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Development of grade 10 students' modelling skills on circulatory system through model-based learning

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Abstract

Aim: This study aims to elevate the modelling skills of Grade 10 students in understanding the circulatory system, using model-based learning, to a level where they can achieve at least a 70% passing score on a relevant unit test.
Method: The study involved 23 students and implemented a model-based learning approach. Research tools included a design for model-based learning, assessments of the modelling process, a modelling ability exam, structural interviews, and student diaries. Data analysis was conducted using percentages and averages, and the action research was structured into two iterative rounds.
Results: Initial findings from the first cycle revealed an average modelling ability score of 18.21 out of 24 (75.87%), with 14 students surpassing the 70% threshold. The second cycle showed marked improvement, with an average score of 19.94 out of 24, translating to an 83.09% success rate. Notably, all 23 students exceeded the 70% benchmark in this cycle.
Conclusion: The implementation of model-based learning significantly enhanced the students' modelling skills in understanding the circulatory system. The method proved effective in not only achieving but surpassing the targeted 70% success threshold, demonstrating its potential as a valuable educational tool in biology.

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INTRODUCTION

In the domain of science education, the incorporation of models significantly facilitates the enhancement of students' understanding of scientific concepts (Schwarz et al., 2009; Teig & Nilsen, 2022; Wilajan et al., 2023). This approach prepares students to adopt a scientific mindset, covering the essence, methodologies, and applied practices of science. Modeling is highlighted as a critical component of the scientific inquiry process, as evidenced by its inclusion as a key indicator and topic within science education standards. Recently, modeling and simulation have emerged as pivotal elements in science instruction, underscoring their importance in fostering scientific literacy (Gilbert et al., 2000). The advancement of students' modeling capabilities is deemed crucial for cultivating a deeper understanding of science in educational settings. Research underscores the pivotal role of models in driving progress within scientific education (Chang, 2008; Schweingruber et al., 2012).

Given the diverse interpretations of biological data, the availability of a wide range of models "ranging from concrete to abstract, and from two-dimensional to three-dimensional" is essential (Eilam, 2013; Thayban et al., 2021). The integration of models in biology lessons significantly enhances students' grasp of the subject matter (Bryce et al., 2016). Moreover, the visual support provided by models aids in the learning process, making it easier for students to comprehend and retain complex information (Hillmayr et al., 2020). Consequently, models facilitate the communication of ideas and concepts, enhancing collaborative understanding and discussion (Schwarz et al., 2009; Nicolaou & Constantinou, 2014).

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Considering the educational assessments from OECD member countries, the emphasis on using and developing models, along with leveraging facts for explanatory purposes, has been highlighted. It was found that students averaged scores of 421 in 2015 and 426 in 2018, with most institutions still performing below the OECD average (Institute for the Promotion of Teaching Science and Technology, 2018). This research involved students in creating models to depict cell division processes, guided by their observations and the sequence of previously reviewed instructions. Challenges emerged, particularly in visualization students struggled with forming images or conceptualizing their tasks. Visualization entails generating mental images through interpreting brain-received information, closely linked to mental models (Gonzalez, 2014). Furthermore, biology encompasses a vast array of content, with conventional classroom teaching often reliant on narrative methods. Such approaches limit students' experiential learning, hindering the development of modeling skills. The complexity and specialized language of the material make it hard to remember. It is increasingly clear that science education should facilitate modeling for students, aiding their comprehension, engagement with the subject matter, and process-related skill development (Fried et al., 2019; Grady & Davis, 2020).

The Model-Centered Instruction Sequence (MCIS) in chemistry has been recognized as a successful strategy for enhancing students' modeling abilities (Yuanphan & Nuangchalerm, 2023). Implementing learning management strategies that encourage the creation of representations can significantly improve students' modeling skills. Model-based learning stimulates creative thinking and the ability to construct scientific models. Students' mental models, derived from an analysis of existing knowledge, form the foundation for their subsequent representations. Should these models fall short in accurately describing or predicting observed phenomena, students are encouraged to apply, assess, and refine them.

Leveraging original models as foundational elements enables students to construct new, more intricate models, a practice supported by findings from Gobert & Buckley (2000) and Gilbert & Justi (2016). Gilbert (2004) emphasizes the importance of educators utilizing models to demystify and convey abstract concepts within the classroom effectively. In the realm of Biology Education, Model-Based Learning has been extensively applied, yielding positive outcomes. Such applications have notably influenced modeling capabilities in biology (Kuatthai & Chookhampaeng, 2020), enhanced learning achievement and scientific reasoning (Kantawang & Singlop, 2020; Nursal et al., 2023), invigorated learning activities (Jantarit & Sonsupap, 2022), and enriched students' experiences alongside iterated models (Park et al., 2023). However, literature review reveals a gap in research concerning the impact of Model-Based Learning on modeling abilities specifically in the context of the Circulatory System. This gap signifies a critical area of investigation, underscoring the need for targeted research to unlock the potential benefits for the concerned demographic. Consequently, this study aims to explore the adoption of Model-Based Learning as a strategy to enhance students' modeling abilities, employing an action research approach to navigate the distinct challenges encountered by educators in this endeavor.

METHOD

Participant

The participants in this study were Grade 10 students attending a school in Mahasarakham Province, Thailand, during the second semester of the 2022 academic year. Utilizing purposive sampling, 37 students were initially selected based on a modeling skills test. The focus group for the study comprised 23 students whose modeling skill scores were below 70% of the total possible score.

Research Instruments

The tools employed in this research included a model-based learning lesson plan focused on the circulatory system, assessments of the modeling process, tests of modeling skills, interviews, and student journals.

Lesson Plan: The study designed six lesson plans for model-based learning, totaling 12 hours of biology instruction. The first cycle, encompassing the first three lesson plans, spanned six hours.

Similarly, the second cycle covered the remaining three lesson plans over another six hours. Each lesson plan underwent review and refinement by five experts to confirm its suitability, achieving a very good quality level after improvements were made based on expert advice.
Modeling Process Assessment: This assessment evaluated students' abilities to create and use models during learning, encompassing four stages as outlined by Schwarz et al. (2009): modeling, model evaluation, model adaptation, and model improvement. The instrument was validated by five experts to ensure its relevance and was subsequently adjusted following their recommendations.
Modeling Skills Test: At the end of each cycle, two open-ended test items were administered, evaluated using a scoring rubric. The test construction was supported by an item-objective congruence index and vetted by five experts for content validity.
Structured Interviews: Interviews were conducted with a select group of students after each learning cycle to gather detailed insights into their modeling skills, covering four comprehensive elements. The development and validation of the interview protocol were carried out by five experts before its application.
Student Journal: Students maintained journals to reflect on the teaching and learning experiences at the conclusion of each action cycle. These reflections were used by the researcher to enhance and develop subsequent learning activities.

Data collection

This research was action research, which consisted of 4 steps: Plan, Act, Observe, and Reflect. The researcher divided the data collection into two phases as follows in Figure 1

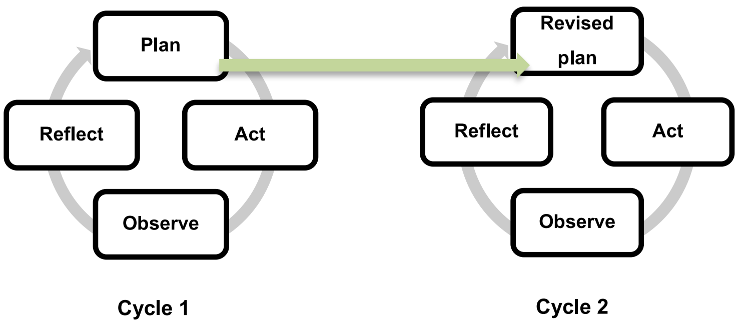

Figure 1. Steps of this research

Cycle 1: The researcher observed the behavior of students in a biology course, focusing on the challenges they faced with modeling abilities. This involved administering a test to assess the modeling skills of 10th-grade students. Those scoring below 70% were identified for further intervention. The researcher then implemented model-based learning through meticulously crafted lesson plans. These plans were divided into three sessions, each designed to progressively enhance the students' understanding and application of modeling skills. Throughout this phase, the researcher closely monitored the students' engagement and progress using a variety of assessment tools, including direct observation and process assessments. At the conclusion of Cycle 1, comprehensive data were collected through a second modeling skills test, interviews, and student journals. This information was then thoroughly analyzed to identify areas for improvement and to refine the learning management strategies for Cycle 2.
Cycle 2: Building on the insights gained from the initial cycle, the researcher refined the educational activities and introduced improved lesson plans for the next set of sessions. These plans, encompassing the fourth to sixth sessions, aimed to further enhance the students' modeling skills through model-based learning. The methodology for observing and assessing student behavior and progress mirrored that of Cycle 1, ensuring a consistent approach to data collection. Upon completing this cycle, additional data were gathered using the same instruments—modeling skills tests, interviews, and student journals. This data was again analyzed to summarize the outcomes and to inform further improvements for subsequent cycles.

Data Analysis

The study's data analysis was aligned with its objectives, employing both qualitative and quantitative methods. Qualitative data, derived from lesson plans, interviews, and student journals, were analyzed to generate comprehensive insights into the learning experiences and outcomes. This analysis aimed to interpret and summarize the data in a descriptive format. Quantitative data, on the other hand, were analyzed based on the scores from the modeling process assessments across both cycles. These scores were evaluated against modified criteria adapted from Schwarz et al. (2009), as detailed in Table 1. The total score is compared to the determined criteria passed the 70% of full score, then 4 levels of modelling skills are individually translated, very good: 21-24, good: 17-20, moderate: 13-16, must be improved: 9-12.

Table 1. Evaluation criteria for modeling processes, adapted from Schwarz et al. (2009)

Component	Level		
	2	1	0
Modeling	Modeling is consistent with evidence, theories related to phenomena, correctly covering all elements	Modeling is consistent with evidence, theory related to phenomena correctly, but 1-2 elements are not identified	Modeling is not consistent with evidence, theory related to phenomena
Using models	Use models to correctly and clearly explain evidence, theories, or phenomena	Use models to correctly but unclearly explain evidence, theories, or phenomena	Models cannot be used explain evidence, theories, or phenomena
Model evaluation	Evaluate and compare the advantages and limitations of the model students create with other models in their entirety, and can decide which models can explain a theory or phenomenon better than others	Evaluate and compare the advantages and limitations of the model students create with other models in their entirety, and can decide which models can explain a theory or phenomenon better than others. but it cannot tell how it is better than others	Cannot compare the advantages and limitations of the models they create with other models
Model improve	Improved, changes, debugging in the model, it is accurate to cover all elements and is used to explain it better than the model before the improvement	Improves, changes, debugging in the model to ensure accuracy, but not all elements are comprehensive	No improves, no changes, no debugging in the model

RESULTS AND DISCUSSION

Before learning by using model-based learning, a total of 37 students received average score of 10.62 representing 65.20% with moderate ability to modelling skills, 14 students had modelling skills passed criteria 70% of full score, representing 37.84%, the researcher selected students who not to meet the 70% of full score, as the target group in order to develop their modelling skills to passed criteria the 70 % of full score (Table 2).

Table 2. Modelling skills of grade 10 students after model-based learning activities

Average score	Test score (16)	Process score (8)	Total (24)	%	Number of students passed the 70 %	Interpret
Cycle 1	12.14	6.07	18.21	75.87	14	Good
Cycle 2	13.27	6.67	19.94	83.09	23	Good

Table 2 displays the outcomes of the students' modeling skills. In Cycle 1, the average total score for modeling skills was 18.21, equating to 75.87%, categorized as a good level. Among these, 14 students surpassed the 70% benchmark, while 9 did not meet this criterion. The breakdown of the average scores was 12.14 (75.84%) and 6.07 (75.92%) for different components. However, a closer examination of the modeling process, comprising four elements—constructing, using, evaluating, and revising—revealed average scores for each component to be 1.89, 1.78, 1.39, and 1, respectively.

In Cycle 2, after implementing and refining model-based learning activities from Cycle 1, it was observed that all 23 targeted students exceeded the 70% threshold. The average total score for modeling abilities rose to 19.94, translating to an 83.09% success rate, again considered a good level. This cycle's detailed averages were 13.27 (82.94%) and 6.67 (83.39%) for respective areas of assessment. Further analysis of the modeling process across its four elements—constructing, using, evaluating, and revising—showed improvements in the average scores to 1.94, 1.89, 1.5, and 1.28, respectively, as illustrated in Figure 2.

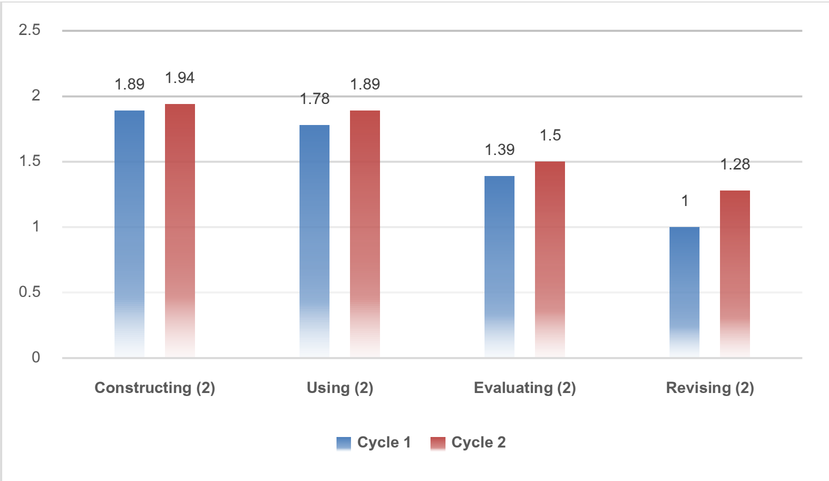

Figure 2. Average score in the modelling skills

The results indicate that employing model-based learning significantly enhanced the modeling skills of Grade 10 students across each cycle of the study. In the first cycle, 14 students demonstrated improved modeling skills, and in the second cycle, all 23 students exhibited further advancements in their abilities. This progression underscores the effectiveness of model-based learning in incrementally developing students' modeling competencies.

Our research into the modeling skills development of Grade 10 students, facilitated through model-based learning, revealed that the first cycle resulted in an average score of 18.21. Upon individual assessment, it was observed that 14 out of 23 students met the 70% benchmark, indicating a proficient level. This success can be attributed to the nature of model-based learning, which actively involves students in the creation and refinement of models. This process requires learners to engage thoroughly with modeling activities, including the construction, application, evaluation, and revision of models to achieve completeness and the capacity to elucidate specific scenarios or phenomena (Schwarz et al., 2009). This approach aligns with Buckley et al. (2004), who described model-based learning as the strategic use of models to facilitate understanding across various scientific concepts. Analysis of the scores across the four key aspects of the modeling process—constructing, using, evaluating, and revising—revealed average scores of 1.89, 1.78, 1.39, and 1, respectively. This data highlights that students performed best in the construction phase, whereas the revision of models was identified as the area with the lowest average score, indicating a need for further emphasis on this aspect of the learning process.

Despite the promising results, 9 students did not achieve the 70% benchmark. These students faced challenges in conceptualizing mental models, often engaging in fewer discussions and comparisons with their peers, both within and across groups. This limitation impacted their ability to enhance their models effectively (Ristanto et al., 2021). In response to these challenges observed in Cycle 1, adjustments were made for Cycle 2. The researchers refined and expanded the activities from the first cycle, leading to an improved average modeling skill score of 19.94, equivalent to

83.09%, which is considered a good level. Consequently, all 23 target students surpassed the 70% threshold.

The modifications included integrating engaging materials, such as relevant news stories and videos, coupled with probing questions designed to stimulate students' responses and foster more nuanced model conceptualizations. This approach facilitated greater interaction among students, encouraging them to discuss and collaboratively refine their models by comparing them with those of other groups. Additionally, a thorough review of data and evidence was conducted to evaluate the models' effectiveness. Through this iterative process, students became increasingly cognizant of their models' strengths and limitations, guided by targeted questions and examples. This strategy enabled them to critically analyze their group's models, assess the extent to which they could explain phenomena, and identify areas for enhancement (Gobert & Buckley, 2000; Gilbert & Justi, 2016; Esther et al., 2020).

Considering the scores in the modeling process, which includes four elements: constructing, using, evaluating, and revising, students achieved average scores of 1.94, 1.89, 1.5, and 1.28 respectively. This data indicates progress in each component of the modeling process. Model-based learning facilitates hands-on activities, enabling students to create their models progressively until a comprehensive model is achieved. This approach fosters continuous development in modeling skills, as models are utilized to represent new scenarios or phenomena. The pedagogy of model-based learning enhances students' modeling capabilities, as highlighted by Lee & Kim (2014), who observed students' ability to construct complex models of the circulatory system. Furthermore, modeling aids in transitioning concepts from abstract to concrete understanding.

The implementation of model-based learning showcases the advancement in the targeted students' modeling abilities. This educational strategy is rooted in constructivist learning theory, promoting active, hands-on learning where students generate knowledge through the modeling process (Krause et al., 2003). Effective modeling skills require an educational setup that supports independent inquiry through modeling. This entails forming a mental model based on prior knowledge, allowing students to express their understanding in various forms. Students are encouraged to use and assess their models, revising them if they inadequately represent the phenomenon under study. This iterative process of evaluation and improvement is crucial, as it enables students to refine their models for better clarity and accuracy. Ultimately, students can expand upon their original models, enhancing their complexity and depth.

CONCLUSION

Students enhanced their modeling skills significantly through model-based learning focused on the circulatory system, achieving the targeted passing score of 70%. The action research methodology encompassed two iterative cycles, allowing for repeated assessment and improvement. Analysis of the initial cycle revealed that the average modeling ability score among students was 18.21 out of 24, corresponding to a 75.87% success rate. Of these, thirteen students met or exceeded the 70% passing threshold, while nine did not. In the subsequent cycle, there was notable improvement, with the average score rising to 19.94 out of 24, or an 83.09% success rate. Remarkably, all 23 students involved in the study surpassed the 70% benchmark during this phase, demonstrating the effectiveness of model-based learning in enhancing students' understanding of the circulatory system.

AUTHOR CONTRIBUTION STATEMENT

KM : Conceptualization, Data retrieval, Writing - Original Draft.
PN : Data collection, Data analysis, Writing - Original Draft.

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