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IMPACT OF AI ROBOT IMAGE RECOGNITION TECHNOLOGY ON IMPROVING STUDENTS' CONCEPTUAL UNDERSTANDING OF CELL DIVISION AND SCIENCE LEARNING MOTIVATION

Pei-Yu Chen,
Yuan-Chen Liu

Abstract. *This study explored the integration of neural networks and artificial intelligence in image recognition for object identification. The aim was to enhance students' learning experiences through a "Learning by Teaching" approach, in which students act as instructors to train AI robots in recognizing objects. This research specifically focused on the cell division unit in the first grade of lower-secondary school. This study employed a quasi-experimental research design involving four seventh-grade classes in a rural lower-secondary school. The experimental group (41 students) were taught via an AI robot image recognition technology, whereas the control group (40 students) were taught via a more conventional textbook-centered approach. The research followed a pre-test design, with three classes lasting 45 min each, totaling 135 min of teaching time over two weeks. Evaluation tools include the "Cell Division Two Stage Diagnostic Test" and the "Science Learning Motivation Scale." The results indicate that learning through teaching AI robot image recognition technology is more effective than textbook learning in enhancing students' comprehension of the "cell division" concept and boosting motivation to learn science.*

Keywords: *artificial intelligence, image recognition technology, cell division, science learning motivation, learning by teaching*

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Introduction

In the genomic era, prevailing scientific advancements revolve primarily around molecular genetics. The term "gene" has gained widespread popularity through media channels, permeating various facets of our daily existence, from healthcare and agriculture to technology. Simultaneously, this surge in genetic knowledge has led to a host of ethical concerns. Thus, it is imperative for students not to perceive genetic information as an enigmatic "black box" but to grasp the fundamental principles of genetics. This understanding empowers individuals to make informed choices in various aspects of life (Nowgen, 2012). Hence, acquiring knowledge in genetics is deemed a crucial component of scientific literacy. Genetics plays a pivotal role in nurturing citizens' scientific thinking and aiding them in making judicious decisions during the decision-making process (Boerwinkel et al., 2017; Haskel-Ittah et al., 2020; Stern & Kampourakis, 2017). With the growing significance of genetics in our daily lives, there should be a broader dissemination of genetic literacy (Kawasaki et al., 2021). Hence, there is an imminent need for widespread genetic literacy among the public. Without a comprehensive grasp of fundamental genetic concepts, citizens may struggle to comprehend aspects such as genetic screening, stem cell research, genetically modified organisms, and genetic modification. This lack of understanding poses a barrier to making well-informed decisions, especially in areas such as food choices. Urgent efforts are required to ensure that students attain scientific literacy in the essential principles of molecular genetics (Aldahmash et al., 2012; Kılıç & Sağlam, 2014; Knippels et al., 2005).

Given this perspective, numerous countries have integrated the fundamental concepts of molecular genetics into the compulsory education curriculum for lower-secondary. According to Okolo and Oluwasegun (2020), "Cell division" serves as the foundational knowledge for students to comprehend genetics. Therefore, for students aspiring to engage with molecular genetics, grasp its essential concepts, and attain genetic literacy, mastering the subject of "cell division" is a prerequisite (Dikmenli, 2010). Recognized as

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a fundamental biological principle crucial for understanding genetic inheritance (Williams et al., 2012), cell division occupies a pivotal place in both the science and biology curriculum. It stands as one of the core ideas in the life sciences, as outlined in the Next Generation Science Standards (NRC, 2013).

Many studies have emphasized the intricacy and abstraction associated with the concept of cell division in the field of biology. This complexity frequently poses challenges for students in K-12 education, hindering their ability to comprehend and proficiently grasp this intricate biological concept (Cimer, 2012; Etobro & Fabinu, 2017; Fauzi & Mitalistiani, 2018; Gungor & Ozkan, 2017; Ozcan et al., 2014). Hence, several academics have advocated teaching approaches that facilitate conceptual change. Notably, the efficacy of visual animation teaching strategies surpasses that of conventional textbook-centered learning methods in enhancing students' learning outcomes, as indicated by studies (Dikmenli, 2010; Kalimuthu, 2017; Kamp & Deaton, 2013; Murtonen et al., 2018; Strand & Boes, 2019). Elangovan (2017) research into real and non-real simulations revealed that students exposed to real simulations demonstrated a reduced presence of misconceptions, thereby learning cell division concepts more effectively.

As a rapidly advancing technology, the exponential growth of artificial intelligence is fundamentally altering the dynamics of how individuals engage, communicate, dwell, acquire knowledge, and perform their professional duties (Chiu, 2021; Chiu et al., 2022; Chiu et al., 2023; Xia et al., 2022). Conventional information and communication technology (ICT) tools utilized for enhancing learning environments, such as projectors, electronic whiteboards, and electronic books, have evolved into interactive educational technologies, including games, robots, virtual reality (VR), computer simulations, programming blocks, and the internet (Chiu et al., 2022; Kassab et al., 2020; Oliveira et al., 2019; Weng et al., 2022; Woo et al., 2021). In the 21st century, artificial intelligence (AI) has emerged as a driving force catalyzing transformative shifts in education (Cox, 2021).AI facilitates adaptive learning and offers personalized guidance, support, and feedback to students. Moreover, AI aids teachers and policymakers in analysis and decision-making processes, contributing to the development of intelligent tutoring systems and more inclusive educational approaches for students (Hasan et al., 2020; Xia et al., 2022; Zawacki-Richter et al., 2019) ; Recent studies have delved into the diverse applications of AI as a teaching tool or platform, including simulation-based instruction that leverages technologies such as virtual reality to showcase students' conceptual understanding or practical demonstrations, thereby providing experiential and hands-on learning opportunities (Timms, 2016). Various studies also delve into the integration of AI and virtual reality in education. For example, Mikropoulos and Natsis (2011) have underscored the use of virtual reality, 3-D technology, and highly interactive simulations as educational tools to enhance students' comprehension of the concepts demonstrated. Additionally, there is a focus on the application of AI in medical education, incorporating virtual reality, simulation, and predictive technologies for tasks such as surgery, understanding human anatomy, and diagnosing the causes of cardiovascular diseases in young individuals based on diverse data sources (Aldeman et al., 2021; Paranjape et al., 2019; Shetty et al., 2022; Wartman & Combs, 2018; Witten et al., 2022). Research findings indicate that the integration of AI technology in teaching can enhance learning effectiveness. Nevertheless, there is currently limited research into the application of image machine learning technology in the educational context.

Research Aim and Research Questions

Hence, this study researched the use of AI robot image recognition technology systems to engage students in a role-reversal scenario in which they take on the role of teachers to instruct AI robots in object recognition. The aim was to enhance students' learning outcomes through the "Learning by Teaching" method. Specifically, the research focused on the cell division unit in the first grade of lower secondary, employing a quasi-experimental research design to validate the impact of the AI robot image recognition technology system on improving students' motivation to learn science and effectiveness in comprehending cell division concepts. As aforementioned, the aim of this research was to elucidate the potential benefits of integrating AI robot image recognition technology in teaching and its actual influence on students' motivation to learn cell division concepts and related scientific content.

1. Are there discernible differences in the impact of AI image recognition technology learning through teaching compared with conventional textbook-centered learning methods on students' conceptual understanding?
2. Is there a variance in the impact of AI image recognition technology learning through teaching versus textbook-centered learning on students' motivation to learn science?

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Research Methodology

Research Design

A quasi-experimental design and quantitative methods approach researched the impact of AI robot image recognition technology learning through teaching on the comprehension of cell division concepts and motivation to learn science. The study involved first-year lower-secondary school students, divided into an experimental group and a control group, both undergoing a science course on cell division. The experiment lasted for two weeks, and the students participated in six nature lessons, three lessons per week, with each section lasting forty-five minutes. In the experimental group, students used the robot equipped with the VIA Pixetto visual sensor to grasp the concept of cell division. Conversely, the control group relied on textbook learning to complete identical course content. After the experiment, all participating students underwent assessments evaluating their understanding of cell division, along with the Science Learning Motivation Scale. Table 1 illustrates the teaching activity processes for each class. In the experimental group, at the beginning of each teaching class, the teacher taught the course topic and the concepts that students needed to learn for 10 minutes. In the next 15 minutes, the teacher divided the students into groups of four, explained and demonstrated how to learn the concept of cell division, and provided exercises. The question requires students to use a 400x microscope to identify images of cell division. In the last 20 minutes, students discussed the concept of cell division, trained the AI image recognition system, and then input the pattern recognition results. The control group had the same lessons as the experimental group for the first 25 minutes at the beginning of each teaching class. In the last 20 minutes, students saw demonstration videos for practice and completed the study sheet. The study was conducted in February 2023.

Table 1
Teaching Activity Process of the Experimental and Control Groups

Teaching mode	Minutes	Experimental Group	Control Group
		AI image recognition technology learning through teaching	Demonstration videos and study sheets
Teaching activities	5	Teachers use animations, videos, or textbook spreads to guide students to observe the cell division process.	Teachers use animations, videos, or textbook spreads to guide students to observe the cell division process.
	5	Students independently read and studied textbook content	Students independently read and studied textbook content
	5	The teacher divides the students into groups of four and explains and demonstrates how to learn the concept of cell division.	The teacher divides the students into groups of four and explains and demonstrates how to learn the concept of cell division.
	10	The teacher provides practice questions and asks students to use a 400x microscope camera. Students practice in groups.	The teacher provides practice questions and asks students to use a 400x microscope camera. Students practice in groups.
	20	Students discuss the concept of cell division, train the AI image recognition system, and then input the pattern recognition results.	Students watch the demonstration videos to practice and complete the study sheets after practicing.

Participants

The participants consisted of all 81 7th-grade students (13-14 years) in four classes, with 40 boys and 41 girls, who were all from a lower secondary school located in a rural area in Taiwan, to fully participate in this study. The participants indicated that they used mBot robot before participating in this research. 40 students in two classes were randomly selected as the control group and received textbook-centered learning, and 41 students in the other two classes served as the experimental group and received AI image recognition technology learning through teaching. At the beginning of the school year, the school administration asked parents for written permission for their children to participate in educational research. In the "Two Stages of Cell Division and Reproduction Diagnostic Test," an independent samples t-test demonstrated that there were no significant differences in the achievement of different groups during the pre-test ($F = 0.002$, $p = .966$, $p > .05$). Similarly, in the Motivation to Learn Science

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Questionnaire, an independent samples *t*-test revealed no significant differences in the achievement of different groups in the pre-test ($F = 3.103$, $p = .082$, $p > .05$).

Instruments

1. mBot robot: This is an enlightenment education robot based on the Makeblock system. (https://www.makeblock.com/steam-kits/mbot)
2. VIA Pixetto visual sensor: The machine learning tool uses the VTS-8787 Smart Sensor, which is a camera module with built-in AI neural networks.
3. The process of the machine learning model; mainly building a model for the process of cell division. Here is a description of each step:

   Step 1: Model definition and design

   The initial phase involves defining the machine learning model and specifying whether it will focus on recognizing mitosis or meiosis. The model is designed to identify and classify various aspects of cell division processes, generating an output that outlines the required features, including the quantity of images or videos to be uploaded (refer to Figure 4).

   Step 2: Media Upload

   In the second part, students participate by uploading pictures or videos that showcase the cell division process. They have the option to select specific objects within the media to highlight cell division phases. This step is iterative, encouraging students to upload content from diverse cell types to enrich the training dataset and enhance the model's robustness (see Figure 5).

   Step 3: Training start

   Upon completion of media uploads, users can initiate the training process by clicking "Start Training." This step marks the start of the machine learning model's learning journey. The model adapts and refines its understanding based on the provided images and videos, with the goal of accurately identifying and classifying the distinctive features of cell division (depicted in Figure 6).

Figure 1
mBot robot

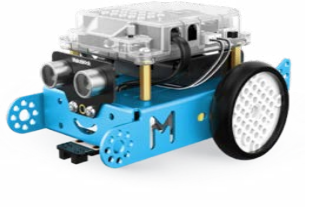

Figure 2
VIA Pixetto visual sensor

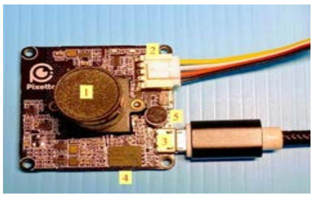

Figure 3
Pixetto online version

Figure 4
Learning mode

Figure 5
Uploading videos or pictures

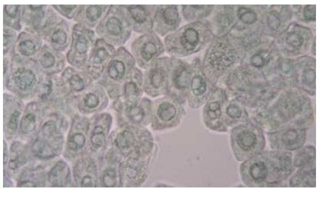

Figure 6
Model transfer to VIA Pixetto

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Data Collection Tools

Second-stage diagnostic test of cell division

This research tool is adapted from the "Two Stages of Cell Division and Reproduction Diagnostic Test" developed by Sesli and Kara (2012). Based on the scientific concept of the "Cell Division" unit, this study selected questions from the "Two Stages of Cell Division and Reproduction Diagnostic Test" that fit the learning content of this study and adapted them into a "Two Stages of Cell Division Diagnostic Test" with 5 questions. The concepts of cell division corresponding to the test question numbers are presented in Table 2. The scale was administered to 62 8th-grade students (14-15 years), yielding a Cronbach's α value of .82, indicating satisfactory internal consistency.

Table 2
Comparison of Cell Division Learning Topics, Scientific Concepts, and Question Numbers

Studying Subjects	Scientific concept	Items
Cell division	Process and results of mitosis	1.2
	Process and results of meiosis	3.4.5

Motivation to Learn Science Questionnaire

This study adapted the Motivation to Learn Science Questionnaire developed by Barak et al. (2011) to refine its scale. This instrument explores students' motivation in science learning across four dimensions: "self-efficacy," "interest and enjoyment," "daily life interrelation," and "importance to students," with each dimension comprising 5 questions and 20 questions overall. The 5-point Likert scale was predominantly employed in the design, ranging from "strongly disagree," "disagree," "average," "agree," to "strongly agree," corresponding to scores of 1, 2, 3, 4, and 5, respectively. The scale was administered to 62 8th-grade students (14-15 years), yielding a Cronbach's α value of .84, indicating satisfactory internal consistency.

Data Analysis

The study gathered both pre-and post-test scores from the "Second Stage Diagnostic Test of Cell Division" and the "Motivation to Learn Science Questionnaire." In accordance with Özmen (2011) framework for conceptual understanding, students' grasp of "cell division" was categorized into two groups: correct scientific concepts and misconceptions. If students correctly answered questions in both the first and second levels of the diagnostic test, they were deemed to possess the correct scientific concepts. Conversely, those who answered some or all questions incorrectly were classified under misconceptions. The overall analysis involved quantifying conceptual understanding assigning a score of 1 point to scientific concepts and 0 points to misconceptions. To research potential differences in the conceptual understanding of "cell division" following experimental teaching, one-way ANCOVA was employed. The focus was on comparing the scores of the two student groups. For a detailed concept analysis, students' number of correct responses to each question in the "Second Stage Diagnostic Test of Cell Division" were converted into percentages. The difference between the post-test scientific concept percentage and the pre-test scientific concept percentage was then calculated, representing the extent of change in scientific concepts. This measure allowed for an examination of the effectiveness of students' transition from misconceptions to scientific concepts.

In the examination of motivation to learn science, a single-factor ANCOVA was executed, incorporating the pretest score from the "Motivation to Learn Science Questionnaire" as the covariate. The teaching method served as the independent variable, and the post-test score was designated as the dependent variable. This statistical analysis discerned whether a noteworthy disparity existed in motivation to learn science between the two student groups following experimental teaching.

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Research Results

Impact of AI Robot Image Recognition Technology Learning through Teaching on Students' Concept of Cell Division

Table 3 shows the descriptive statistics of the students' performance on the concept of cell division after the two groups studied under different "teaching modes."

Table 3
Descriptive Statistics for the Two Groups of Students on the Cell Division Concept

Cell Division Concept	The experimental group (n=41)		The control group (n=40)	
	M	*SD*	*M*	*SD*
Pre-test	0.56	0.84	0.55	0.87
Post-test	4.15	1.01	2.80	2.04

Table 3 displays the scores of the two student groups in the pre-and post-tests on the concept of cell division. Although the experimental and control groups performed similarly in the pre-test, the experimental group's mean score in the post-test was significantly higher than that of the control group. To gain deeper insights into this distinction, a single-factor covariate analysis was undertaken, starting with the "homogeneity of regression coefficients within the group" test. As indicated in Table 4, F = 1.788, p = .185, p >.05, failing to reach the significance level. This implies that the relationship between pretest and posttest scores does not exhibit significant differences under various treatment levels. Consequently, an independent sample one-way covariance analysis can be conducted to further comprehend the disparities in the representation of the cell division concept between the two groups.

Table 4
Intragroup Homogeneity Test of Regression Coefficients for Two Groups of Students on the Concept of Cell Division

Source of variation	*SS*	*df*	*MS*	*F*	*p*
Group* pre-test	3.968	1	3.968	1.788	.185
Error	170.932	77	2.22		
Total	1222.000	81			
Adjusted Total	240.222	80			

*p < .05; ** p < .01; ***p < .001

Table 5 employs various "teaching modes" as independent variables, with the "Cell Division Concept" post-test score as the dependent variable and uses the "Cell Division Concept" pre-test score as a covariate. The analysis involves an independent sample one-way covariate analysis to examine the impact of teaching modes on students' post-test scores in the "Cell Division Concept" while controlling for the influence of pre-test scores.

Table 5
Covariance Analysis of the Two Groups of Students on the Concept of Cell Division

Source of Variation	*SS*	*df*	*MS*	*F*	*p*
Group	36.272	1	36.272	16.176	< .001
Error	174.900	78	324.37		
Total	1222.000	81			
Adjusted Total	240.222	80			

*p < .05; ** p < .01; ***p < .001

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The results of the covariate analysis for the cell division concept presented in Table 5 indicate that after accounting for the influence of pre-test scores on post-test scores, the impact of the teaching model on students' understanding of the cell division concept is highly significant (F = 16.176, p < .001). This indicates a substantial difference in the understanding of the cell division concept between the experimental and control groups following the AI robot image recognition technology. The statistical analysis further reveals that the experimental group outperformed the traditional teaching method in enhancing the learning outcomes related to the concept of cell division. In summary, the integration of AI robot image recognition technology in teaching proved to be highly effective in improving students' comprehension of the concept of cell division.

Impact of AI Image Recognition Technology Learning through Teaching on Students' Understanding of Individual Concepts in Cell Division

Table 6 presents the count and percentage of students' conceptual understanding before and after the "Two Stages of Cell Division Diagnostic Test." By subtracting the pre-test science concept percentage from the post-test science concept percentage, the scientific concept change amount is calculated. This measure is used to assess the effectiveness of students' transition from misconceptions to scientific concepts. The questions in Table 6 are clearly linked to the concepts of mitosis and meiosis. Figure 7 illustrates the line chart depicting the changes in scientific concepts among students in the experimental and control groups across the first to fifth questions. The data from Table 6 and Figure 7 highlight that, compared to textbook learning, AI robot image recognition technology learning through teaching has induced more significant changes in scientific concepts among students regarding "cell division." This underscores the technology's effectiveness in enhancing students' understanding of cell division, showcasing superior results compared to textbook-centered learning.

Table 6
Changes in Scientific Concepts, Misconception, and Scientific Concepts Between the Two Groups in Each Question of "Diagnosis of the Second Stage of Cell Division"

The concept type of each question		Textbook learning					AI image recognition technology learning through teaching				
		Pre-test		Post-test		Difference	Pre-test		Post-test		Difference
		N	%	*N*	%	%	*N*	%	*N*	%	%
1	Scientific concept	6	15	25	62.5	47.5	6	14.6	36	87. 8	73.2
	Misconception	34	85	15	37.5		35	85.4	5	12.2	
2	Scientific concept	5	12.5	22	55	42,5	5	12.2	36	87.8	75.6
	Misconception	35	87.5	18	45		36	87.8	5	12.2	
3	Scientific concept	3	7.5	21	52.5	45	3	7.3	33	80.5	73.2
	Misconception	37	92.5	19	47.5		38	93.7	8	19.5	
4	Scientific concept	4	10	20	50	40	4	9.8	35	85.4	75.6
	Misconception	36	90	20	50		37	90.2	6	14.6	
5	Scientific concept	4	10	20	50	40	5	12.2	30	73.2	61.0
	Misconception	36	90	20	50		36	87.8	11	26.8	

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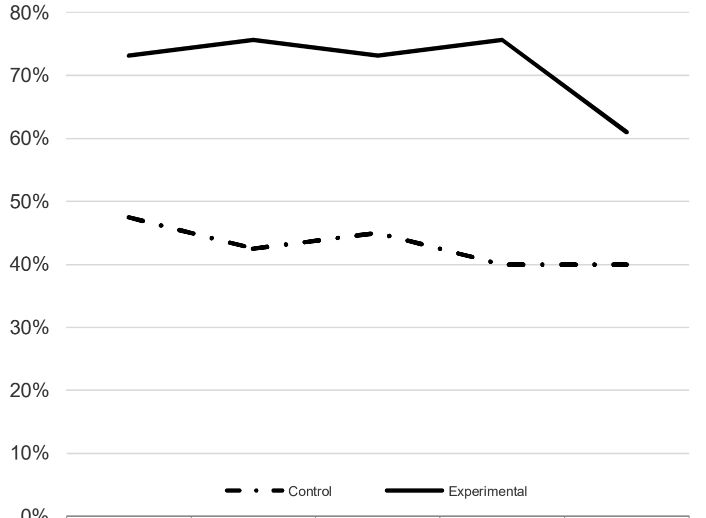
Figure 7

Changes in Scientific Concepts Between the Two Groups in the Pre- and Post-Tests of Each Question of the "Two Stages of Cell Division Diagnostic Test"



	1	2	3	4	5
Control	47,5%	42,5%	45,0%	40,0%	40,0%
Experimental	73,2%	75,6%	73,2%	75,6%	61,0%

Impact of AI Robot Image Recognition Technology Learning Through Teaching on Students' Science Learning Motivation

Table 7 shows the descriptive statistics of students' performance in "science learning motivation" after two groups of students studied under different "teaching models".

Table 7

Descriptive Statistics of the Two Groups of Students on Science Learning Motivation

Science Learning Motivation	The experimental group (n = 41)		The control group (n = 40)	
	M	***SD***	***M***	***SD***
Pre-test	63.00	7.37	63.55	9.816
Post-test	75.24	9.21	70.75	6.986

Table 7 displays the scores of the two student groups in the pre-and post-tests of the Science Learning Motivation Scale. While both groups exhibited similar performance in the pretest, the experimental group's post-test mean score was significantly higher than that of the control group. To delve deeper into these differences, a single-factor covariate analysis was performed, preceded by the "homogeneity of regression coefficients within the group" test. As depicted in Table 8, $F = 3.454$, $p = .067$, indicating that $p > .05$ and did not reach the significance level. This implies the absence of a significant interaction between the independent variable (pre-test scores) and the covariate (post-test scores), aligning with the assumption of homogeneity of regression coefficients in the covariate analysis. Consequently, an independent sample single-factor covariance analysis can be conducted to further explore disparities in science learning motivation performance between the two groups.

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Table8

Homogeneity Test of Regression Coefficients within the Group for the Two Groups of Students on Science Learning Motivation

Source of variation	*SS*	*df*	*MS*	*F*	*p*
Group* Pre-Test	180.101	1	180.101	3.454	.067
Error	4015.015	77	52.143		
Total	437645.000	81			
Adjusted Total	5703.951	80			

*$p < .05$; ** $p < .01$; *** $p < .001$

Table 9 employs different "teaching models" as independent variables, the post-test scores from the "Science Learning Motivation Scale" after the experimental course as the dependent variable and uses the pre-test scores from the same scale as a covariate. The analysis involves an independent sample single-factor covariance analysis to examine the impact of teaching models on students' post-test scores in the "Science Learning Motivation Scale," while controlling for the influence of pre-test scores.

Table 9

Covariable Analysis of the Two Groups of Students' Motivation for Science Learning

Source of Variation	*SS*	*df*	*MS*	*F*	*p*
Group	452.672	1	452.672	8.417	.005
Error	4195.116	78	53.784		
Total	310654.00	81			
Adjusted Total	5703.951	80			

*$p < .05$; ** $p < .01$; *** $p < .001$

In Table 9, the covariate analysis for "Science Learning Motivation" demonstrates a statistically significant impact of teaching mode on students' motivation for science learning ($F = 8.417$, $p = .005$, $p < .05$) after adjusting for pre-test scores influence on post-test scores. This implies a noteworthy disparity in science learning motivation between the experimental and control groups following learning through teaching in AI robot image recognition technology. In addition, the experimental group displayed a more substantial improvement compared with the control group, indicating a significantly higher level of science learning motivation within the experimental group. In conclusion, the integration of AI robot image recognition technology in learning has proven to be highly effective in enhancing students' motivation for science learning, outperforming textbook-centered learning.

Discussion

This research stems from the persistent challenges encountered throughout the stages of comprehending the concept of cell division, as highlighted in previous studies (Osman et al., 2017; Salleh et al., 2021; Williams et al., 2012). Even upon completion of a cell division course, students often retain misconceptions that prove resistant to correction. Despite the implementation of various innovative teaching approaches, such as concept mapping, 5E exploratory teaching methods, and computer-assisted teaching, the anticipated breakthrough in dispelling these misconceptions remains elusive (Etobro & Fabinu, 2017; Okolo & Oluwasegun, 2020; Özbudak & Özkan, 2014; Salleh et al., 2021; Şen et al., 2018; Wright & Newman, 2011).

Consequently, the study posits that the challenges associated with teaching the intricate concept of cell division may persist because of the limitations of current teaching approaches. In response, we propose a novel learning method rooted in "Learning by Teaching," which underscores the idea that students can enhance their understanding and command of knowledge by engaging in teaching activities (Fiorella & Mayer, 2013). This transformative approach redefines students as educators, challenging them not only with comprehending specific topics but also with articulating and

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communicating this knowledge effectively, even to an artificial entity like a robot. By adopting this learning method, students not only bolster their mastery of the subject matter but also refine their teaching and presentation skills (Pi et al., 2021). The research also posits that teaching humanoid robots in a manner akin to how humans teach can enhance students' conceptual comprehension and foster greater interest in learning (Jamet et al., 2018; Yadollahi et al., 2018). This "Learning by Teaching" approach is viewed as a promising strategy for advancing the understanding of basic biology. The teaching methodology of "Learning by Teaching" encompasses group cooperative learning discussions, formulation of accurate learning plans, and examination of common misunderstandings and their origins. Subsequently, the students convey these learned concepts to the robot. The objective of this approach is to deepen students' understanding of the concept of cell division, transforming it into a more nuanced and scientific comprehension. Upon comparing the outcomes of the experimental and control groups, it was evident that by the end of the teaching period, students in the experimental group demonstrated a significantly superior understanding of cell division compared with the control group. The experimental group not only achieved higher assessment scores but also exhibited increased motivation for science learning. This translated into their ability to produce a more precise instructional video for teaching the robot, incorporating a deeper grasp of correct concepts than they initially had at the beginning of the course. Initially, the evaluation scores of the experimental and control groups were similar. However, following the teaching intervention, the scientific concepts of students in the experimental group showed a substantial increase on the cell concept test. Recognizing the need for improvement, the "Learning by Teaching" teaching method requires students to reassess their prior concepts when engaging with teaching robots, fostering active participation in class discussions. This approach is considered a strategic avenue for enhancing learning outcomes. Research findings indicate that students commonly misconceive mitosis and meiosis as identical processes or confuse metaphase with mitosis in the context of meiosis. Integrating AI imaging machine learning into teaching holds promise for a more profound application of machine learning in education, fostering increased student participation (Martins et al., 2023; Sanusi et al., 2022). By involving students in the tasks of teaching robots, they gain more opportunities to observe and distinguish between these two processes through a microscope, thereby enhancing their understanding of the distinctions. As observed by Elangovan (2017), realistic simulations play a crucial role in reducing student misunderstandings and improving the learning efficiency of cell division concepts. In addition, this aligns with the research outcomes of Carlan et al. (2014), where the use of microscopes and comic books has proven effective in enhancing the learning abilities of eighth-grade students in this domain. Upon analyzing the conceptual understanding of both the experimental and control groups, it was evident that students encountered the most challenges when grasping the concept of meiosis. Meiosis, recognized as a complex topic, is often perceived as difficult to comprehend (Strand & Boes, 2019). The core concept of meiosis is typically confined to textbooks and classroom instruction, resulting in a disconnect between theoretical knowledge and practical experience. The abundance of concepts presented in textbooks and during teaching processes may cause difficulties (Kim et al., 2022). The findings align with the perspectives of Hung and Fung (2017), who posited that a prevalent challenge hindering students' comprehension of cell division is the level of abstraction involved. Due to the small size of cells, students may struggle to visualize the actual process of cell division. Therefore, when teaching cell concepts in schools, it is crucial to elevate students' awareness of metaconcepts, guiding them toward a more profound understanding of scientific concepts. These metaconcepts often have implications for subsequent learning. Recognizing the intrinsically abstract nature of cell division concepts, students frequently encounter challenges in mastering them. To address this difficulty, employing hands-on microcamera capture of cell division images and encouraging students to embody understanding through interactions with robotic models has validated established learning principles. This approach is in harmony with findings from prior research studies (Adeoye, 2021; Luwoye et al., 2021; Leslie Kate Wright et al., 2022; L Kate Wright et al., 2022). Using this hands-on simulation teaching strategy has the potential to significantly enhance the effectiveness of teaching cell division concepts. Nevertheless, this research employs AI robot image recognition technology that learns through a teaching process, capable only of conducting observations at the chromosome level. However, more intricate gene identification requires additional advancement.

Conclusions and Implications

This study harnesses artificial intelligence image machine learning technology to enable students to guide robots using a vast collection of microscope images. A profound comprehension of the nuanced alterations across the early, middle, and late stages of mitosis and meiosis constitutes the linchpin of effective instruction. This method not only enhances students' grasp of biological cell division concepts but also fosters a more authentic and dynamic learning milieu. By amalgamating self-study with teaching, educators must adapt and structure materials for presentation, ensuring clarity in foundational constructs. Consequently, mastering teaching methodologies

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outweighs independent learning. By juxtaposing the self-study and teaching requisites of students, it facilitates greater dedication to selecting pertinent components and organizing them into coherent depictions. Assessments, predicated on cognitive merits, reveal that students primed for teaching exhibit superior performance, particularly those afforded actual teaching opportunities. Through this innovative pedagogical approach, students adeptly apprehend the intricacies of cell division, establishing an accurate conceptual framework while mitigating potential misconceptions endemic to conventional teaching paradigms. This research not only enhances the caliber of biology education but also kindles students' enthusiasm for scientific inquiry.

Contemporary trends in digital media development favor students' autonomous learning, with this study integrating the post-autonomous learning teaching paradigm. Thus, it is recommended that future learning systems facilitate students' transition to autonomous learning anchored in teaching, such as incorporating practical practice mechanisms or imagery like demonstrative operations or practice exercises for a smoother learning experience.

Declaration of Interest

The authors declare no competing interest.

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