

Effects of Inquiry-Based Learning Using Minecraft Education on Students' Achievement and Motivation in Transport in Living Things

Tan Wee Ling*

School of Educational Studies, Universiti Sains Malaysia, 11800,
Pulau Pinang, Malaysia

*corresponding author: tanweeling@usm.my

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Abstract

Studying biology, the transport in living things or the heart anatomy and blood circulation in the heart is the challenging topic for students to comprehend because of the complication of the physiological processes involved. This study examined the effect of an inquiry-based learning strategy by using Minecraft Education as a digital platform for conceptual modeling on the academic performance and motivation of secondary school students in the theme of Transport in Living Things. A quasi-experiment was employed with a sample of 60 secondary school students (30 experimental, 30 control). The quantitative data were obtained from academic performance tests and motivation surveys and analysed using ANCOVA ($p < .05$). The results displayed a significant increment in academic achievement, $F(1, 57) = 5.315$, $p = .025$, $\eta^2p = .085$ and student motivation, $F(1, 57) = 7.732$, $p = .007$, $\eta^2p = .119$, in the experimental group. The integration of IBL and ME is effective to improve cognitive and psychological learning output in biology education. This study presents an innovation approach to develop the creative instruction for teaching complex biological concepts in secondary schools.

Keywords: Inquiry-Based Learning, Minecraft Education, Transport in Living Things, Blood Circulation, Academic Performance, Student Motivation, Biology Education

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Introduction

A fundamental science, biology education is designed to help students in comprehending the relationship between living organisms and their surroundings. The topic of Transport in Living Things, which includes blood circulation, the structure of the heart, and its function, is critical in the secondary school biology curriculum, as it provides essential knowledge about human physiology and health (Campbell & Reece, 2020). However, the abstract concepts of blood circulation, heart structure and function, students' inability to directly observe internal physiological mechanisms provide obstacles in the teaching and learning of these concepts (Michael, 2007; Modell, 2000).

Students have to design their own mental models of processes on the circulatory system with its complex network of blood vessels, the mechanical functioning of the heart and the continuous flow of blood throughout the body based on their own understanding. Static textbook diagrams and vocal explanations in the traditional teaching approach are always difficult in helping students visualize the correct concept knowledge in dynamic 3D processes (Treagust & Duit, 2008). This scenario always created misconceptions about blood circulation, heart function and the structure-function relationship in the cardiovascular system (Bahar et al., 1999; Reiss & Tunnicliffe, 2001).

To address these problems, the Inquiry-Based Learning (IBL) pedagogical approach has been proposed in science education. IBL supports a student-centred approach (Piaget, 1970; Vygotsky, 1978). In IBL, students actively construct knowledge via questioning, exploration, investigation and drawing conclusions based on constructivist learning theories (Piaget, 1970; Vygotsky, 1978). The potential of IBL in student achievement, increasing critical thinking skills, and elevating science learning engagement was highly proven (Banchi & Bell, 2008; Minner et al., 2010). Even though IBL demonstrates the beneficial framework for learning, the abstract concepts explanation in blood circulation is still limited without appropriate visualisation tools (Lahlali et al., 2023; Antonio & Prudente, 2024).

The digital technologies' advancement, such as game-based learning environments and virtual simulations, unlocked a new approach in solving the visualisation problems in biology teaching. In providing interactively explore, manipulation and visualisation complex biological systems (Squire, 2011; Watson et al., 2011; Zeng et al., 2024), ME has been identified as a flexible three-dimensional (3D) virtual learning platform for creating immersive environments where students can build, explore and visualise scientific topics (Short, 2012; Slattery et al., 2025).

The ME provides the safe virtual platform for creating and visualising 3D models of abstract biological systems and simulating physiological processes (Nkadimeng & Ankiewicz, 2022; Darmawan et al., 2025). The ME's building blocks enable the students to build detailed models of the heart, blood vessels and circulatory pathways. The engaging features in ME empower students to actively craft blood flow and cardiac function models (Slattery et al., 2025; Kersánszki et al., 2024). The construction and manipulation of visual representations in ME empowers students to craft more accurate mental models of complicated biological systems (Adaayah & Aznam, 2024; Babazadeh & Ferreras, 2026) and reduce misconception.

Despite the potential offered by ME, research on its use in biology education, particularly in teaching transport in living organisms, remains limited. Most of the research primarily focuses on the application of Minecraft in fields such as mathematics, history, and language arts, with limited studies in biology education (Darmawan et al., 2025; Kersánszki et al., 2024). Moreover, the integration of IBL and ME on cognitive and affective learning in biology has not been examined in studies (Creswell & Creswell, 2023; Premthaisong & Srisawasdi, 2024). The study aims to fill the gap by examining the impact of IBL integrated with ME on students' achievement and motivation in the content of Transport in Living Things, including blood circulation, heart structure, and heart function. The study utilised a quantitative approach (Fraenkel et al., 2023) to study the effect of this integrated on resulted learning and motivation by answering the following research questions.

1. Is there a significant difference in academic achievement in Transport in Living Things between students who use IBL integrated with ME and students who use traditional methods, controlling for pretest achievement scores?
- 2: Is there a significant difference in students' motivation towards learning biology between students who use IBL integrated with ME and students who utilise conventional methods after controlling for the pre-motivation scores?

Literature Review

Problems of Teaching Transport in Living Organisms

In biology education, students are required to study the structural components and how these components interact together to maintain the physiological function of the living organism as well as the interaction between the living organisms. Among all the themes, the circulatory system theme appeared to be the most difficult theme to be learned due to the complexity, dynamism and challenge in visualizing the blood circulation during contraction and relaxation of heart structure (Gusmalini et al., 2020). Research regularly identifies the students' hardship with the cardiovascular system. Bahar et al. (1999) found misconceptions such as the circulation of blood in the heart, blood not being continuously circulated, oxygenation in the lungs and pulmonary and systemic circulation. Gusmalini et al. (2020) reported recurrent misconceptions, including the belief that arteries always carry oxygenated blood and veins carry deoxygenated blood (except for pulmonary circulation), confusion about the function of the heart valves, and misunderstanding of blood pressure. Tekkaya (2002) similarly disclosed that students had difficulties in differentiating the paths of oxygenated and deoxygenated blood and the consecutive contractions of heart chambers. The abstract nature of physiological processes also contributes to the hardship in understanding content knowledge. Internal processes, in contrast to external anatomical features, are not open to direct observation and only can be inferred using diagrams, models and animations (Treagust & Duit, 2008). However, static two-dimensional representations are often insufficient in conveying the dynamic, 3D nature of circulation leading to incomplete or misleading comprehension (Adaayah & Aznam, 2024). These misconceptions are the biggest obstacle to teaching and they suggest a need for better teaching methods.

Teaching Strategies: Inquiry Learning, Visuals and the New Technology.

Inquiry Learning in Science Teaching

Inquiry-based learning (IBL) is broadly recognized as a productive teaching strategy that is grounded in constructivist learning theories. In IBL, students actively participate in asking questions, exploring, collecting and analysing data and developing evidence-

based explanations (Banchi & Bell, 2008; National Research Council, 2000). The execution of IBL varies depending on the level of direction provided. There are four levels of direction in IBL, namely confirmation, structured, guided, and open inquiry (Banchi and Bell, 2008). The guided inquiry is most suited for secondary students learning complicated topics such as circulation. Hence, IBL was proven to have a strong track of the highest record of research funding. Minner et al. (2010) analysed 138 research studies and demonstrated that the inquiry-based training was much more productive than the traditional approach, especially in learning science subjects. Based on the systematic review of 35 research studies from 2010 to 2024 by Gomez (2025), IBL was found to enhance achievement and engagement continually with a large effect size (Cohen's $d=0.72$). This is due to the IBL being aligned with self-directed, intuitive knowledge acquisition driven by curiosity rather than formal instruction via exploration and discovery. Additionally, the meta-analysis done by Antonio and Prudente (2024) on 47 IBL trials reported statistically significant gains in higher-order thinking skills ($g = 0.68$, 95% CI [0.54, 0.82]) such as critical thinking, problem-solving and analytical skills to understand complicated biological concepts. Besides that, 64 papers reviewed by Suryati et al. (2024) reported that the integration of constructivist notions with the techniques of scientific inquiry in IBL in learning chemistry and biology subjects were the most useful. Just 34% of the studies had true inquiry, which highlights the need for implementation.

Minecraft Education (ME) as a Tool for Visualisation and New Technology

ME is a fabulous tool for game-based learning that creates a fun, interactive platform. The 3D block-based architecture platform promotes self-directed learning, creativity, collaboration and problem-solving as students build, explore and design virtual worlds, which convert the abstract concepts more concretely (Nkadimeng & Ankiewicz, 2022). Minecraft is widely applied in science education in explaining model phenomena, reproducing experiments and visualise complex systems (Nkadimeng & Ankiewicz, 2022). For example, Nkadimeng and Ankiewicz (2022) demonstrated the potential of ME in teaching atomic structure. The finding proved that 3D visualisation in ME helped students to understand the abstract atomic structure topics that were difficult to learn through traditional instruction, resulting in significant improvement in accomplishment ($p < .05$, $d = 0.61$) and motivation. Minecraft provides excellent effects on visual and interactive representations. Kersánszki et al. (2024) used Minecraft in teaching 89 students in the renewable energy topic. The study reported significant positive impacts on conceptual knowledge ($g = 0.73$) and engagement. The potential of ME on academic, cognitive and motivational factors is fully supported by Slattery et al. (2025). Darmawan et al. (2025) also demonstrated that the use of ME can increase conceptual understanding and collaboration in biology teaching and facilitate peer learning and knowledge development.

IBL integration with ME creates powerful meaning learning environments that solve the pedagogical and representational challenges in teaching abstract concepts. The positive integration of technology in inquiry methodologies was considered beneficial. Premthaisong and Srisawasdi (2024) demonstrated that technology-integrated active inquiry learning produces meaningful changes in students' motivation in learning science. Rustad and Andersen (2022) revealed that inquiry-based collaborative projects using Minecraft and explained that the game offers an open-ended platform for 21-st century skills ($p < .05$). This supports the premise that the open-ended nature of the game was favorable to inquiry approaches in which students

could investigate, experiment and create knowledge through hands-on activities. However, there are limited studies on the integration of IBL and ME in biology teaching. Researchers have primarily concentrated on individual techniques or integration in non-biological areas. Teaching difficult concepts in biology, such as blood circulation and heart function, holds immense value.

Motivation for Learning Science

Student motivation is the main indicator of learning outcomes and engagement. The motivation determines the students' participation in academic activities and amount of invested effort in study (Ryan & Deci, 2000). The Self-Determination Theory (SDT) framework is used to explain the intrinsic motivation. The SDT suggests that intrinsic motivation is increased when three basic psychological needs are satisfied: autonomy (volition and choice), competence (feeling accomplished) and relatedness (connection to others) (Ryan & Deci, 2000). Educational interventions that show the potential to meet these criteria are likely to stimulate motivation. Kadiresan (2021) performed the research on factors influencing the motivation of undergraduate. The author found intrinsic motivation, self-efficacy, and perceived learning value to be the strongest indicators of success and engagement. The study emphasizes that designing learning environments is important in promoting competence and helping students understand the relevance of learning.

This study has proven that technology-assisted learning is highly motivating in research (Lahlali et al., 2023). In chemistry education, virtual environments and playable prototype platforms in ME were found to significantly improve motivation, engagement, and achievement compared to traditional teaching methods (Lahlali et al., 2023, $p < .05$). This highlights that the interactive and visual nature of the simulations boosts the students' engagement and involvement. The results indicated that Minecraft fostered intrinsic motivation via self-directed learning in discovery, creative exploration, and opportunities for collaborative learning. Additionally, in the Malaysian context, Kadiresan (2021) also agreed that teaching methods and learning environment have the significant impact on student motivation. Hence, the innovative teaching approaches with technology and active directed learning are needed to boost students' motivation in learning, especially biology abstract concepts.

Research on IBL, ME and students' motivation in science learning has been increasing; however the gaps still exist that this study aims to bridge. There are limited studies using the ME program in biology education, especially in teaching human physiology. To date, most of the research has focused on the application of Minecraft in other subjects or in teaching basic biological concepts such as cells and ecosystems with little focus on complex systems such as blood circulation. Second, the integration of IBL and ME has not been widely studied, especially in the secondary school biology context. This study aims to fill in these gaps by investigating the effect of IBL with ME on secondary school students' achievement and motivation in learning blood circulation, heart shape and heart function among Malaysian secondary school students.

Methodology

Research Design

This study applied a quasi-experimental research design with a pretest-posttest control group design to study the influence of IBL integrated with ME on students' achievement and motivation in Transport in Living Things. The quasi-experimental method was selected over the actual experimental design, as the random assignment was impossible in the natural classroom setting with the use of intact classes (Fraenkel et al., 2023; Creswell & Creswell, 2023). There are two groups in the study: the experimental group with IBL instruction integrated with ME and the control group with conventional teaching methods.

Participants and Sampling

The 60 secondary school students were purposively sampled, with the criteria of currently enrolled in the biology subject and having not studied Transport in Living Things. 30 in the experimental and 30 in the control group with the same demographic characteristics and previous academic achievement, taught by the same teacher to control for teacher effects and were given instruction on the same material for the same amount of time.

Instruments

Achievement Test

The Transport in Living Things Achievement Test (TLTAT) was developed to measure students' achievement. TLTAT consisted of four subtopics, like blood composition and functions, blood circulation system, heart structure and heart function and cardiac cycle. The test was divided into two sections; Section A consisted of 20 multiple-choice questions (20 marks) and Section B consisted of 4 structured questions (30 marks) for a total of 50 marks. The test was developed to measure cognitive levels C1 to C4 according to the revised Bloom's Taxonomy (Anderson & Krathwohl, 2001). Pre-existing differences between the groups were controlled by including pretest scores as a covariate in an ANCOVA analysis. Content validity was obtained through expert review by two biology education specialists and one measurement expert. They assessed items on a 4-point scale, and the Content Validity Ratio (CVR) was calculated using Lawshe's (1975) formula. Items with $CVR \geq 0.00$ for $N = 2$ experts were kept (Ayre & Scally, 2014). Reliability was examined in a pilot study with 30 students, producing a Cronbach's alpha of $\alpha = 0.82$, which is above the minimum acceptable level of 0.70 (Pallant, 2020). The items also had good item quality, ranging from 0.35 to 0.68 in item difficulty indices (p) and 0.32 to 0.71 in discrimination indices (d).

Motivation Questionnaire

The Students' Motivation Toward Science Learning (SMTSL) questionnaire, adapted from Tuan et al. (2005), was used to measure the students' motivation with self-efficacy (6 items), value of learning science (6 items), and learning environment stimulation (6 items). The 5-point Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree) in SMTSL was administered as both a pretest and a posttest, whereby pretest scores acted as covariates. Content validity was conducted by two biology education experts and one educational psychology expert, with all 18 items achieving acceptable Content Validity Ratio values ($CVR \geq 0.00$). The pilot study with 30 students had the reliability testing and resulted the Cronbach's alpha coefficients of $\alpha = 0.87$ for Self-Efficacy, $\alpha = 0.83$ for Value of Learning Science, $\alpha = 0.81$ for Learning Environment Stimulation,

and $\alpha = 0.84$ for the overall SMTSL, all exceeding the minimum acceptable threshold of 0.70 (Pallant, 2020).

Intervention

The experimental group was taught by IBL with the integration of ME for four 90-minute sessions in four weeks. The IBL framework was adapted from (Duran & Duran, 2004). The intervention was conducted in five phases. In Phase 1, the orientation activity links prior knowledge to a real-world scenario. In Phase 2, the questioning activity was conducted for students to create inquiry questions in small groups. In Phase 3, the exploration activity using ME to build 3D models of blood components, circulatory systems, heart structures and simulate cardiac cycles over the four sessions was conducted. In Phase 4, the analysis activity involved diagram drawing, worksheet completion and group discussions and the last phase is the evaluation with self-assessment and reflection. ME was used as a conceptual visualisation tool, which enabled students to actively create biological structures and processes representations (Nkadimeng & Ankiewicz, 2022) with worksheets and guided questions. The control group experienced traditional teacher-centered training in the same five sessions (90 minutes each) using lectures, textbook diagrams and anatomical model demonstrations, note-taking, and worksheet activities, but no digital simulations. The same teacher taught both groups for the same amount of instructional time (total 360 minutes) and the same topic was covered according to curriculum criteria to control for teacher effects.

Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics version 26.0. The analysis involved descriptive statistics (mean, standard deviation, minimum, and maximum) to calculate pretest and posttest scores of both achievement and motivation for both groups. This provided an initial overview of the data distribution and group characteristics. One-way Analysis of Covariance (ANCOVA) was used to test the two research questions. The ANCOVA was selected because it allows for the control of pre-existing differences between groups by using pretest scores as covariates, thereby increasing the precision of the comparison between groups (Field, 2018; Pallant, 2020). The significance level was set at $p < 0.05$, and effect sizes were reported using partial eta squared (η^2p). Effect sizes were interpreted using Cohen's (2013) guidelines: small ($\eta^2p = 0.01$), medium ($\eta^2p = 0.06$), and large ($\eta^2p = 0.14$).

Results and Discussion

Descriptive Statistics

Achievement Test Scores

Table 1 displays the descriptive statistics for achievement test scores for both groups at pretest and posttest stages.

Table 1: Descriptive Statistics for Achievement Test Scores

Group	Test	N	Mean	SD	Minimum	Maximum
Experimental	Pretest	30	24.33	5.82	14	36
Experimental	Posttest	30	38.47	6.21	26	49
Control	Pretest	30	23.87	5.45	13	35
Control	Posttest	30	34.20	6.08	22	46

The mean increase of the experimental group was 14.14 points from pretest (M=24.33, SD=5.82) to posttest (M=38.47, SD=6.21) and mean increase of the control group was 10.33 points from pretest (M=23.87, SD=5.45) to posttest (M=34.20, SD=6.08). The experimental group outperformed the control group. At pretest, the mean scores for the experimental is 24.33 and control groups is 23.87, with a difference of 0.46 points, revealing that the groups were initially equivalent in achievement levels. However, the experimental group scored 4.27 points higher than the control group at posttest (Experimental = 38.47, Control = 34.20).

Motivation Scores

Table 2 displays the descriptive statistics for motivation scores for both groups.

Table 2: Descriptive Statistics for Motivation Scores

Group	Test	N	Mean	SD	Minimum	Maximum
Experimental	Pretest	30	56.40	11.85	35	78
Experimental	Posttest	30	68.23	12.47	45	87
Control	Pretest	30	55.17	10.92	34	76
Control	Posttest	30	58.90	11.28	38	79

The experimental group (pretest M = 56.40, SD = 11.85; posttest M = 68.23, SD = 12.47) had a significant increase in motivation, with an average increase of 11.83 points. However, the control group showed a smaller increase from the pretest (M = 55.17, SD = 10.92) to the posttest (M = 58.90, SD = 11.28) with only 3.73 points of mean gain. Pretest motivation scores were comparable across groups (Experimental = 56.40 and Control = 55.17) with a difference of 1.23 points. However, the experimental group had a significantly higher score than the control group on posttest (Experimental = 68.23, Control = 58.90). The difference is 9.33 points.

Table 3 indicates that all the three dimensions of motivation increased in the experimental group. The highest increase was found in Learning Environment Stimulation (+4.27), followed by Self-Efficacy (+3.93) and Value of Learning Science (+3.63). This trend suggests that the IBL integrated Minecraft intervention was successful in creating an engaging and exciting learning environment.

Table 3: Descriptive Statistics for Motivation by Dimension

Group	Dimension	Pretest Mean	Posttest Mean	Gain
Experimental	Self-Efficacy	19.20	23.13	+3.93
Experimental	Value of Learning	18.67	22.30	+3.63
Experimental	Environment Stimulation	18.53	22.80	+4.27
Control	Self-Efficacy	18.87	20.67	+1.80
Control	Value of Learning	18.43	19.50	+1.07
Control	Environment Stimulation	17.87	18.73	+0.86

Hypothesis Testing

The first research question was to examine whether there was a significant difference in academic achievement between the experimental and control groups after controlling for pretest scores. A posttest achievement was used as a dependent

variable, a group as an independent variable, and a pretest achievement as a covariate in the ANCOVA. The results are presented in Table 4.

Table 4: ANCOVA Results for Achievement Test

Source	Type III Sum of Squares	df	Mean Square	F	p	Partial η^2
Pretest	2847.36	1	2847.36	74.52	<.001	-
Group	203.47	1	203.47	5.315	.025	.085
Error	2179.84	57	38.24	-	-	-

The ANCOVA analysis indicated a significant difference in achievement between the experimental and control groups controlling for pretest scores, $F(1, 57) = 5.315$, $p = .025$, $\eta^2p = .085$. According to Cohen’s (2013) guidelines, a partial eta squared of .085 is a medium effect. The experimental group adjusted mean difference was 3.57 points. When controlling for pretest achievement, there was a significant difference in academic accomplishment in Transport in Living Things between students exposed to IBL combined with ME and students exposed to conventional education. The experimental group had a medium effect size compared to the control group.

The second research question asked whether there was a statistically significant difference in student motivation between the experimental and control groups after controlling for pretest motivation levels. Posttest motivation was the dependent variable in the analysis of covariance (ANCOVA), whereas group was the independent variable and pretest motivation was the covariate. The results are shown in Table 5.

Table 5: ANCOVA Results for Motivation

Source	Type III Sum of Squares	df	Mean Square	F	p	Partial η^2
Pretest	9847.52	1	9847.52	287.34	<.001	-
Group	264.83	1	264.83	7.732	.007	.119
Error	1951.47	57	34.24	-	-	-

ANCOVA results displayed a significant difference in motivation between the experimental and control groups after controlling for pretest scores, $F(1, 57) = 7.732$, $p = .007$, $\eta^2p = .119$. This partial eta squared of .119 is a medium-big effect size. The adjusted means differ by 8.57 points in favour of the experimental group. After controlling for pretest motivation, students with IBL integrated with ME had a significantly greater difference in motivation toward learning biology than students with conventional teaching. There was significantly increased motivation for the experimental group compared to the control group with a medium to large effect size.

The effect size for motivation ($\eta^2p = .119$) was larger than the effect size for achievement ($\eta^2p = .085$), showing that the IBL-Minecraft intervention had a greater impact on the affective domain compared to the cognitive domain.

Achievement Outcomes

The findings provide empirical proof that IBL integrated with ME significantly enhances student achievement in the topic of Transport in Living Things compared to conventional teaching methods. The experimental group exceeded the control group with a statistically significant difference ($p = .025$) and a medium effect size ($\eta^2p = .085$), supporting the effectiveness of IBL with ME-integrated pedagogical approach. This study's findings are consistent with Gomez (2025) that IBL improved student achievement (Cohen's $d = 0.72$) across multiple studies. The IBL is potential also being proven in enhancing students' higher-order thinking skills in science ($g = 0.68$) (Antonio and Prudente, 2024). This study's findings extend the potential of IBL by demonstrating its effectiveness specifically for teaching complex biological concepts, such as blood circulation and heart function. Minecraft is especially useful for teaching blood circulation and heart structure because of its visualisation capability and making abstract physiological processes tangible (Babazadeh & Ferreras, 2026). This active crafting in ME is in line with the research on multiple representations, which prompts the students to create and manipulate their own representations rather than passively viewing the static illustration by teachers (Aduyah & Aznam, 2024).

The IBL approach's feature contributes to positive achievement outcomes. First, the inquiry framework enables students to actively construct the knowledge rather than passively accept the information. The questioning, exploration, and analysis phases in IBL actively develop concepts, make connections, and deepen understanding (Banchi & Bell, 2008). This active engagement is parallel with constructivist learning theories that focus on the concept that understanding can be built through one's own experience and reflection (Piaget, 1970; Vygotsky, 1978). Second, the ME provided powerful visualization tools that helped students visualize the abstract circulatory system concepts. The building of a 3D heart and simulating a blood flow model in the 3D heart inside the ME supported the development of accurate mental models, which is important for comprehending the complex biological systems (Aduyah & Aznam, 2024). The students' achievement in this study is supported by the studies by Nkadimeng and Ankiewicz (2022) using ME to teach atomic structure ($d = 0.61$), and by Kersánszki et al. (2024) in their research on Minecraft in STEAM education ($g = 0.73$). These consistent findings across different subject areas and concepts strongly support ME being widely applied as a visualization tool in science education.

Motivation Outcomes

The study found that IBL integrated with ME had a significant positive effect on students' motivation. The motivation of the experimental group was significantly higher than the motivation of the control group ($p = .007$) with a medium to large effect size ($\eta^2p = .119$). The effect size for motivation was greater than for achievement, indicating that the intervention had a greater effect on the emotive domain than the cognitive domain. These findings are aligned with other scholars' findings on technology-enhanced learning and student motivation. Interactive simulations were found to significantly increase students' motivation in chemistry education (Lahlali et al., 2023; $p < .05$) and ME was identified as providing high impact on intrinsic motivation (Babazadeh & Ferreras, 2026; $d = 0.82$). The current finding adds to previous findings

by demonstrating the same motivational benefits in the context of biology instruction in Malaysian secondary schools.

The motivational boost can be explained by the SDT framework (Ryan & Deci, 2000) which explains that when autonomy, competence and relatedness are met, intrinsic motivation will be achieved. The autonomy perspective acquired in this IBL-integrated ME enabled students to pursue their questions, determine how to explore them and build their own understanding. In the Minecraft environment, students had choices in how they crafted the heart models and explored topics, enabling them to have the sense of autonomy over their learning that is often missed in traditional teaching approaches (Kadiresan (2021). In the competence aspect, the Minecraft exercises and structured IBL five phases in the study enabled students to experience success with complex concepts as well as increased student confidence in their learning ability to understand difficult information, which was seen when heart models were constructed and blood flow was visualized. The increment in Self-Efficacy dimension (+3.93) fully supports this conclusion. Finally, the collaborative and teamwork nature of both IBL and Minecraft activities fostered social relationships among students. The collaborative work on questions, models and sharing of findings created chances for peer connection and support, fulfilling the need for relatedness (Li et al., 2024).

The Learning Environment Stimulation dimension, with a score of +4.27, shows the greatest improvement in this study. It indicated that IBL-integrated Minecraft strategy resulted in an engaging and stimulating learning environment. This finding is consistent with studies that game-based learning environments can promote student engagement and interest (Squire, 2011; Watson et al., 2011). The Minecraft activities were highly engaging and hands-on in the safe virtual platform which, when combined with the inquiry framework, offered an active learning experience. The results strongly supported that the intervention was effective in enhancing the cognitive and affective outcomes, but especially in the development of positive attitudes towards learning biology. This is important as motivation is a strong indicator of persistence, long-term learning, future course and career selection (Ryan & Deci, 2000). Motivated students are more likely to engage well in learning and gaining a good achievement in the future. The increment in the Value of Learning Science dimension (+3.63) demonstrated that the students in the experimental group had a greater awareness of the importance and relevance of learning about blood circulation and heart function and creating meaningful learning and transferring knowledge to real-world contexts (Magwilang, 2016).

Conclusion

The aim of this study was to analyse the effect of IBL integrated with ME on students' achievement and motivation in Transport in Living Things, blood circulation, heart structure and heart function. The results indicate that the combination of IBL and ME constitutes a successful pedagogical approach for teaching complex biological concepts. The framework of inquiry engaged students in active knowledge construction, while ME provided powerful visualisation tools that made abstract physiological processes concrete and accessible. The combination addressed both cognitive and affective learning outcomes and had particularly high effects on students' motivation. The study contributes to the growing body of research on technology-

enhanced inquiry-based science education by empirically validating the combination of game-based learning platforms with solid pedagogical frameworks, filling a gap in the field of ME biology. The findings of this study have implications for teachers, curriculum developers and policymakers who are interested in improving biology education through creative teaching practices. In conclusion, IBL with ME is a promising approach to improving student learning in biology through active inquiry and interactive visualisation to help students overcome difficulties learning abstract biological concepts and develop positive attitudes toward science learning. Future research should investigate long-term effects, generalisation to other topics and contexts, and specific mechanisms through which it helps learning.

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