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Development and the Effectiveness of the *Hemomarvel* to Understand the Circulatory Blood System among Form 4 Students

Nur Zaidatul Ilma Purwadi[1], Adibah Abu Bakar[1], Ulya Fawaida[2], Syazwan Saidin[1*]

[1] Department of Biology, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia
[2] Department of Education, Institut Agama Islam Negeri Kudus, Indonesia

ABSTRACT

Game-based learning has emerged as a powerful pedagogical approach, offering engaging and interactive experiences that enhance students' understanding and retention of complex concepts. In the context of secondary school biology education, topics such as the circulatory system are often challenging for students to grasp using conventional methods. This study aimed to address this issue by developing *HemoMarvel*, an educational board game designed to facilitate learning of the circulatory system, and by evaluating its effectiveness in enhancing students' academic achievement compared to the conventional 'talk and chalk' method. The study employed the input–process–output (IPO) model to design and develop *HemoMarvel* systematically. A quasi-experimental research design was adopted to test its effectiveness. Two groups of students participated in the study: an experimental group (n=15), which utilized *HemoMarvel*, and a control group (n=15), which followed traditional instructional methods. Students' achievement was assessed through pre-and post-tests, and their scores were analyzed to evaluate the impact of the intervention. Results demonstrated that the mean post-test scores of students in the experimental group were significantly higher than those of the control group, with t (15) = 5.579, $p < 0.05$. These findings highlight the potential of game-based learning tools like *HemoMarvel* to foster deeper understanding and improve academic performance. The implications of this study extend to the practice of biology education in schools, providing an alternative teaching and learning tool that enhances comprehension and engagement. Future research should expand on these findings by exploring larger and more diverse student populations, incorporating qualitative assessments, and extending the study duration to evaluate the long-term effectiveness of *HemoMarvel.*

Keywords:
HemoMarvel; game-based learning;
circulatory blood system; teaching aid;
biology

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1. Introduction

Game-based learning (GBL) integrates instructional content into interactive game frameworks, offering learners an engaging and effective way to master complex subjects. This approach leverages intrinsic motivation, encouraging students to participate in tasks while building knowledge through

* *Corresponding author.*
E-mail address: syazwan@fsmt.upsi.edu.my

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experiential learning actively. Research consistently highlights the benefits of GBL, including fostering critical thinking, collaboration, and problem-solving skills, which are often underdeveloped in traditional teaching practices [1-3]. For instance, GBL provides immersive and challenging environments that enhance motivation and facilitate deeper understanding [4]. Furthermore, it promotes improved knowledge retention and creates a more enjoyable learning experience [5-7]. However, its adoption in educational settings remains uneven, as educators frequently face challenges such as limited resources, insufficient expertise in game design about its effectiveness [8]. Despite these barriers, interest in gamified teaching strategies continues to grow, particularly in STEM disciplines, where these tools have demonstrated significant potential in making abstract concepts more accessible and relatable [9,10].

The blood circulatory system, a foundational topic in biology, presents significant challenges for both teaching and learning. Understanding this subject requires visualizing dynamic processes such as blood movement, the roles of various vessels, and heart function concepts that are difficult to observe directly in a classroom setting. These abstract ideas often lead to misconceptions, such as confusion about blood flow direction or the roles of oxygenated and deoxygenated blood. Furthermore, misconceptions in biology are well-documented and are often attributed to the abstract nature of many scientific concepts [10-12]. Additionally, the lack of hands-on experiments or accurate models simulating the circulatory system leaves many students reliant on rote memorization rather than achieving meaningful understanding [13,14]. These challenges underscore the urgent need for innovative teaching tools that bridge the gap between theoretical knowledge and practical learning. In Malaysia, traditional teaching methods have long dominated classrooms, with the 'talk and chalk' approach relying heavily on direct instruction and routine memorization. Printed textbooks serve as the primary teaching resource, often making learning a more passive and repetitive process. While these methods offer structure and consistency, they may not fully accommodate diverse learning needs or effectively enhance student engagement. This is particularly problematic for complex topics like the circulatory system, which require active visualization and interactive learning to develop a deeper understanding. As education systems increasingly emphasize 21st-century skills and student-centered pedagogies, traditional methods face criticism for their inability to nurture creativity, critical thinking, and practical scientific knowledge [15]. In response to these challenges, this study explores the effectiveness of *HemoMarvel*, an innovative game-based teaching aid developed to enhance students' understanding of the circulatory system, specifically among Form 4 students. By integrating gamification with biology instruction, this research addresses the limitations of conventional teaching approaches, offering an alternative that emphasizes engagement, conceptual clarity, and experiential learning. Moreover, the findings from this study aim to provide valuable insights into innovative teaching practices, demonstrating the potential of game-based tools to transform teaching and learning session in biology education.

2. Methodology

A quasi-experimental research design was employed in this study, which aimed to enhance students' achievement in the topic of the circulatory blood system through the development of an educational board game. The study consisted of two phases: Phase 1 involved the creation of a board game, *HemoMarvel*, tailored to align with the secondary biology curriculum set by the Ministry of Education (MoE), Phase 2 evaluated the effectiveness of *HemoMarvel* in improving biology students' achievement. The conceptual framework of the study is illustrated in Figure 1.

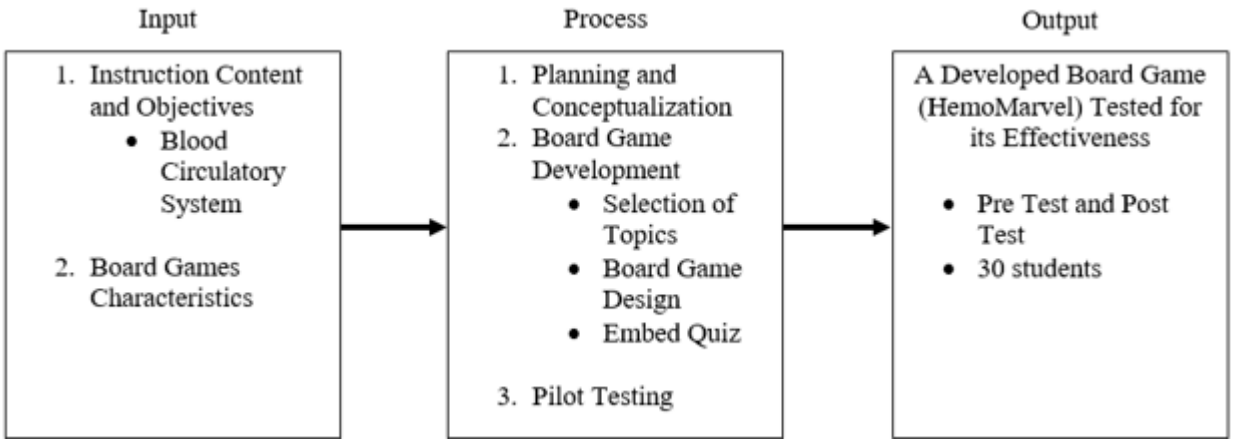

Fig. 1. Conceptual framework of the study

2.1 Step 1: Input: Instructional Content and Objectives

The instructional content is designed to promote active and collaborative learning while catering to the cognitive abilities of Form 4 students according to Vygotsky's Constructivism Theory and Piaget's Cognitive Development Theory. The *HemoMarvel* tool incorporates scaffolded and interactive activities, such as problem-solving tasks, visual aids, and real-world applications, to enhance student engagement and deepen their understanding of the circulatory blood system. The primary objectives of this phase are to develop *HemoMarvel* as an innovative educational tool, enhance students' comprehension and participation, and establish a basis for assessing its effectiveness in comparison to conventional teaching methods. It features engaging 3D pop-up models of the human circulatory system, including the heart, blood vessels, and blood components, allowing students to visualize and interact with the anatomical structures (Figure 2a). The game also incorporates detailed, color-coded diagrams to differentiate between open and closed circulatory systems across various species (Figure 2b). Additionally, *HemoMarvel* includes a set of scenario-based question cards that challenge students' critical thinking and application skills by presenting real-life problems related to the circulatory system (Figure 2c). The questions are accompanied by illustrative diagrams to support visual learning. Packaged in an attractive and organized box, the game provides a hands-on and collaborative learning experience that aligns with constructivist teaching principles, making complex biological concepts accessible and engaging for Form 4 students.

2.2 Step 2: Process: Planning and Conceptualization

The development of *HemoMarvel* began with planning and conceptualization, guided by Vygotsky's Constructivism Theory and Piaget's Cognitive Development Theory, to ensure the game aligns with the cognitive abilities of Form 4 students and promotes collaborative, scaffolded learning. Key learning objectives were identified from the Form 4 Biology curriculum, focusing on the circulatory blood system. The game design integrated visually engaging 3D pop-up models, scenario-based question cards, and interactive diagrams to facilitate conceptual understanding and critical thinking. During the development phase, prototypes were created and tested with students and teachers to refine the game mechanics, ensuring it provided an effective and enjoyable learning experience. The final product features user-friendly materials, vivid designs, and a professional, durable package, making it a practical and engaging tool for classroom use.

(a) (b)

(c)

Fig. 2. *HemoMarvel* board game (a) 3D pop-up models of the human circulatory system, (b) circulatory systems across various species, (c) scenario-based question cards of *HemoMarvel*

2.3 Step 3: Output: Evaluation of Developed Hemomarvel

A four-week quasi-experimental study was conducted with 30 Form 4 students at Sekolah Menengah Kebangsaan (SMK) Seri Mulia, Cheras, Kuala Lumpur, to evaluate the effectiveness of the *HemoMarvel* board game in teaching the circulatory system. Although the sample size was relatively small (n=30, with 15 students per group), it aligns with prior educational research utilizing quasi-experimental designs with controlled sample sizes [16-18]. The experimental group was taught using *HemoMarvel*, while the control group received instruction through the traditional talk and chalk method. Students were assigned based on their Biology test scores, ensuring homogeneity in prior academic performance to minimize bias as well as to control potential pre-existing differences between groups. Students in the experimental group engaged with *HemoMarvel* once per week for 20-minute sessions over four weeks. A teacher training session was conducted before the study to standardize instructional strategies, and a monitoring checklist ensured consistency in lesson delivery. Additionally, the pre-test and post-test instruments used to assess students' understanding of the circulatory system consisted of 20 multiple-choice questions and five structured questions. These questions, developed based on the Form 4 Biology syllabus, were validated through expert reviews and a pilot test to ensure content accuracy and reliability. The assessments measured conceptual understanding, application of knowledge to the circulatory system. Data obtained were

quantitatively analyzed using a paired sample t-test to compare students' performance before and after using the board game. This study was approved by the Ministry of Education Malaysia (Ref No: KPM.600-3/2/3-eras (19829)) and the Kuala Lumpur Federal Education Department (Ref No: JPWPKL.600-9/1/5Jld.14(12)). Furthermore, informed consent was obtained from all participating students, ensuring voluntary participation and compliance with ethical guidelines.

3. Results and Discussion

Table 1 summarizes the mean scores for the experimental group (M = 73.333, SD = 10.635) and the control group (M = 79.333, SD = 11.932). Statistical analysis of the pre-test scores between the two groups produced a t-value of -1.454 and a p-value of 0.157, indicating that $p > 0.05$. These results demonstrate no significant difference in the mean pre-test scores between the experimental and control groups before the implementation of *HemoMarvel*. Therefore, the null hypothesis (H_{o1}) cannot be rejected.

Table 1
Pre-test mean score for experimental and control group

Group	N	Mean	Standard deviation	t-value	Sig. (2-tailed)
Experimental	15	73.333	10.635	-1.454	0.157
Control	15	79.333	11.932		

Table 2 displays the mean scores for the experimental group, with a pre-test mean of M = 73.333 (SD = 10.635) and a post-test mean of M = 93.667 (SD = 4.419). A paired t-test analysis revealed a t-value of -8.994 and a p-value of 0.001, indicating statistical significance at $p < 0.05$. These results demonstrate a significant improvement in the mean scores from pre-test to post-test, leading to the rejection of the null hypothesis (H_{o3}). This suggests that the implementation of *HemoMarvel* had a positive and significant effect on students' performance, as reflected in the higher post-test scores.

Table 2
The experimental group's mean score for pre-test and post-test

Group	N	Mean	Standard deviation	t-value	Sig. (2-tailed)
Experimental					
Pre-test	15	73.333	10.635	-8.994	0.001
Post-test	15	93.667	4.419		

Table 3 presents the mean scores for the control group, with a pre-test mean of M = 79.333 (SD = 11.932) and a post-test mean of M = 82.333 (SD = 6.510). Statistical analysis yielded a t-value of -1.041 and a *p*-value of 0.298, indicating no statistical significance ($p > 0.05$). These findings suggest no significant difference between the pre-test and post-test scores for the control group. As a result, the null hypothesis cannot be rejected, implying that the conventional teaching method did not lead to a significant improvement in students' performance in this study.

Table 3
Control group's mean score for pre-test and post-test

Group Control	N	Mean	Standard deviation	t-value	Sig. (2-tailed)
Pre-test	15	79.333	11.932	-1.041	0.298
Post-test	15	82.333	6.510		

Table 4 provides the mean post-test scores for the treatment group (M = 93.667, SD = 4.419) and the control group (M = 82.333, SD = 6.510). Statistical analysis yielded a t-value of 5.579 and a p-value of 0.001, indicating significance at $p < 0.05$. These findings reveal a significant difference in post-test scores between the treatment and control groups. Consequently, the null hypothesis (H_{o2}), which posits no significant difference in post-test performance between the two groups, is rejected.

Table 4
Post-test mean score for experimental and control group

Group	N	Mean	Standard deviation	t-value	Sig. (2-tailed)
Experimental	15	93.667	4.419	5.579	0.001
Control	15	82.333	6.510		

The findings of this study demonstrate the effectiveness of the *HemoMarvel* board game in improving students' understanding of the circulatory system. The experimental group showed a significant increase in mean scores from the pre-test (M = 73.333, SD = 10.635) to the post-test (M = 93.667, SD = 4.419), with a t-value of -8.994 and a *p*-value of 0.001, indicating a substantial improvement in achievement. In contrast, the control group, which followed the conventional teaching method, exhibited only a slight increase in mean scores from the pre-test (M = 79.333, SD = 11.932) to the post-test (M = 82.333, SD = 6.510), which was not statistically significant ($p > 0.05$). The performance of the experimental group highlights the potential of game-based learning tools like *HemoMarvel* to make abstract and complex biological concepts more accessible and engaging for students. These results are consistent with prior studies that advocate for the use of interactive and game-based learning in education. For instance, Adeyele [19] found that multimedia-based approaches lead to higher student achievement compared to traditional methods, while Bayeck [20] emphasized the ability of board games to foster a deeper understanding of complex scientific concepts. Similarly, Lasala [21] highlighted the pedagogical advantages of game-based learning, and Punyasettro and Yasri [22] demonstrated the efficacy of the VERT card game in enhancing students' comprehension of chordate taxonomy. A comprehensive meta-analysis of game-based learning methods revealed a substantial positive effect on students' academic achievement across various disciplines and educational levels [23]. This broad analysis supports the overall effectiveness of board games in educational settings.

Our findings support the hypothesis and demonstrate the educational value of incorporating game-based learning strategies in secondary school biology. The significant difference in post-test performance between the experimental and control groups underscores the transformative impact of interactive tools on student learning outcomes. By providing both educators and students with an engaging and effective method to tackle complex biological concepts, this study contributes to the growing body of research advocating for innovative approaches in biology education. However, some limitations should be noted. The relatively small sample size may limit the generalizability of the findings, and the short duration of the study does not allow for assessing long-term knowledge retention. Additionally, the reliance on test scores as the primary measure of learning outcomes does not capture qualitative aspects such as student engagement, motivation, or deeper conceptual understanding. Variability in teacher delivery, despite structured lesson plans, may also introduce minor inconsistencies in instructional methods. While the results indicate a positive impact of *HemoMarvel*, we acknowledge that this study provides preliminary evidence rather than definitive proof of its effectiveness. Future research should expand on these findings by exploring larger and more diverse student populations, incorporating qualitative assessments, and extending the study duration to evaluate the long-term effectiveness of game-based learning tools like *HemoMarve*l.

4. Conclusion

In conclusion, this study investigated the effectiveness of the *HemoMarvel* board game as a game-based learning tool for teaching the circulatory system to secondary school students. The results demonstrated that students who engaged with *HemoMarvel* showed improved academic performance compared to those taught using traditional methods. HemoMarvel offers a highly interactive and immersive learning experience, enabling students to actively visualize and interact with complex biological concepts. The structured gameplay promotes active participation, and conceptual comprehension, which are critical elements for successful biology education. By incorporating board games like *HemoMarvel* into classroom instruction, teachers can enrich teaching and learning session, enhance student engagement, and facilitate a deeper understanding of challenging biological concepts.

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