Development of Human Circulatory System Prototype as a Teaching Tool Among Secondary School Students

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ABSTRACT

The Form 3 Science curriculum in Malaysia includes the Maintenance and Continuity of Life theme, within which students often encounter difficulties visualizing internal organ structures and circulatory processes, particularly heart anatomy. To address these challenges, this study reports a preliminary evaluation of CirculaBody, an interactive circulatory system prototype comprising a Heart Anatomy Puzzle and a Blood Flow Board. The prototype was developed using the ADDIE instructional design model and aims to support experiential learning through tactile and visual representations. Prototype testing was conducted with 15 Form 3 students from a single secondary school using a pre-test and post-test design. Results indicate a modest overall improvement in test scores, with greater learning gains observed in items requiring spatial and structural understanding of heart anatomy. Questionnaire feedback suggests that students perceived the prototype as helpful for visualizing circulatory structures compared to conventional two-dimensional representations. However, the absence of a control group and the small sample size limit causal inference and generalizability. The findings provide initial insights into the pedagogical potential of hands-on and representational learning tools for lower secondary biology and highlight areas for refinement and further investigation through larger-scale, controlled studies.

Keywords— circulatory system, interactive prototype, anatomy education, experiential learning, science and technology development

INTRODUCTION

In the dynamic landscape of secondary education, the science curriculum for Form 3 students in Malaysia pivots around the theme of Maintenance and Continuity of Life. This thematic framework endeavors to provide students with a comprehensive understanding of life processes inherent to all living organisms. Key emphasis is placed on vital aspects such as stimulation and response, respiration, and transportation – integral for the survival of both humans and other living entities. Within this context, the Science DSKP Form 3 delineates the fundamental knowledge that lays the groundwork for students considering participation in the Science stream. These foundational concepts, particularly in the domain of Biology, become pivotal for comprehending the physiology of humans and animals. As underscored in the Biology DSKP, a critical emphasis is placed on understanding organ functions within each physiological process, with the overarching goal of contributing to the development of personal care knowledge and advancements in science and technology.

However, despite the structured curriculum, a significant challenge persists – the difficulty students encounter in visualizing internal organ processes, particularly in understanding the intricate anatomy of the heart. Educators, too, grapple with the complexities of teaching heart anatomy, as highlighted by research [2]. Moreover, student engagement tends to wane in the face of the formidable challenge of comprehending and memorizing the intricacies of the heart's anatomy [6]. In response to these challenges, a paradigm shift is observed in contemporary learning preferences. The modern student population gravitates towards experiential learning, where tactile and interactive experiences take precedence over traditional instructional methods. Recognizing this shift, our innovation, CirculaBody - The Human Body's Circulatory System, emerges with the purpose of bridging the gap in knowledge acquisition. By offering a tangible and immersive learning experience, CirculaBody aims to rekindle interest, enhance understanding, and facilitate the memorization of organ parts and their functions. In this narrative, we delve into the contextual framework and problem background that underscore the necessity for a transformative educational tool like CirculaBody.

PURPOSE OF THE STUDY

The purpose of this study is to address the challenges faced in teaching the Maintenance and Continuity of Life theme in Form 3 Science, with the goal of creating a more effective and engaging learning experience. Firstly, the project aims to develop an interactive circulatory system prototype as a teaching tool for secondary school students. This tangible and hands-on educational resource simulates the circulatory system, enabling students to directly engage with the processes of heart anatomy, respiration, and blood transportation. Secondly, the project seeks to evaluate the preliminary impact of the prototype in enhancing students' understanding of life processes, with a focus on heart anatomy, respiration, and blood transportation. By emphasizing the intricate details of stimulation and response, respiration, and transportation within the circulatory system, the evaluation aims to ensure that the tool significantly improves students' comprehension and fosters deeper learning.

RESEARCH QUESTIONS

The research questions of this study include:

1. What is the problem faced by the Secondary School students in learning the Human Circulatory System in the Analysis phase in ADDIE Model?

2. What design of the Human Circulatory System Prototype and Module is suitable as a teaching tool in the design phase in ADDIE Model?

3. What is the content of the Human Circulatory System Module that is suitable for the Secondary School Students in the development phase in ADDIE Model?

4. What is evaluation of the evaluator about the Human Circulatory System Prototype and Module in the evaluation phase in ADDIE Model?

5. What is the preliminary learning outcomes of the Human Circulatory Prototype and Module among Secondary School Students?

METHODOLOGY

The product testing phase for the innovative prototypes, the blood flow prototype and heart anatomy puzzle within the "CirculaBody: The Human Body's Circulatory System," is integral to ensuring their efficacy in addressing the identified challenges faced by educators and students in understanding the complex human circulatory system. The product development and design process, following the ADDIE Model (Analysis, Design, Development, Implementation, and Evaluation), incorporates a meticulous approach.

During the analysis phase, it was identified that educators encounter difficulties teaching human heart structure and function to Form 3 students, leading to challenges in grasping and memorizing vital organ parts. This laid the foundation for developing an interactive 3D model that aligns with the feasibility and simplicity required in Malaysian schools. Next, the design phase focuses on three key components which are hardware, software, and a labeled human structure model. Arduino IDE is employed for software development to control the button switch, while the hardware assembly ensures a functional circuit. The human structure model is carefully designed and labeled with detailed annotations corresponding to the circulatory system components. The development phase involves the actualization of the software using Arduino IDE, the assembly of hardware components, and the creation of the human structure model. This comprehensive approach ensures the

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integration of technology, physical representation, and educational content in a harmonious manner. The implementation phase foresees the utilization of the Human Circulatory System Model by secondary-level teachers, particularly in national and private schools offering Science and Biology subjects. This stage marks the practical application of the prototypes in an educational setting. The Evaluation phase will show that the preliminary impact of the Human Circulatory System Model will be rigorously evaluated based on student achievements after engaging with the prototypes. This evaluation will provide insights into the impact of the prototypes on enhancing the teaching of Science and Biology, specifically addressing topics related to the human circulatory system.

In summary, the meticulous process of product development and design, aligned with the ADDIE Model, ensures that the blood flow prototype and heart anatomy puzzle are not only technologically sound but also pedagogically effective. The integration of hands-on experience, technological innovation, and a labeled human structure model aims to support the teaching and learning of the human circulatory system, ultimately benefiting educators and students in the realm of Science and Biology education.

FINDINGS AND DISCUSSION

This section explains the developed product and presents the research results. It describes the features and functions of the innovation in detail, highlighting its role in teaching the circulatory system. The findings from the research are also discussed to demonstrate the product's impact in achieving the intended learning outcomes.

Product Description

CirculaBody represents an effective and engaging resource in science education, introducing an engaging and comprehensive learning experience for students exploring the intricacies of the human circulatory system. At its core, the CirculaBody Prototype comprises two integral components: the Heart Anatomy Puzzle and the Blood Flow Board. Designed to align seamlessly with the Form 3 Science curriculum, this educational tool aims to support the teaching and understanding of the circulatory system.

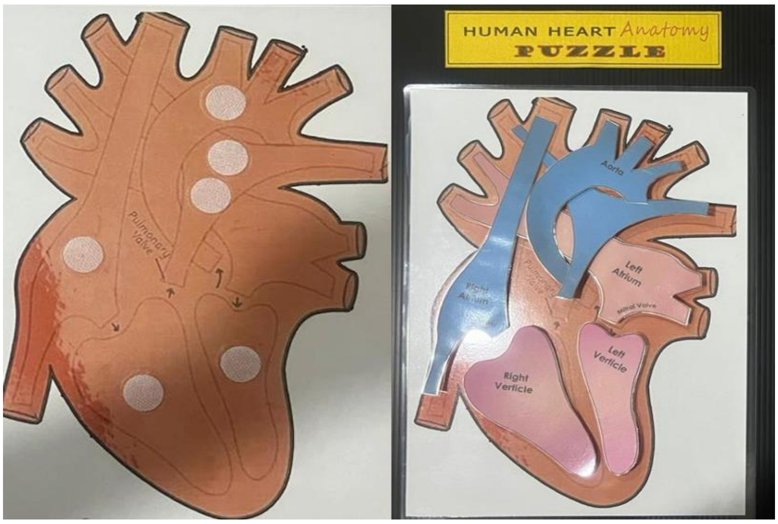

Fig. 1 The before and after image of the Heart Anatomy Puzzle

The Heart Anatomy Puzzle is an interactive and educational tool designed to facilitate a hands-on learning experience for students studying the circulatory system. Crafted with precision, this puzzle comprises intricately designed pieces that represent various components of the human heart. By assembling the puzzle, students gain a tangible understanding of the anatomical structure of the heart, including chambers, valves, and major blood vessels. Labeled with detailed annotations, the puzzle serves as a visually engaging aid for educators to impart essential knowledge about the heart's role in the circulatory system. This tactile approach enhances students' ability to grasp complex concepts and fosters a deeper appreciation for the physiological intricacies of the human heart.

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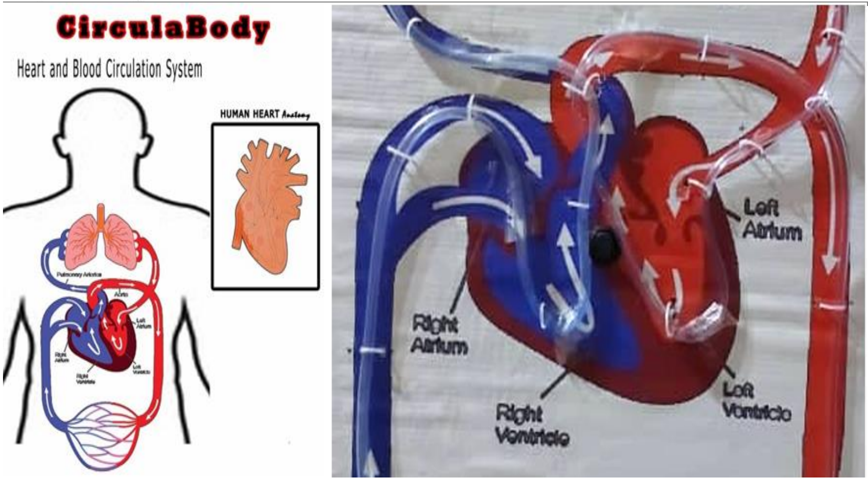

Fig. 2 The CirculaBody Prototype

The Blood Flow in Circulation Prototype is an interactive learning tool that brings the circulatory system to life. Utilizing Arduino technology and color-coded pipes, this prototype simulates the flow of oxygenated and deoxygenated blood throughout the human body. Activated by a user-friendly button switch, students can observe the real-time representation of blood circulation. The red and blue watercolors distinctly depict oxygenated and deoxygenated blood, enhancing the visual impact of the circulatory process. This hands-on experience not only reinforces theoretical knowledge but also caters to diverse learning styles. The prototype is meticulously designed to align with the Form 3 Science curriculum, providing educators with an effective and engaging resource to teach complex circulatory system concepts in an accessible and memorable way.

Together, the CirculaBody prototype provides an integrated approach to circulatory system instruction by combining tactile learning with dynamic simulations. As a classroom resource, it supports students' engagement with hands-on representations of the human circulatory system in alignment with the Form 3 Science curriculum.

TESTING RESULT AND DISCUSSION

Prototype testing was conducted with 15 Form 3 students from SMK Ulu Tiram. Participants were selected through convenience sampling based on class availability and teacher consent. The implementation of the CirculaBody prototype resulted in an average score increase from 59% to 65%. While this 6% gain is modest, a granular analysis of individual questions suggests that the prototype's impact varies by conceptual complexity. Question 5, which focused on the identification and spatial arrangement of major heart chambers and valves in a three-dimensional structure, saw the most significant improvement of 26%. This pattern suggests that the tactile nature of the Heart Anatomy Puzzle may be particularly supportive of spatial recognition tasks, consistent with Experiential Learning Theory, which emphasizes learning through physical interaction. As this was an exploratory pilot study with a small sample, no inferential statistical tests or effect size calculations were conducted; therefore, the observed score changes should be interpreted descriptively rather than as evidence of statistically significant impact.

Conversely, the slight decrease in performance on one specific question warrants critical attention. This may suggest that while the Blood Flow Board effectively supports students' visualization of overall circulatory pathways, it is less effective in facilitating understanding of valve pressure dynamics, which require abstract reasoning beyond directional flow. This limitation may stem from the simulation pacing or labelling emphasis, which could inadvertently draw attention away from pressure-based mechanisms. Future iterations should therefore refine these elements to better align the technological interface with the targeted conceptual demands.

Survey feedback provided valuable insights into students' perceptions of the CirculaBody prototype, with a majority strongly agreeing that the tactile elements, such as buttons and tubes imitating circulatory functions, significantly aided their memory and understanding. The comparison between CirculaBody and traditional 2D diagrams revealed overwhelmingly positive feedback, with 80% strongly agreeing that the prototype enhanced their understanding. Moreover, a majority strongly agreed that the CirculaBody facilitated a better visualization of the human circulatory system compared to 2D diagrams in books or online resources.

The overall positive feedback underscores the prototype's preliminary impact in aiding students' comprehension of the circulatory system. In conclusion, the prototype testing demonstrated tangible improvements in test scores and received strong endorsement from students, affirming the CirculaBody's value as an interactive and impactful educational tool. Continuous refinement based on feedback is recommended to further enhance the prototype's effectiveness in science education.

Limitations

This study serves as a preliminary pilot evaluation of the CirculaBody prototype. A key limitation is the small sample size ($n = 15$)drawn from a single institution (SMK Ulu Tiram), which restricts the generalizability of the findings to the broader Malaysian secondary education context. In addition, the absence of a control group receiving instruction through conventional two-dimensional learning materials limits the ability to attribute the observed 6% improvement solely to the implementation of the prototype. Consequently, while the results offer initial evidence of student engagement and perceived instructional value, they should be interpreted with caution. Future research employing larger samples and randomized controlled designs is necessary to establish the statistical robustness and instructional efficacy of the CirculaBody prototype.

CONCLUSION

This study presents a preliminary evaluation of the CirculaBody prototype, developed to support Form 3 students' learning of heart anatomy and circulatory processes within the Maintenance and Continuity of Life theme in the Malaysian Science curriculum. The findings indicate that students experienced modest overall learning gains, with more pronounced improvements observed in questions requiring spatial and structural understanding of the heart. These outcomes suggest that physical and visual interaction with anatomical representations can support learning when abstract biological concepts pose cognitive challenges.

From a theoretical perspective, the results align with Experiential Learning Theory, which emphasizes learning through active engagement and manipulation of physical materials. The heart anatomy puzzle appears to reduce the cognitive demands associated with visualizing three-dimensional structures, thereby supporting students' representational competence at the macroscopic and structural levels. However, the comparatively weaker performance on items related to valve pressure mechanics indicates that not all conceptual demands are equally supported. This finding is consistent with Cognitive Load Theory, suggesting that dynamic simulations may inadvertently increase extraneous load if visual pacing or labelling is not carefully aligned with the targeted conceptual focus.

Based on the evidence generated in this pilot study, three implications for classroom practice can be highlighted. First, tactile and manipulable learning tools can be effectively integrated into lower secondary science classrooms to support students' understanding of spatially complex biological structures. Second, instructional design should deliberately differentiate between tools intended for structural visualization and those aimed at abstract process-based reasoning, such as pressure dynamics. Third, teachers may need to provide explicit scaffolding to guide students' attention when using simulations, ensuring that key theoretical mechanisms are not overshadowed by visual features.

While the findings offer initial insights into the pedagogical potential of the CirculaBody prototype, they should be interpreted within the study's limitations, including the small sample size and absence of a control group. Future research employing larger samples and controlled experimental designs is required to examine learning outcomes more rigorously and to explore how different representations can be optimally combined to support conceptual understanding in biology. Overall, this study contributes to ongoing discussions in science education on the role of hands-on and representational tools in facilitating meaningful learning at the secondary school level.

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