with graphing equations like $y = x + 2$ and $y = -x + 4$. The intersection of the lines reveals a coordinate pair (e.g., $x = 1$, $y = 3$) that serves as the code to open another lock.
Challenge 4: Systems of Equations
To disable the security system, students solve simultaneous equations such as: $2x + y = 10$, $x - y = 2$
Correctly solving for x and y reveals the final code to escape.

Digital escape room when used for teaching mathematics help the student's to encourage metacognition and problem-solving skill.

Scavenger Hunt

A scavenger hunt in education is an interactive learning approach where students are tasked with finding and solving clues, questions, or challenges scattered across physical or digital locations. This method promotes engagement, teamwork, and critical thinking by encouraging students to actively explore and apply knowledge in a fun and dynamic environment. Scavenger hunts can be physical (e.g., searching for clues around a classroom or school) or digital (e.g., using online tools or apps to navigate through challenges.

For example, after teaching the concepts of algebra and geometry. The teacher give them activity.

Students are on a mission to uncover a "hidden treasure" by solving a series of mathematics problems. Each correct solution provides the next clue to progress toward the final location or task.

Preparation: Create a sequence of math problems or clues related to the syllabus (e.g., solving equations, calculating areas, or identifying geometric properties). Hide physical clues around the classroom/school or use a digital platform to provide tasks.

Clue Examples:

Clue 1:Solve for x: 3x + 7 = 22. The solution will reveal the locker number where the next clue is hidden."

Answer: x = 5 leads students to locker 5

Clue 2:Find the area of a triangle with a base of 10 cm and a height of 6 cm. Your answer will match the page number in a textbook containing the next clue."

Answer: Area = 30 cm^2 leads students to page 30.

Clue 3:Using the graph y = 2x + 1, find the y-coordinate when x = 3. The solution unlocks the combination to the box with the final clue."

Answer: y = 7

Final Challenge: Combine all previous answers to form a code or solve a final problem (e.g., "Sum the solutions from all clues to find the treasure's location").

Scavenger Hunt helps to understand various mathematics concepts through practical application and also encourage problem-solving and critical thinking.

Pause Procedure

The pause procedure is a teaching strategy that involves intentionally pausing during a lecture or lesson to allow students to reflect, discuss, or process the information presented. This method helps improve comprehension, encourages active participation, and supports retention by breaking the content into manageable segments. During pauses, students may engage in activities such as summarizing key points, asking questions, or solving a quick problem related to the topic. The strategy is particularly effective for complex subjects like mathematics, where students benefit from structured opportunities to reflect on and practice new concepts.

For example, teacher is preparing a lesson plan usin pause procedure on toping solving quadratic equation by factoring.

Introduction (5-10 minutes):

The teacher introduces the concept of quadratic equations and demonstrates how to solve one by factoring, e.g., solving (x^2+ 5x + 6 = 0\).

First Pause (2-3 minutes):

Activity:Students work individually or in pairs to factor and solve x^2 + 7x + 10 = 0.

Second Segment (5-10 minutes):

The teacher explains how to verify solutions by substituting values back into the equation.

Second Pause (2-3 minutes):

Activity: Students verify solutions for x ^2 - 4x - 5 = 0 after factoring.

Discussion: Pairs compare results and discuss any errors.

Third Segment (5-10 minutes):

The teacher introduces slightly more complex equations, such as those requiring factoring out a common term first (e.g., 2x^2 + 8x = 0).

Third Pause (3-5 minutes):

Activity: A group discussion or quick Q&A session to address difficulties and ensure clarity before moving on.

Pause Procedure when used for teaching mathematics help the student's to develop self-reflection and metacognitive skills.

Model Eliciting Activities

Model Eliciting Activities (MEAs) are a teaching strategy used to help students develop mathematical modelling skills by engaging them in solving complex, real-world problems. The strategy encourages students to work collaboratively and apply mathematical concepts to represent, analyze, and solve authentic problems. MEAs are designed to promote deep thinking, communication, and reasoning, and they often require students to create and refine mathematical models that represent real-life situations. It involves MEAs involve realistic scenarios that students can relate to, making the learning process more engaging and meaningful.

For example,
The principal of a high school wants to maximize the number of students that can fit comfortably in each classroom while maintaining safety and accessibility. Each classroom is a rectangle with a given area, and there are fixed resources such as desks and space requirements for aisles.

Task: Students are asked to design the seating arrangement for a typical classroom based on the following criteria:

Area Constraints: Each classroom has a specific area (e.g., 36 square meters) which must be filled with desks.
Safety and Accessibility: There must be at least one aisle along which students can move freely. This aisle must be at least 1 meter wide.
Desks: Desks are of a standard size (e.g., 60 cm by 90 cm) and cannot be altered.
Maximizing Seating Capacity: Students need to find the arrangement that maximizes the number of students seated while adhering to the area, safety, and accessibility constraints.

Mathematical Concepts:

Geometry: Area and perimeter calculations.
Optimization: Finding the arrangement that maximizes or minimizes a particular quantity.
Proportions: Ensuring the correct ratio of desk space to aisle space.

Steps to follow:

1. Calculate Area: Determine the total area of the classroom and the desk size.
2. Determine Desk Placement: Decide on the best placement for desks based on the area available and the need for aisles.
3. Safety and Accessibility: Design the classroom layout so that the aisle meets the safety requirement (at least 1 meter wide).
4. Optimization: Experiment with different configurations to see which allows for the most seating while still meeting all constraints.

Students can create a scaled diagram of the classroom and desks, using graph paper or digital drawing tools. They might use algebraic equations or inequalities to represent the area and constraints. The final model would show the optimal layout of desks and aisles. After completing the task, students can reflect on their design choices, discuss why certain arrangements worked better than others, and consider how different variables (e.g., classroom size, number of desks, aisle width) affect the seating capacity.

Model Eliciting Activities are practical way for students to see the application of mathematics in everyday situations and also encourages critical thinking and problem-solving in a real-world context.

CONCLUSION

In conclusion, developing competency in mathematical modelling equips individuals with essential skills for tackling complex problems systematically and effectively. As our world becomes more data-driven, these skills will continue to be invaluable in various professional domains. Enhancing mathematical modelling competency among secondary school students requires a shift towards innovative pedagogic interventions that promote engagement, collaboration, and real-world application. The integration of mathematical modelling into secondary education is essential for developing students' competencies in mathematics. It not only enhances their understanding and application of mathematical concepts but also prepares them for real-world challenges by fostering critical thinking, problem-solving skills, and collaborative abilities. By integrating different pedagogic interventions like Design-Thinking Process, Crossover teaching, Digital escape room, Scavenger hunt, Pause procedure, Model Eliciting Activities, educators can create a dynamic learning environment that prepares students for future challenges in mathematics and beyond. As educational practices continue to evolve, prioritizing mathematical modelling will be crucial in cultivating a mathematically literate society capable of addressing contemporary issues effectively.

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