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ORIGINAL

An Exploration of English Intelligence, Digital Literacy, IoT Knowledge, and Project Learning Attitudes on Biological Knowledge and Biological Attitudes

Una exploración de la inteligencia inglesa, la alfabetización digital, el conocimiento de la IoT y las actitudes de aprendizaje de proyectos sobre el conocimiento biológico y las actitudes biológicas

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ABSTRACT

Introduction: this study aims to investigate the influence of English Intelligence, Digital Literacy, IoT Knowledge, and Project Learning Attitude on Biological Knowledge and Biological Attitude of biology education students in Indonesia.
Method: the research design used quantitative explanatory and Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis, data were collected from 792 students in three large islands of Indonesia, Sumatra, Java, and Kalimantan.
Results: the results showed that English Intelligence significantly increased Digital Literacy, IoT Knowledge, and Project Learning Attitude, and had a positive effect on Biological Knowledge. However, this variable had a negative impact on Biological Attitude, indicating a mismatch between linguistic competence and affective engagement in biology. Digital Literacy and Project Learning Attitude were shown to have a positive contribution to Biological Knowledge and Biological Attitude, while IoT Knowledge had a significant negative effect on Biological Attitude and no significant effect on Biological Knowledge. The strongest effect was found in the path between Biological Knowledge and Biological Attitude, confirming that cognitive mastery is the main predictor in shaping students' biology attitudes.
Conclusions: these findings highlight the importance of aligning digital and linguistic competencies with pedagogical approaches to optimize biology learning outcomes in the digital age.

Keywords: English Intelligence; Digital Literacy; Iot Knowledge; Project Learning Attitude; Biological Knowledge; Biological Attitude.

RESUMEN

Introducción: este estudio busca investigar la influencia de la inteligencia en inglés, la alfabetización digital, el conocimiento de IoT y la actitud de aprendizaje en proyectos sobre el conocimiento y la actitud biológica de estudiantes de biología en Indonesia.
Método: el diseño de la investigación empleó un análisis cuantitativo explicativo y un modelo de ecuaciones estructurales de mínimos cuadrados parciales (PLS-SEM). Se recopilaron datos de 792 estudiantes en tres grandes islas de Indonesia: Sumatra, Java y Kalimantan.
Resultados: los resultados mostraron que la inteligencia en inglés incrementó significativamente la alfabetización digital, el conocimiento de IoT y la actitud de aprendizaje en proyectos, y tuvo un efecto positivo en el

conocimiento biológico. Sin embargo, esta variable tuvo un impacto negativo en la actitud biológica, lo que indica una discrepancia entre la competencia lingüística y la implicación afectiva en biología. Se demostró que la alfabetización digital y la actitud de aprendizaje en proyectos contribuyeron positivamente al conocimiento y la actitud biológica, mientras que el conocimiento de IoT tuvo un efecto negativo significativo en la actitud biológica y no tuvo un efecto significativo en el conocimiento biológico. El efecto más fuerte se observó en la relación entre el Conocimiento Biológico y la Actitud Biológica, lo que confirma que el dominio cognitivo es el principal predictor en la formación de las actitudes de los estudiantes hacia la biología. **Conclusiones**: estos hallazgos resaltan la importancia de alinear las competencias digitales y lingüísticas con los enfoques pedagógicos para optimizar los resultados del aprendizaje de la biología en la era digital.

Palabras clave: Inteligencia Inglesa; Alfabetización Digital; Conocimiento de Iot; Actitud de Aprendizaje de Proyectos; Conocimiento Biológica; Actitud Biológica.

INTRODUCTION

The rapid development of information and communication technology and the increasingly massive flow of globalization have pushed the world of education to adapt rapidly to the needs of 21st-century competencies.[1,2,3] In biology learning, this challenge requires students not only to master biological concepts cognitively, but also to possess supporting skills such as English language proficiency (English Intelligence), digital literacy, and knowledge of cutting-edge technologies like the Internet of Things (IoT). Furthermore, learning success is greatly influenced by students' attitudes toward the learning approach itself, including their attitude toward project-based learning.[4] Several recent studies have shown that the integration of language skills, digital literacy, and technological understanding has a positive contribution to science learning in general.[5,6,7,8]

The literature also shows that a project-based learning approach can increase student engagement, conceptual understanding, and foster positive attitudes toward science, including biology.[9,10] Digital literacy provides broader access to a variety of learning resources, while english language proficiency enables students to understand global scientific references.[11] Knowledge of the IoT is increasingly relevant because it opens up interdisciplinary insights between biology and technology, which are crucial in the era of the 4.0 industrial revolution.[12,13] Therefore, it is important to explore how the combination of these four elements can simultaneously influence the formation of biological knowledge and biological attitudes.

Although various studies have examined the relationship between some of these variables, the findings are still partial. Research by Sobach et al.[14] and Toharuddin et al.[15], highlights the influence of digital literacy on science learning outcomes, while Sánchez Fajardo et al.[16] and Vettori et al.[17] emphasizes the importance of English language skills in understanding scientific texts. Similarly, a study by Kandil et al.[18], Liston et al.[19], and Hale et al.[20] demonstrates the potential of the IoT in enhancing biological understanding, and confirms that attitudes toward project-based learning are positively correlated with students' scientific attitudes. However, to date, no study has combined these four variables within a single conceptual framework and simultaneously examined their influence on knowledge and attitudes in biology learning.

This research gap is further clarified by the fact that most existing studies fail to integrate a quantitative approach based on structural models to uncover the direct and indirect contributing pathways of each variable. Only examined the effects of digital literacy without considering the role of mediating variables such as learning attitudes or technological knowledge.[21,22,23] Other studies also tend to isolate variables and fail to consider the complex interrelationships between cognitive, affective, and technological aspects that influence biology learning holistically. Therefore, it is necessary to develop a model that can illustrate the interrelationships between english intelligence, digital literacy, iot knowledge, and project learning attitude in the formation of biological knowledge and biological attitude.

This study aims to identify the extent to which english intelligence, digital literacy, IoT knowledge, and project learning attitudes influence students' biological knowledge and attitudes. This research is expected to serve as a foundation for quality learning processes in the future, particularly in the context of empowering english intelligence, digital literacy, IoT knowledge, project-based learning attitudes, and biological knowledge and attitudes.

Conceptual Framework and Hypothesis Development

H1: There is a positive and significant effect of English Intelligence on Digital Literacy.

English language proficiency is an important foundation for developing digital literacy, especially since the majority of digital resources and global scientific content are available in English.[24,25] Individuals with high English Intelligence proficiency have broader access and better ability to understand, evaluate, and utilize digital-based information.[26,27] In the context of biology learning, digital literacy is not only about technical skills but also about critical understanding of scientific content, which is often presented in a foreign language.

H2: There is a positive and significant effect of English Intelligence on IoT Knowledge

Understanding of Internet of Things (IoT) technology generally comes from technical documentation, tutorials, and case studies, most of which are available in English.[28,29] Therefore, English language proficiency can facilitate access and understanding of IoT knowledge.[30] English Intelligence is key for reading diagrams, interpreting technical instructions, and even participating in online courses related to the application of IoT in science, including biology.[31,32]

H3: There is a positive and significant effect of English Intelligence on Project Learning Attitude

Project-based learning encourages students to learn independently, seek information, and collaborate to solve real-world problems.[33] In the process, English Intelligence is necessary for understanding international references, establishing communication, and expressing ideas in a global context.[34,35] Students with good English skills tend to be more confident and active in project-based learning because they are able to access a wider range of information sources.[36,37]

H4: There is a positive and significant effect between English Intelligence and Biological Knowledge

Understanding biology material is strongly influenced by scientific literacy skills, including language literacy.[38,39] English, as the primary language of scientific publications, provides a variety of important learning resources such as journals, articles, and instructional videos. Students with high English Intelligence have a greater potential to access and understand this content, thereby expanding their biological knowledge.[40,41,42]

H5: There is a positive and significant eåffect between English Intelligence and Biological Attitude

Attitudes toward a subject are often shaped by confidence and comfort in participating in the learning process.[43,44] Good English language skills can reduce barriers to understanding and increase active participation in biology learning, especially when learning resources are available in a foreign language.[40,45,46] This creates a positive perception of the subject and contributes to a better attitude toward biology in general.

H6: There is a positive and significant effect between Digital Literacy and Biological Knowledge

Digital Literacy reflects students' ability to search for, manage, and evaluate relevant digital information.[47] In biology learning, these skills are crucial for understanding contemporary topics that are often dynamic and based on digital data.[48,49] Individuals with high digital literacy are able to optimally utilize technology-based learning resources, interactive simulations, and online learning platforms.[50] Therefore, the higher the digital literacy, the more likely students are to master biological knowledge in depth.[51]

H7: There is a positive and significant effect between Digital Literacy and Biological Attitude

Digital literacy also impacts students' affective aspects.[52,53] The ability to utilize technology productively in learning can increase student motivation, engagement, and satisfaction with biology.[54,55] Students who feel comfortable with digital learning media will exhibit more positive attitudes because they perceive learning to be more engaging, relevant, and suited to their learning styles.[56] Therefore, digital literacy skills are predicted to contribute to forming positive attitudes toward biology learning.

H8: There is a positive and significant influence between IoT Knowledge and Biological Knowledge

The integration of IoT in biology learning allows students to observe, collect, and analyze biological data in real time through smart devices.[57,58] Understanding how IoT works and its applications provides a concrete and contextual data-driven learning experiencee.[59,60] With this technological understanding, students can connect biological concepts with their practical implementation in the real world, such as monitoring body temperature, heart rate, or the environment.[4,61] Therefore, IoT Knowledge has significant potential to improve students' Biological Knowledge.

H9: There is a positive and significant influence between IoT Knowledge and Biological Attitude

In addition to cognitive aspects, understanding IoT can also increase students' interest and attitudes toward biology.[62] Through the use of modern and relevant technology, biology learning feels more applicable and meaningful. When students are able to see the direct connection between biology and the IoT devices they use daily, they will have a positive perception of the subject.[63,64] Therefore, IoT Knowledge is assumed to have a positive impact on students' attitudes toward learning biology.[65]

H10: There is a positive and significant influence between Project Learning Attitude and Biological Knowledge

A positive attitude toward project-based learning encourages students to be more active, independent, and reflective in the learning process.[66,67,68] Successful implementation of project-based learning involves exploring real-world problems, finding solutions, and collaborating, which indirectly strengthens conceptual

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understanding of the material.[69] Students who are enthusiastic and open to this method will be more optimal in absorbing and understanding biology content in depth.[70,71,72]

H11: There is a positive and significant influence between Project Learning Attitude and Biological Attitude

Project-based learning not only emphasizes learning outcomes but also shapes values, attitudes, and perspectives on the learning process itself.[1] Students who enjoy exploratory, collaborative, and contextual learning processes tend to develop positive attitudes toward biology.[61] In the context of biology, a positive attitude toward project-based learning can increase students' interest in biology as an applicable and life-relevant field.[73,74,75]

H12: There is a positive and significant influence between Biological Knowledge and Biological Attitude

A strong understanding of a subject often shapes a positive attitude toward it.[4] Students who feel capable and have mastered biological concepts will feel more confident and motivated in participating in the learning process.[76,77] In-depth knowledge fosters a greater appreciation and interest in the content being studied, thus fostering a more positive attitude.[78,79] Therefore, Biological Knowledge is considered an important predictor of students' Biological Attitude.

METHOD

Research Type and Design

This study is explanatory research, aiming to explain the causal relationship between english intelligence, digital literacy, iot knowledge, and project learning attitude on biological knowledge and biological attitude (figure 1). The research design used was a quantitative correlational survey with a cross-sectional model, where data was collected once at a specific point in time, in July 2025.[80] The research model is multivariate with latent constructs measured through reflective indicators.

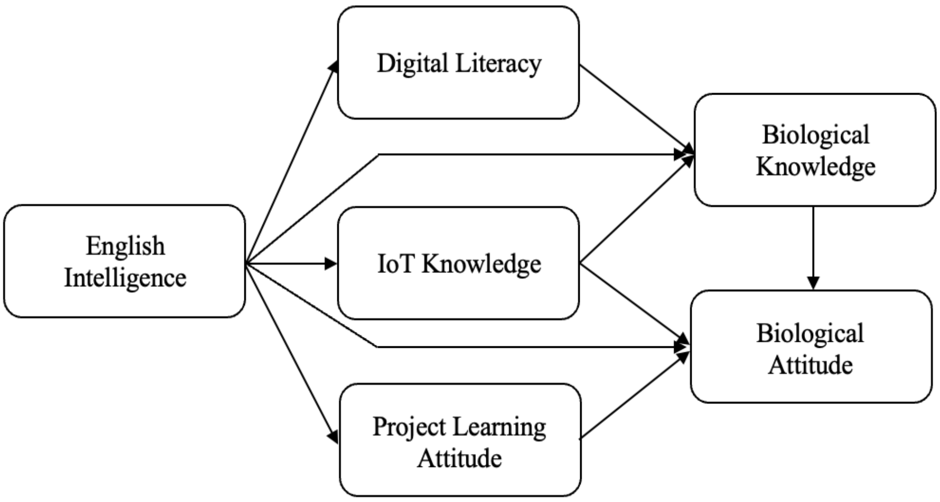

Figure 1. Path Diagram Analysis and Hypotheses

Research Subjects and Location

The subjects of this study were biology education students who had participated in biology learning with a project-based approach and english language. The sample was selected using purposive sampling, considering universities that have implemented project-based learning and English language and have access to digital technology in the learning process. The sample size was determined based on the recommendations of Hair et al.[81] for the PLS-SEM model, which is at least 10 times the number of indicators for the construct with the most indicators. The number of respondents who filled out the questionnaire was 1205 spread across 3 large islands in Indonesia, namely Sumatra Island (Universitas PGRI Sumatera Barat, Universitas Jambi, Universitas muhammadiyah bengkulu, and Universitas Muhammadiyah Palembang), Java Island (Universitas Negeri Malang, Universitas Negeri Semarang, Universitas Ahmad Dahlan, and Universitas Muhammadiyah Malang), and Kalimantan Island (Universitas Borneo Tarakan and Universitas Islam Negeri Sultan Aji Muhammad Idris Samarinda). However, only 792 students qualified to continue with data analysis. These students fulfilled the requirements by completing the biodata and questionnaire completely. Furthermore, they had previously participated in project-based learning and English language courses, and had access to digital technology in their learning.

Research Instrument

Table 1. Research instruments

Item Variable	Questionnaire Statement	Modification Source
EGI1	I can understand English reading well.	(82,83,84,85,86)
EGI2	I can write sentences or paragraphs in English correctly.	
EGI3	I am confident speaking in English in discussions or presentations.	
EGI4	I can understand conversations or videos in English without subtitles.	
EGI5	I have a sufficient English vocabulary to support my academic activities.	
EGI6	I frequently read English articles or books to broaden my knowledge.	
EGI7	I am interested in further improving my English skills through courses or training.	
DLC1	I am able to search for academic information online effectively.	(87,88,89)
DLC2	I understand how to evaluate the reliability and validity of the digital information I find.	
DLC3	I can use online collaboration applications (e.g., Google Docs, Teams) for college assignments.	
DLC4	I understand the importance of maintaining the privacy and security of personal data online.	
DLC5	I regularly stay up-to-date on the latest digital technologies relevant to my field.	
DLC6	I can wisely manage my social media accounts for professional purposes.	
DLC7	I feel confident using various online learning (e-learning) platforms.	
IOT1	I understand the basic concepts of the Internet of Things (IoT).	(90,91,92)
IOT2	I know examples of IoT applications in everyday life.	
IOT3	I can explain the benefits of using IoT in various fields.	
IOT4	I understand the security risks associated with IoT.	
IOT5	I have used or interacted directly with IoT devices.	
IOT6	I follow IoT technology developments through articles, seminars, or technology news.	
IOT7	I am interested in learning more or developing IoT-based projects.	
PLA1	I feel motivated when learning through real-life projects.	(78,93,94)
PLA2	Project-based learning helps me understand course material better.	
PLA3	I can work well in a team when working on projects.	
PLA4	I feel that project-based learning enhances my creativity.	
PLA5	I am accustomed to managing my time well when working on projects.	
PLA6	I gain valuable practical experience through project-based learning.	
PLA7	I believe project-based learning better prepares me for the world of work.	
BIK1	I understand basic biology concepts such as cells, tissues, and organs.	(95,96,97,98)
BIK2	I can explain metabolic processes in living organisms.	
BIK3	I understand the role of DNA in the inheritance of traits.	
BIK4	I can distinguish the characteristics of living organisms based on their classification.	
BIK5	I understand the relationship between ecosystems and biodiversity.	
BIK6	I can explain the difference between mitosis and meiosis.	
BIK7	I feel confident in taking exams or discussions about biology material. I feel enthusiastic about studying biology.	
BIA1	I believe biology is important to understand life.	(71,99,100,101,102)
BIA2	I enjoy doing biology labs and experiments.	
BIA3	I feel biology helps me think more logically and critically.	
BIA4	I'm interested in reading additional articles and books about biology outside of class.	
BIA5	I appreciate the diversity of living things and the environment after studying biology.	
BIA6	I'm motivated to study biology topics more deeply in the future.	
BIA7	I can understand English reading well.	

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This research instrument was developed as a structured questionnaire modified from several sources (table 1). Each construct was measured through a number of indicators formulated as closed-ended statements, and answered using a 4-point Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Agree, and 4 = Strongly Agree. The 4-point scale was chosen to encourage respondents to provide more definitive answers and avoid neutral options, thus strengthening the validity of the data obtained. The instrument underwent a validation process by three experts, each with expertise in biology education, learning technology, and psychometric measurement. Validation was conducted to ensure wording clarity, the appropriateness of the indicators to the construct, and relevance to the Indonesian educational context. The validation results indicated that the instrument met the criteria with a valid score (3,29). Input from the experts was used to revise and strengthen the instrument's substance. Before being widely implemented, the questionnaire was also tested on a limited basis (50 students in Universitas PGRI Sumatera Barat) to identify technical weaknesses and estimate the initial reliability of the instrument.

Data Collection and Analysis Techniques

Data collection was conducted online through a digital questionnaire distributed using the Google Forms platform. Prior to completion, participants were provided with an explanation of the research objectives and informed consent was confirmed. Data were collected between July and August 2025, and data were checked for completeness and consistency. Data analysis in this study employed the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach using SmartPLS software version 3.2. This technique was chosen because it is capable of testing relationships between complex, multivariate latent constructs and is suitable for theory development in exploratory contexts. PLS-SEM also offers advantages in analyzing data that is not fully normally distributed and has a relatively moderate sample size. The analysis process was carried out in two main stages: evaluation of the measurement model (outer model) and evaluation of the structural model (inner model).

Evaluation of the outer model was conducted to assess the validity and reliability of the constructs. Convergent validity testing was conducted by observing the outer loading or loading factor value (> 0,70) and the Average Variance Extracted (AVE), which must exceed 0,50. Construct reliability was analyzed through Composite Reliability (CR) and Cronbach's Alpha values, which were expected to be above 0,70.[104,105] Furthermore, discriminant validity was tested using the HTMT criterion (below 0,850) and cross-loading,[106,107] where the construct's value was higher than the other constructs, to ensure that each construct was unique in its measurement. The inner model stage examined the path coefficients, which reflect the direct relationship between constructs. The coefficient values were interpreted based on their direction (positive/negative) and magnitude, then tested for significance using bootstrapping techniques with 5,000 subsamples. The bootstrapping results produced t-statistics and p-values, which served as the basis for hypothesis testing. A relationship was considered significant if the t-statistic was > 1,96 and the p-value < 0,05 at the 5 % significance level.[108] Next, an analysis was performed on the R-Square (R^2) value to determine the proportion of variance in the endogenous construct that can be explained by the exogenous construct. The R^2 value is categorized as weak (> 0,25), moderate (> 0,50), or strong (> 0,75).[81] The higher the R^2 value, the greater the contribution of the independent variables in explaining the dependent variable, which reflects the predictive power of the model.

RESULTS

Based on the results of the reliability and convergent validity analysis (table 2), all constructs in the model meet the requirements for use in PLS-SEM analysis. All Composite Reliability (CR) values are above the threshold of 0,70, indicating strong internal consistency, with the highest values found in the IoT Knowledge (0,946) and English Intelligence (0,945) constructs. Similarly, the Average Variance Extracted (AVE) values for all constructs also exceed the minimum threshold of 0,50, indicating convergent validity is met. Several indicators were removed because they had loadings below 0,70 (e.g.: EGI7, DLC1, DLC4, PLA2, PLA3, BIA5), which is the right decision to improve construct validity. The Cronbach's Alpha values for all constructs are also above 0,7, indicating adequate initial reliability. Overall, the measurement instruments in this model can be said to be reliable and valid for use in testing the relationships between latent variables.

Based on the results of the Heterotrait-Monotrait Ratio (HTMT) analysis (table 3), all inter-construct values are below the conservative threshold of 0,85, and none exceed the liberal value of 0,90, indicating that the discriminant validity between constructs has been met well. The highest value is between Biological Knowledge (BIK) and Biological Attitude (BIA) at 0,804, which is still within the safe limit, although approaching the upper threshold. This indicates that although the two constructs are closely related conceptually, they can still be distinguished statistically. Thus, there is no indication that the constructs in the model experience conceptual overlap problems, and the model meets the requirements to proceed to the structural evaluation stage (inner model).

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Table 2. Evaluation of Convergent Validity and Construct Reliability

Variable Items	Outer Loadings	Cronbach's Alpha	Rho_A	Composite Reliability	AVE
EGI1	0,818	0,931	0,943	0,945	0,742
EGI2	0,898				
EGI3	0,861				
EGI4	0,900				
EGI5	0,833				
EGI6	0,855				
EGI7	0,681 (out)				
DLC1	0,658 (out)	0,797	0,805	0,868	0,623
DLC2	0,634 (out)				
DLC3	0,754				
DLC4	0,473 (out)				
DLC5	0,849				
DLC6	0,723				
DLC7	0,824				
IOT1	0,859	0,933	0,935	0,946	0,715
IOT2	0,880				
IOT3	0,828				
IOT4	0,814				
IOT5	0,859				
IOT6	0,866				
IOT7	0,810				
PLA1	0,780	0,849	0,853	0,892	0,624
PLA2	0,677 (out)				
PLA3	0,676 (out)				
PLA4	0,869				
PLA5	0,751				
PLA6	0,784				
PLA7	0,761				
BIK1	0,820	0,922	0,927	0,937	0,682
BIK2	0,863				
BIK3	0,838				
BIK4	0,858				
BIK5	0,829				
BIK6	0,744				
BIK7	0,824				
BIA1	0,807	0,899	0,910	0,922	0,665
BIA2	0,769				
BIA3	0,808				
BIA4	0,869				
BIA5	0,660 (out)				
BIA6	0,868				
BIA7	0,764				

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Table 3. Heterotrait-Monotrait Ratio (HTMT) Analysis

	EGI	DLC	IOT	PLA	BIK	BIA
EGI						
DLC	0,546					
IOT	0,562	0,703				
PLA	0,370	0,646	0,612			
BIK	0,406	0,601	0,520	0,670		
BIA	0,265	0,602	0,374	0,694	0,804	

Table 4. Cross Loading Analysis

Variable Items	EGI	DLC	IOT	PLA	BIK	BIA
EGI1	0,818	0,425	0,477	0,409	0,430	0,355
EGI2	0,898	0,494	0,544	0,367	0,384	0,247
EGI3	0,861	0,280	0,369	0,149	0,201	0,107
EGI4	0,900	0,410	0,442	0,268	0,384	0,224
EGI5	0,833	0,361	0,385	0,249	0,261	0,187
EGI6	0,855	0,473	0,504	0,318	0,310	0,185
DLC3	0,348	0,754	0,523	0,525	0,404	0,324
DLC5	0,364	0,849	0,546	0,445	0,500	0,415
DLC6	0,351	0,723	0,406	0,363	0,323	0,462
DLC7	0,467	0,824	0,437	0,366	0,428	0,424
IOT1	0,497	0,517	0,859	0,505	0,429	0,325
IOT2	0,494	0,519	0,880	0,480	0,401	0,254
IOT3	0,441	0,449	0,828	0,388	0,453	0,282
IOT4	0,469	0,516	0,814	0,495	0,353	0,345
IOT5	0,492	0,564	0,859	0,455	0,435	0,300
IOT6	0,424	0,495	0,866	0,401	0,433	0,277
IOT7	0,359	0,512	0,810	0,546	0,382	0,319
PLA1	0,227	0,387	0,346	0,780	0,416	0,551
PLA4	0,297	0,377	0,400	0,869	0,462	0,444
PLA5	0,395	0,472	0,534	0,751	0,636	0,471
PLA6	0,124	0,322	0,422	0,784	0,407	0,498
PLA7	0,325	0,518	0,444	0,761	0,443	0,454
BIK1	0,263	0,426	0,368	0,485	0,820	0,591
BIK2	0,390	0,548	0,455	0,570	0,863	0,634
BIK3	0,340	0,358	0,344	0,521	0,838	0,641
BIK4	0,422	0,533	0,475	0,549	0,858	0,663
BIK5	0,238	0,357	0,386	0,489	0,829	0,640
BIK6	0,260	0,263	0,305	0,357	0,744	0,523
BIK7	0,353	0,505	0,461	0,529	0,824	0,646
BIA1	0,367	0,460	0,443	0,512	0,808	0,807
BIA2	0,212	0,421	0,251	0,440	0,544	0,769
BIA3	0,075	0,378	0,140	0,421	0,438	0,808
BIA4	0,289	0,498	0,323	0,550	0,699	0,869
BIA6	0,184	0,397	0,263	0,603	0,600	0,868
BIA7	0,096	0,339	0,253	0,444	0,503	0,764

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Based on the Cross Loading analysis (table 4), all indicators show the highest loading value on the constructs they are supposed to measure, indicating that discriminant validity through the cross-loading method has been met. For example, the EGI1 indicator has the highest loading of 0,818 on the English Intelligence (EGI) construct, much higher than its loading on other constructs such as DLC (0,425), IOT (0,477), and BIA (0,355). This pattern is consistent across all other indicators, such as IOT2 which has a loading of 0,880 on IoT Knowledge, PLA4 with 0,869 on Project Learning Attitude, and BIK2 with 0,863 on Biological Knowledge.

Based on the results of the path analysis using PLS-SEM (table 5), most of the relationships between variables in the model were statistically significant at the 5 % level ($p < 0,05$). There was a very strong and significant direct effect of English Intelligence on IoT Knowledge ($\beta = 0,539$, $t = 19,105$, $p = 0,000$) and Digital Literacy ($\beta = 0,487$, $t = 17,185$, $p = 0,000$), indicating that English language proficiency significantly contributes to students' technological readiness. Furthermore, English Intelligence also significantly influenced Project Learning Attitude ($\beta = 0,358$, $p = 0,000$). Meanwhile, an increase in English Intelligence was associated with a decrease in Biological Attitude ($\beta = -0,074$, $p = 0,004$), despite simultaneously increasing biology knowledge ($\beta = 0,106$, $p < 0,000$).

The strongest relationship was found between Biological Knowledge and Biological Attitude ($\beta = 0,600$, $t = 19,984$, $p = 0,000$), confirming the central role of knowledge as a predictor of attitude. Other significant paths were from Project Learning Attitude to Biological Knowledge ($\beta = 0,424$) and Biological Attitude ($\beta = 0,256$), and from Digital Literacy to both biology variables. However, the relationship from IoT Knowledge to Biological Knowledge was not statistically significant ($\beta = 0,074$, $p = 0,071$), although the direction of the effect was positive, indicating that mastery of IoT does not necessarily directly influence mastery of biology concepts. Conversely, a negative and significant relationship emerged from IoT Knowledge to Biological Attitude ($\beta = -0,156$, $p = 0,000$), which can be interpreted as indicating that high familiarity with technology does not necessarily align with positive attitudes toward biology lessons.

Table 5. Hypothesis Path

H	Path	Original Sample (β)	T Statistics (|O/STDEV|)	P Values
H1	English Intelligence -> Digital Literacy	0,487	17,185	0,000
H2	English Intelligence -> IoT Knowledge	0,539	19,105	0,000
H3	English Intelligence -> Project Learning Attitude	0,358	13,372	0,000
H4	English Intelligence -> Biological Knowledge	0,106	3,762	0,000
H5	English Intelligence -> Biological Attitude	-0,074	2,863	0,004
H6	Digital Literacy -> Biological Knowledge	0,204	6,198	0,000
H7	Digital Literacy -> Biological Attitude	0,194	5,126	0,000
H8	IoT Knowledge -> Biological Knowledge	0,074	1,804	0,071
H9	IoT Knowledge -> Biological Attitude	-0,156	6,106	0,000
H10	Project Learning Attitude -> Biological Knowledge	0,424	15,169	0,000
H11	Project Learning Attitude -> Biological Attitude	0,256	6,992	0,000
H12	Biological Knowledge -> Biological Attitude	0,600	19,984	0,000

Based on the structural model (figure 2), the highest R^2 value is found in the Biological Attitude variable at 0,634, which means that 63,4 % of the variance in attitudes towards biology can be explained by English Intelligence, Digital Literacy, IoT Knowledge, Project Learning Attitude, and Biological Knowledge. Furthermore, Biological Knowledge has an R^2 of 0,445 (moderate), indicating a substantial proportion of explanation. Meanwhile, Digital Literacy, IoT Knowledge, and Project Learning Attitude have lower R^2 values (0,237, 0,291, and 0,128), indicating that these variables are only partially influenced by English Intelligence.

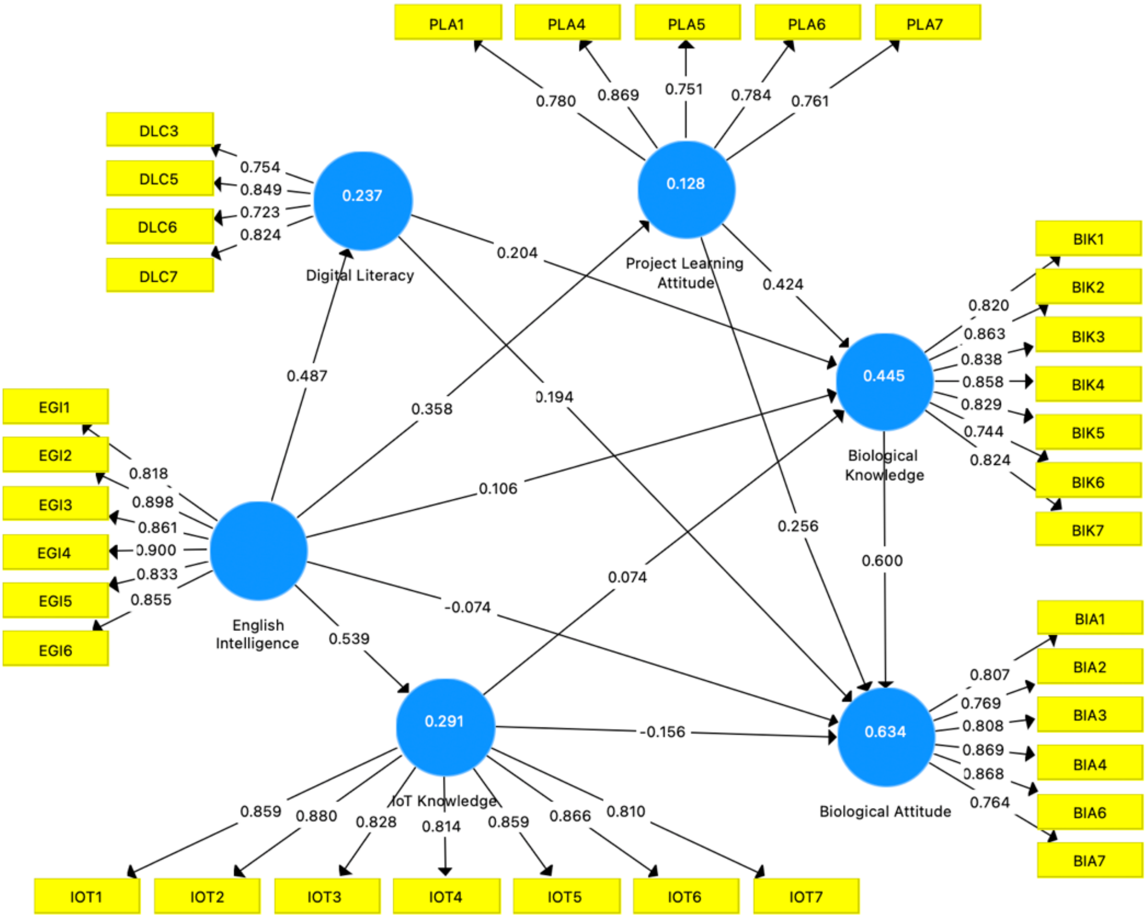

Figure 2. SEM Diagram Analysis

DISCUSSION

These results reinforce the conceptual model that language proficiency, digital literacy, and attitudes toward project learning contribute significantly to improving students' knowledge and attitudes toward biology. Hypotheses H2 and H4 revealed that English Intelligence significantly influences IoT Knowledge and Biological Knowledge, indicating that students with high English proficiency are better able to understand technical materials, documentation, and the operation of IoT systems, as well as a deeper understanding of biology, generally due to the richness of learning resources and media available in English. This reinforces the view that foreign language proficiency not only impacts communication skills but also opens access to complex technological knowledge, making it important to include it as part of a digital science curriculum.[109,110] Meanwhile, Digital Literacy was also shown to significantly contribute to Biological Knowledge. This suggests that students with high abilities in accessing, evaluating, and using digital information are better able to build a broad conceptual understanding of biology.[74] These skills are highly relevant in the era of online and open-source learning, where the quality and validity of the information consumed are key determinants of the quality of academic knowledge.

Project Learning Attitude also demonstrated a strong and significant effect on Biological Knowledge, indicating that students with positive attitudes toward project-based learning are better able to build a deeper biological understanding. Project-based learning allows students to relate biological concepts to real-world contexts, increasing engagement, and developing critical and reflective thinking skills.[61] This approach encourages active exploration and meaningful learning, which not only strengthens conceptual memory but also facilitates the process of knowledge construction.[1,3] Hypothesis H12 also received strong support, with the largest coefficient value in the model, for the effect of Biological Knowledge on Biological Attitude. This confirms that a good understanding of biological material not only improves academic achievement but also strengthens students' positive attitudes toward biology as a whole. Students who understand biological concepts well tend to appreciate the importance of biology in life and demonstrate greater enthusiasm.[100,111] These findings confirm the theory that knowledge is the foundation of affective learning and highlight the importance of teaching strategies that balance cognitive achievement and affective reinforcement.

This study also found unique findings, such as English Intelligence having a negative but significant effect on Biological Attitude. This finding contradicts the initial hypothesis, which assumed that English proficiency would

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support a positive attitude toward biology learning. One critical interpretation of these results is the possibility that students with high English proficiency have higher expectations for the quality of teaching materials and methods. When biology learning is perceived as insufficiently challenging, contextualized, or lacking adequate English-language international references, students may become less engaged, thus decreasing their positive attitudes toward biology.(77,112,113) Furthermore, an academic orientation skewed toward language and technology can shift students' interest away from biology, which may be perceived as more descriptive or theoretical. In other words, high English proficiency does not necessarily equate to an appreciation or interest in biological content, especially if the learning context does not integrate the material globally and transdisciplinary.

Furthermore, the IoT Knowledge on Biological Knowledge pathway shows a positive but insignificant relationship between IoT Knowledge and Biological Knowledge. Conceptually, it is hoped that mastery of Internet of Things technology can help students understand biological phenomena through sensor data, visualization, and automatic monitoring. However, the insignificance of this path indicates a gap between technological mastery and its integration into the biology learning process. One key reason is that IoT is generally understood, such as the use of smart devices in everyday life, but has not yet been directly applied in experimental contexts or in biological scientific studies in academic settings.(1,114) In other words, although students understand IoT, their direct experience connecting this technology to biological concepts is still minimal. The absence of IoT devices in biology laboratories or the absence of technology-based projects means that the effect of IoT knowledge on biology mastery is not strong enough to reach statistical significance.(115,116)

The findings from the correlation between IoT Knowledge and Biological Attitude also show a significant negative effect of IoT Knowledge on Biological Attitude, which is the most contradictory result in this model. This result indicates that students who are more familiar with or familiar with IoT technology actually exhibit less positive attitudes toward biology. A deeper explanation for this finding could be attributed to the misalignment between students' technological preferences and biology learning content, which is still dominated by conventional approaches. Students with high technological literacy tend to have expectations for dynamic, data driven, and interactive learning.(59) If their biology learning doesn't facilitate IoT use or provide space for technological exploration, students will perceive a lack of relevance between biology and their technological competencies. This, in turn, creates the perception that biology is an outdated subject or not applicable to their digital reality, ultimately diminishing positive attitudes toward the subject.

While this study provides important insights into the role of english intelligence, digital literacy, IoT knowledge, and project learning attitudes on students' biology knowledge and attitudes, it has several limitations. The cross-sectional design limits the ability to uncover long-term causal relationships between variables. Furthermore, although the sample included three major islands in Indonesia, this geographic scope does not fully represent the context of biology education across Indonesia. These limitations could guide future research using longitudinal approaches, multi-source measurement methods, and broader population coverage to strengthen the generalizability and depth of analysis.

CONCLUSIONS

This study confirms that the integration of English language proficiency, digital literacy, and attitudes toward project-based learning plays a crucial role in shaping both students' knowledge acquisition and affective responses to biology. English Intelligence was shown to be a significant factor influencing Digital Literacy, IoT Knowledge, and Project Learning Attitude, suggesting that language proficiency serves as a gateway to accessing broader academic and technological resources. However, a surprising finding was the negative effect of English Intelligence on Biological Attitude, indicating a pedagogical gap: students with high language proficiency likely perceive biology learning as insufficiently globally relevant or insufficiently integrated with technology.

Digital Literacy and Project Learning Attitude were shown to positively influence knowledge and attitudes toward biology, while IoT Knowledge showed no significant effect on Biological Knowledge but a significant negative impact on Biological Attitude. This suggests that technological mastery does not automatically have a positive impact without contextual application in biology learning. The very strong effect between Biological Knowledge and Biological Attitude confirms that cognitive mastery is the foundation for student engagement and affective motivation. Therefore, biology learning in higher education needs to be directed appropriately to be more integrated in an interdisciplinary and applicable manner, in line with the digital and linguistic competencies of today's students, in order to build an understanding and appreciation of biology in the 21st century.

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BIBLIOGRAPHIC REFERENCES

1. Mdarbi S, Simour L, Boufarouj C, Belkebir Z, Stili K, Ennadi M. The Role of Individual Performance in the Effect of ICT Appropriation on Educational Performance of Students in Public Universities in the Casablanca-Settat Region, Morocco. European Scientific Journal Esj. 2024; https://doi.org/10.19044/esj.2024.v20n28p67

2. Sain ZH, Lama A. Bridging Knowledge Divides: Examining the Dynamic Landscape of ICT Integration in Pakistan's Education Sector. American Journal of Education and Learning. 2024; https://doi.org/10.55284/ajel.v9i1.1042

3. Lokpo C, Deku JK, Donkor BM, Kumah MS. Impact of Access to and Use of ICT in School on Students' Perceived Performance. Journal of Education and Teaching Methods. 2023; https://doi.org/10.58425/jetm.v2i3.191

4. Kisaalita WS, Mativo J, Youngblood K. What Do Reflective Essays Tell Us About Student Learning Outcomes From Inquiry- And/or Design-Based International Engagement Projects? J Community Engagem Scholarsh. 2022; https://doi.org/10.54656/jces.v14i2.29

5. Mouboua PD, Atobatele FA, Akintayo OT. Bridging STEM and Linguistic Gaps: A Review of Multilingual Teaching Approaches in Science Education. Open Access Research Journal of Multidisciplinary Studies. 2024; https://doi.org/10.53022/oarjms.2024.7.2.0030

6. Budiman B, Putra Ishak JI, Rohani R, Halilurrahman Lalu LM, Slamet Jaelani MPJ. Enhancing English Language Proficiency: Strategies for Improving Student Skills. Journal of Scientific Research Education and Technology (Jsret). 2023; https://doi.org/10.58526/jsret.v2i3.205

7. Mardiani E, Mokodenseho S, Matiala TF, Azzahrah Limbalo SS, Mokodompit NY. Implementation of Digital Science and Literacy Teaching in Developing Science Literacy in Middle School Students in Indonesia. The Eastasouth Journal of Learning and Educations. 2024; https://doi.org/10.58812/esle.v2i01.228

8. Charamba E. Translanguaging in a Multilingual Class: A Study of the Relation Between Students' Languages and Epistemological Access in Science. Int J Sci Educ. 2020; https://doi.org/10.1080/09500693.2020.1783019

9. Mao P, Cai Z, He J, Chen X, Fan X. The Relationship Between Attitude Toward Science and Academic Achievement in Science: A Three-Level Meta-Analysis. Front Psychol. 2021; https://doi.org/10.3389/fpsyg.2021.784068

10. Sripaoraya N, Spronken-Smith R, Longnecker N. Intensive, Short-Term Presenting With a Science Outreach Program Enhances Positive Science Attitudes and Interest in Lifelong Learning About Science. Front Educ (Lausanne). 2022; https://doi.org/10.3389/feduc.2022.719686

11. Eden CA, Chisom ON, Adeniyi IS. Promoting Digital Literacy and Social Equity in Education: Lessons From Successful Initiatives. International Journal of Management & Entrepreneurship Research. 2024; https://doi.org/10.51594/ijmer.v6i3.880

12. ÖZGÜL E, Ocak MA. The Effect of Internet of Things Education Through Distance Education on Student Success and Motivation. Journal of Educational Technology and Online Learning. 2023; http://doi.org/10.31681/jetol.1241362

13. Wang YJ, Seow CK, Hesse H, Wang PC. Digital Solutions for Natural Event Management: Leveraging IoT and Drones for Biodiversity Conservation and Disease Control. 2023; https://ieeexplore.ieee.org/document/10539556

14. Sobach NV, T. Marpaung RR, Maulina D, Yolida B. The Effect of Project-Based Learning Model Assisted by Interactive Digital Modules on Scientific Literacy in Biotechnology Topic in in 9th Grade of Junior High School. Assimilation Indonesian Journal of Biology Education. 2023; https://doi.org/10.17509/aijbe.v6i2.61482

15. Toharudin U, Damaianti LF, Nurul Hizqiyah IY, Kurniawan I. Developing Students' Scientific Literacy Through Wikipedia Digital Library. International Journal of Emerging Technologies in Learning (Ijet). 2023; https://doi.org/10.3991/ijet.v18i24.45605

16. Sánchez Fajardo JA, Vargas-Sierra C. Introduction to the Special Issue “On Communicative Skills in Foreign Language Teaching and Academic Language Instruction: Tools, Resources and Methods in the Digital Era.” Revista De Lenguas Para Fines Específicos. 2022; https://ojsspdc.ulpgc.es/ojs/index.php/LFE/article/view/1517

17. Vettori G, Casado-Ledesma L, Tesone S, Tarchi C. Key Language, Cognitive and Higher-Order Skills for L2 Reading Comprehension of Expository Texts in English as Foreign Language Students: A Systematic Review. Read Writ. 2023; https://link.springer.com/article/10.1007/s11145-023-10479-3

18. Kandil O, Rosillo R, El Aziz RA, la Fuente D de. Investigating the Impact of the Internet of Things on Higher Education: A Systematic Literature Review. Journal of Applied Research in Higher Education. 2024; https://doi.org/10.1108/JARHE-05-2023-0223

19. Liston M, Morrin AM, Furlong T, Griffin L. Integrating Data Science and the Internet of Things Into Science, Technology, Engineering, Arts, and Mathematics Education Through the Use of New and Emerging Technologies. Front Educ (Lausanne). 2022; https://doi.org/10.3389/feduc.2022.757866

20. Hale J, Harkess A, Könyves K. The Jersey Daffodil Project: Integrating Nanopore Sequencing Into Classrooms Improves STEM Skills, Scientific Identity and Career Development. Plants People Planet. 2024; https://doi.org/10.1002/ppp3.10550

21. Shihomeka SP. Assessing Staff Digital Literacy Level vs Attitude Toward Online Teaching and Learning. NJLC. 2023;

22. Lopez MDPA, Ong BA, Borrat X, Fernández AL, Hicklent RS, T. Obeles AJ, et al. Digital Literacy as a New Determinant of Health: A Scoping Review. Plos Digital Health. 2023; https://doi.org/10.1371/journal.pdig.0000279

23. Rice M, Bailon M. A Qualitative Analysis of Publicly Available Standards and Guidance About Digital Literacies in U.S. States. Educ Inf Technol (Dordr). 2022;

24. Diantari Dewi LP, Purnamika Utami IGAL, Santosa MH. The Importance of Digital Literacy Skills in the Context of Learning English for Specific Purposes: A Systematic Review. Jurnal Indonesia Sosial Teknologi. 2024; https://doi.org/10.59141/jist.v5i8.1291

25. İstifçi İ, Göksel N. The Relationship Between Digital Literacy Skills and Self-Regulated Learning Skills of Open Education Faculty Students. English as a Foreign Language International Journal. 2022; https://doi.org/10.56498/164212022

26. Hong Y. Impact of Electronic Resources and Digital Literacy on Autonomous English Learners. Frontiers in Educational Research. 2023;

27. Sutrisno D, Noor Azlinda ZA, Pambudi N, Aydawati EN, Sallu S. Exploring the Benefits of Multimodal Literacy in English Teaching: Engaging Students Through Visual, Auditory, and Digital Modes. GSE-Journal. 2024; https://doi.org/10.61667/xh184f41

28. Zin RM. Unraveling the Dynamics of User Acceptance on the Internet of Things: A Systematic Literature Review on the Theories and Elements of Acceptance and Adoption. Jes. 2024; https://doi.org/10.52783/jes.2392

29. Geng B, Yuan G, Wu D, Shi E, Yang Z. Implementation of Multidimensional Environmental-Economic Collaborative Management in IoT Environment. Sci Program. 2022; https://doi.org/10.1155/2022/8684581

30. Nourildean SW, Hassib MD, Mohammed YA. Internet of Things Based Wireless Sensor Network: A Review. Indonesian Journal of Electrical Engineering and Computer Science. 2022; http://doi.org/10.11591/ijeecs.v27.i1.pp246-261

31. Bahari A. Teacher Identity in Technology-Assisted Language Learning: Challenges and Affordances. E-Learning and Digital Media. 2022; https://doi.org/10.1177/204275302210928

32. Yu L, Chen M, Chiu CW, Hsu CC, Yuan YP. Examining English Ability-Grouping Practices by Aligning CEFR Levels With University-Level General English Courses in Taiwan. Sustainability. 2022; https://doi.org/10.3390/su14084629

33. Fan H, Xie H, Feng Q, Bonizzoni E, Heidari H, McEwan M, et al. Interdisciplinary Project-Based Learning: Experiences and Reflections From Teaching Electronic Engineering in China. Ieee Transactions on Education. 2023; https://ieeexplore.ieee.org/document/9833275

34. Morena K. The Analysis of Scholars' English Language Needs. Bellaterra Journal of Teaching & Learning Language & Literature. 2024; https://revistes.uab.cat/jtl3/article/view/v17-n2-morena

35. Fang Jing JH, Ishak N, Arshad A, Sarijari H, Adam S. Assessing the Impact of Effective Team Collaboration on Individual Outcomes in Collaborative Presentation. International Journal of Research and Innovation in Social Science. 2025; https://dx.doi.org/10.47772/IJRISS.2025.90400088

36. Fan JY, Ye J. The Effectiveness of Inquiry and Practice During Project Design Courses at a Technology University. Front Psychol. 2022;

37. Zen Z, Reflianto R, Syamsuar, Ariani F. Academic Achievement: The Effect of Project-Based Online Learning Method and Student Engagement. Heliyon. 2022; https://doi.org/10.1016/j.heliyon.2022.e11509

38. Gina, Ramadani R, Zebua DR. Utilization of Test Instruments Using Safe Exam Browser for Scientific Literacy Seen From the Perspective of Students. International Journal of Education and Teaching Zone. 2024; https://doi.org/10.57092/ijetz.v3i2.256

39. Setyowati AP, Gunarhadi G, Musadad AA. Development of an Inquiry-Based Virtual Laboratory to Facilitate Biology Practicum for High School Students. Multidisciplinary Science Journal. 2023; https://10.0.124.149/multiscience.2024205

40. Jufri AW, Imam B, Amalina Wahab AD, Riyanto AA. Implementation of English for Biology Based on CLIL Student Handbook to Improve English Proficiency of Prospective Student Biology Teacher. Jurnal Penelitian Pendidikan Ipa. 2023; https://10.29303/jppipa.v9i1.2437

41. Banafi N. Nursing Students' Knowledge and Attitude Towards Medical Writing Skills in the English Language. Journal of Language Teaching and Research. 2023; https://10.17507/jltr.1403.19

42. Sélem-Mojica N, Karakulak T, Anjum A, Pashkov A, Pérez-Estrada R, Enriquez-Guillén K, et al. Closing the Computational Biology 'Knowledge Gap': Spanish Wikipedia as a Case Study. Bioinformatics. 2024; https://doi.org/10.1093/bioinformatics/btae247

43. Thomas K, Jacobs N, Vera AL. A Proposal to Teach Medical Students How to Use Interpreters. Discover Education. 2024; https://link.springer.com/article/10.1007/s44217-024-00177-9

44. Gelderen M van. Using a Comfort Zone Model and Daily Life Situations to Develop Entrepreneurial Competencies and an Entrepreneurial Mindset. Front Psychol. 2023; https://doi.org/10.3389/fpsyg.2023.1136707

45. Satayev M, Balta N, Shaymerdenovna IR, Cézar RF, Mármol GA. Content and Language Integrated Learning Implementation Through Team Teaching in Biology Lessons: A Quasi-Experimental Design With University Students. Front Educ (Lausanne). 2022; https://doi.org/10.3389/feduc.2022.867447

46. Wilson N, Mavuru L. Multilingual Learners' Perceptions of the Role of English and Scientific Language on Natural Sciences Learning. 2023; https://hdl.handle.net/10210/504117

47. Walker S. Digital Literacy Activities. 2024; https://10.4018/979-8-3693-1143-1.ch012

48. Riyanto AA, Bachtiar I, Jufri AW, Amalina Wahab AD. Need Analysis in Learning English for Preservice Biology Teacher. 2022; https://www.atlantis-press.com/proceedings/access-21/125977613

49. Suryaningsih Y, Aripin I. Ecopreneurship Biology Learning With Local Resources to Raise High School Student Entrepreneurial Interest. International Journal of Educational Innovation and Research. 2022; https://doi.org/10.31949/ijeir.v1i1.1864

50. Le H, Thông NN, Vu PT, Tan T. Impact of AI on Self-Learning Capabilities of Employees in SMEs. Journal of Resilient Economies (Issn 2653-1917). 2024; https://doi.org/10.25120/jre.4.2.2024.4176

51. Kocoglu E, OĞUZ-HAÇAT S, Gocer V. The Relationship Between Digital Literacy and Digital Citizenship Levels of STEM Teacher Candidates: The Mediating Role of Digital Teaching Material Development Self-Efficacy. J Educ Environ Sci Health. 2023; https://doi.org/%2010.55549/jeseh.1331283

52. Ussarn A, Pimdee P, Kantathanawat T. Needs Assessment to Promote the Digital Literacy Among Students in Thai Community Colleges. International Journal of Evaluation and Research in Education (Ijere). 2022; http://doi.org/10.11591/ijere.v11i3.23218

53. Mayisela T. A Practice-Based Approach to Developing First-Year Higher Education Students' Digital Literacy. International Journal of Mobile and Blended Learning. 2022; http://10.4018/IJMBL.314582

54. Timotheou S, Miliou O, Dimitriadis Y, Villagrá-Sobrino S, Giannoutsou N, Cachia R, et al. Impacts of Digital Technologies on Education and Factors Influencing Schools' Digital Capacity and Transformation: A Literature Review. Educ Inf Technol (Dordr). 2022; http://doi.org/10.1007/s10639-022-11431-8

55. Yin X, Zhang J, Li G, Luo H. Understanding Learner Satisfaction in Virtual Learning Environments: Serial Mediation Effects of Cognitive and Social-Emotional Factors. Electronics (Basel). 2024; https://doi.org/10.3390/electronics13122277

56. Anders S, Steen A, Müller T, Krause W, Sanwald A, Raupach T, et al. Adventure Legal Medicine: A Free Online Serious Game for Supplementary Use in Undergraduate Medical Education. Int J Legal Med. 2023; https://link.springer.com/article/10.1007/s00414-023-02946-x

57. Lai YH. Learning Efficacy of Understanding by Design-Internet of Things (UbD-IoT) Education Integrated With Design Thinking And computational Thinking. Library Hi Tech. 2023; https://doi.org/10.1108/LHT-01-2023-0002

58. Dr. Arunkumar VR, Thiyagarajan Shreenivasan ProfS. Impact of IOT on Campus; Smart Student Information System in the Educational Sector. Jier. 2024; https://doi.org/10.52783/jier.v4i2.836

59. Senn LG, Heim AB, Vinson E, Smith MK. How Do Undergraduate Biology Instructors Engage With the Open Educational Resource Life Cycle? Front Educ (Lausanne). 2022; https://doi.org/10.3389/feduc.2022.835764

60. Wang H, Peng H, Chen Z, Wang Y, Wu Z, Wang P. Development and Implementation of a Pediatric Clinical Teaching Case Library Based on Massive Real-Time Data. J Multidiscip Healthc. 2024; https://pmc.ncbi.nlm.nih.gov/articles/PMC11471076/

61. Ederon L. Inquiry-Based Learning Resource Material for Improved Integrated Process Skills in Elementary Science. International Journal of Multidisciplinary Research and Analysis. 2024; https://doi.org/10.47191/ijmra/v7-i04-40

62. Thi P. IoT Applications in Agriculture: Enhancing Crop Yield in Vietnam. Ajcet. 2024;

63. Baudin P V, Sacksteder RE, Worthington A, Voitiuk K, Ly VT, Hoffman RN, et al. Cloud-Controlled Microscopy Enables Remote Project-Based Biology Education in Underserved Latinx Communities. Heliyon. 2022; https://doi.org/10.1016/j.heliyon.2022.e11596

64. Dadkhah M, Mehraeen M, Rahimnia F, Kimiafar K. Exploring the Experts' Perceptions of Barriers to Using Internet of Things for Chronic Disease Management in Iran. Journal of Science and Technology Policy Management. 2022; https://doi.org/10.1108/jstpm-07-2021-0104

65. Khadir K, Guermouche N, Guittoum A, Monteil T. A Genetic Algorithm-Based Approach for Fluctuating QoS Aware Selection of IoT Services. Ieee Access. 2022; https://ieeexplore.ieee.org/document/9705594

66. Wang X, Sitthiworachart J. Effects of Project-Based Learning on Students' Learning Performance and Engagement in Computer Science. Kuey. 2024; https://doi.org/10.53555/kuey.v30i4.1169

67. L. Brown ME, Ahuja N, Sivam V, Khanna A, Parekh R. A Qualitative Evaluation of the Impact of a Medical Student School Outreach Project on Both Medical Students and School Pupils. BMJ Open. 2023; https://bmjopen.bmj.com/content/13/11/e070508

68. Boppre B, Reed SM, Belisle LA. "Real Students Helping Others": Student Reflections on a Research-Based Service-Learning Project in a Gender and Victimization Course. Journal of Experiential Education. 2022; https://doi.org/10.1177/10538259221134873

69. Usmeldi U, Amini R. Creative Project-Based Learning Model to Increase Creativity of Vocational High School Students. International Journal of Evaluation and Research in Education (Ijere). 2022; http://doi.org/10.11591/ijere.v11i4.21214

70. Hornejas JS, A. Guntalidad JA. Project-Based Learning Approach on Content Mastery and Cognitive Skills: A Pedagogical Model for Senior High School Biology Students. Sapienza International Journal of Interdisciplinary Studies. 2024; https://doi.org/10.51798/sijis.v5i2.763

71. Heryanti E, Azrai EP, Melvinasari MW. The Relationship Between Motivation to Learn Biology and Discipline With Students' Cognitive Learning Outcomes During Online Learning. Bioedukasi Jurnal Pendidikan Biologi. 2022; https://jurnal.uns.ac.id/bioedukasi/article/view/53849

72. Schmidthaler E, Anđić B, Schmollmüller M, Sabitzer B, Lavicza Z. Mobile Augmented Reality in Biological Education: Perceptions of Austrian Secondary School Teachers. Journal on Efficiency and Responsibility in Education and Science. 2023; https://doi.org/10.7160/eriesj.2023.160203

73. Berglund H. Biology Teachers' Collaborative Experiences: Benefits and Difficulties in Different Contexts in Relation to Perceived Value. Cult Stud Sci Educ. 2022; https://link.springer.com/article/10.1007/s11422-022-10127-2

74. Арбузова ЕН, Yaskina OA, Nazarov S V, Poleshchuk P V, Fortus A V. Augmented Reality Technology as an Immersive Teaching Tool in the Middle School Biology Course. SHS Web of Conferences. 2023; https://doi.org/10.1051/shsconf/202317201041

75. Cahya MD, Priantari I, Pamungkas Y, Ayu Utami NS, Hernowo B. Improving Collaboration and Cognitive Learning Outcomes of Biology Students Using PBL Through Lesson Study. International Social Sciences and Humanities. 2023; https://doi.org/10.32528/issh.v2i2.268

76. Murniati N, Susilo H, Listyorini D. Retention Achievement in Brain-Based Whole Learning Is Supported by Students' Scientific Literacy and Concept Mastery. Pegegog. 2023; https://doi.org/10.47750/pegegog.13.03.30

77. Bizimana E, Mutangana D, Mwesigye A. Effects of Concept Mapping and Cooperative Mastery Learning Strategies on Students' Achievement in Photosynthesis and Attitudes Towards Instructional Strategies. International Journal of Learning Teaching and Educational Research. 2022; https://doi.org/10.26803/ijlter.21.2.7

78. Darmawan E, Sukmawati I, Damayanti BA. The Effect of the Project-Based Learning (PjBL) on Concept Understanding and Environmental Care Attitudes. Jpbio (Jurnal Pendidikan Biologi). 2023; https://doi.org/10.31932/jpbio.v8i2.2413

79. Prayitno BA, Sugiharto B, Titikusumawati E. Effectiveness of Collaborative Constructivist Strategies to Minimize Gaps in Students' Understanding of Biological Concepts. International Journal of Emerging Technologies in Learning (Ijet). 2022; https://doi.org/10.3991/ijet.v17i11.29891

80. Syamsiah, Jamaluddin A Bin, Pratiwi AC. Exploring the impact of educational background, spiritual beliefs, and media exposure on environmental knowledge and attitudes. Eurasia Journal of Mathematics, Science and Technology Education. 2024;20(11). https://doi.org/10.29333/ejmste/15644

81. Hair JF, Ringle CM, Hult GTM, Sarstedt M. Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R. Cham: Springer. 2021. 587–632 p. https://doi.org/10.1007/978-3-319-05542-8_15-2

82. Naeem W, Jamal S, Khan SA. Students English Language Proficiency and Their Academic Motivation. Journal of Languages Culture and Civilization. 2022;

83. Bucay PB, Rosil CB. Academic Motivation and Cognitive Abilities as Predictors of English Language Proficiency Among Senior High School Students. Asian Journal of Education and Social Studies. 2024; https://doi.org/10.9734/ajess/2024/v50i61418

84. Kanamitie JN, Nketsiah J, Asenso K. English Language Proficiency: A Predictor of Academic Performance in Biology. International Journal of Research and Innovation in Social Science. 2023; https://doi.org/https://dx.doi.org/10.47772/IJRISS.2023.7303

85. Kithinji W, OHirsi AI. Relating English Language Proficiency to Academic Performance Among Non-English Speaking Undergraduate Students in Kenyan Universities. East African Journal of Education Studies. 2022; https://doi.org/10.37284/eajes.5.1.560

86. Xiong X, Wang M. The Mediating Effect of Academic Engagement on the Relationship Between Second Language Grit and Language Proficiency. Advances in Education Humanities and Social Science Research. 2023; https://doi.org/10.56028/aehssr.7.1.319.2023

87. Thuy Nguyen LA, Habók A. Tools for Assessing Teacher Digital Literacy: A Review. Journal of Computers in Education. 2023; https://link.springer.com/article/10.1007/s40692-022-00257-5

88. Nikou S, Reuver M de, Kanafi MM. Workplace Literacy Skills—how Information and Digital Literacy Affect Adoption of Digital Technology. Journal of Documentation. 2022; https://doi.org/10.1108/JD-12-2021-0241

89. Mursidi A, Buyung B, Murdani E. Digital Literacy Competence Levels of Indonesian Junior High School Students Based on Activities Through the 5m Approach. Jetl (Journal of Education Teaching and Learning). 2022; http://dx.doi.org/10.26737/jetl.v7i2.3775

90. Abichandani P, Sivakumar V, Lobo D, Iaboni C, Shekhar P. Internet-of-Things Curriculum, Pedagogy, and Assessment for STEM Education: A Review of Literature. Ieee Access. 2022; https://ieeexplore.ieee.org/document/9749084

91. El-Sofany HF, El-Seoud SA, Sharma N. An Analytical Study on the Implementation of a Healthcare App to Assist People With Disabilities Using Cloud Computing and IoT. International Journal of Online and Biomedical Engineering (Ijoe). 2023; https://doi.org/10.3991/ijoe.v19i18.44207

92. Kilicay-Ergin N, Barb AS, Chaudhary N. Knowledge Elicitation Methodology for Evaluation of Internet of Things Privacy Characteristics in Smart Cities. Systems Engineering. 2023; https://doi.org/10.1002/sys.21726

93. Noermanzah N, Suryadi S, Syafryadin S. The Effect of Project-Based Learning Methods on Students' Ability in Developing Research Instruments of CDA. Journal of English Education and Teaching. 2023; https://doi.org/10.33369/jeet.7.3.652-665

94. Pradanti P, Muqtada MohR. Students' Perceptions on Learning, Motivation, and Performance Through Project-Based Learning: Undergraduate Students' Case. Pythagoras Jurnal Program Studi Pendidikan Matematika. 2023; https://doi.org/10.33373/pythagoras.v12i1.5011

95. Abdelkarim S, Almarei SO, Elyas A, Ahmed Amri RA, Mohammed Khawaji EA, Khormi GJ, et al. Knowledge and Attitude Toward Biological Warfare Among Health-Related Students: A Cross-Sectional Questionnaire-Based Survey. J Family Med Prim Care. 2023; https://doi.org/10.4103/jfmpc.jfmpc_1123_22

96. Angeloni-Duarte M, Rosa M, Santos-Alfaya JV. Analysis of the Conceptions of Future Biological Sciences Teachers About Concepts of Evolutionary Theory. Pro-Posições. 2022; https://doi.org/10.1590/1980-6248-2020-0020en

97. Adiyiah M, Mutangana D, Ameyaw Y. Comparing the Efficacy of Two Teaching Strategies on Students' Attitudes Towards Biology: A Case in Ashanti Mampong Municipality, Ghana. J Educ Elearn Res. 2023; https://doi.org/10.20448/jeelr.v10i4.5218

98. Marlina R, Suwono H, Yuenyong C, Ibrohim I, Mahanal S, Saefi M, et al. Technological Pedagogical Content Knowledge (TPACK) for Preservice Biology Teachers: Two Insights More Promising. Participatory Educational Research. 2023; https://doi.org/10.17275/per.23.99.10.6

99. Gharash H Al, Alharbi A, Alshahrani Y, Mousa O. Knowledge and Attitude of Nursing Interns Toward Pressure Injury Prevention in Saudi Arabia: A Multiregional Cross-Sectional Study. SAGE Open Nurs. 2024; https://doi.org/10.1177/23779608241251631

100. Chengere AM, Dobo BB, Zinabu SA, Jilo KW. Enhancing Secondary School Students' Attitudes Towards Biology Through Guided Inquiry-Based Lab Instructions. 2025;

101. Fauzi A, Fatmawati D, Hali AU. Relationship Between the Attitudes of Biology Education Students Towards Statistics With Knowledge of Data Analysis. Jpbi (Jurnal Pendidikan Biologi Indonesia). 2023; https://doi.org/10.22219/jpbi.v9i1.24490

102. Adejimi SA, Nzabalirwa W, Shivoga WA. Enhancing Students' Attitudes Toward Biology Using Consensus and Cooperative Reflective Journal Writing Educational Strategies. Problems of Education in the 21st Century. 2022;

103. Hair JF, Ringle CM, Sarstedt M. PLS-SEM: Indeed a silver bullet. Journal of Marketing Theory and Practice. 2011;19(2):139–52. https://doi.org/10.2753/MTP1069-6679190202

104. Hair JF, Risher JJ, Sarstedt M, Ringle CM. When to use and how to report the results of PLS-SEM. European Business Review. 2019;31(1):2–24. https://doi.org/10.1108/EBR-11-2018-0203

105. Mahande RD, Abdal NM, Nasir N, Rahmi U. Design and effectiveness of the HyFlex-VR learning model for emancipated learning in higher education. Journal of Applied Research in Higher Education. 2025; https://doi.org/10.1108/JARHE-12-2024-0713

106. Benitez J, Henseler J, Castillo A, Schuberth F. How to perform and report an impactful analysis using partial least squares: Guidelines for confirmatory and explanatory IS research. Information and Management. 2020;57(2):103168. Available from: https://doi.org/10.1016/j.im.2019.05.003

107. Henseler J, Ringle CM, Sarstedt M. A new criterion for assessing discriminant validity in variance-based structural equation modeling. J Acad Mark Sci. 2015;43(1):115–35. https://link.springer.com/article/10.1007/s11747-014-0403-8

108. Henseler J. PLS-MGA: A Non-Parametric Approach to Partial Least Squares-based Multi-Group Analysis. In: Gaul WA, Geyer-Schulz A, Schmidt-Thieme L, Kunze J, editors. Challenges at the Interface of Data Analysis, Computer Science, and Optimization. Berlin, Heidelberg: Springer Berlin Heidelberg; 2012. p. 495–501. https://doi.org/10.1007/978-3-642-24466-7_50

109. Wang GA, He J. Bibliometric Analysis on Research Trends of Digital Literacy in Higher Education From 2012 to 2021. International Journal of Emerging Technologies in Learning (Ijet). 2022; https://doi.org/10.3991/ijet.v17i16.31377

110. Chunping N, Dehua S, Ding L. A Study on the Professional Development of Foreign Language Teachers in Universities Based on the Background of AI. Frontiers in Educational Research. 2024; https://doi.org/10.25236/FER.2024.070508

111. Manishimwe H, Shivoga WA, Nsengimana V. Effect of Inquiry-Based Learning on Students' Attitude Towards Learning Biology at Upper Secondary Schools in Rwanda. Journal of Baltic Science Education. 2022; https://doi.org/10.33225/jbse/22.21.862

112. Bizimana E, Mutangana D, Mwesigye A. Students' Perceptions of the Classroom Learning Environment and Engagement in Cooperative Mastery Learning-Based Biology Classroom Instruction. Educ Res Int. 2022; https://doi.org/10.1155/2022/5793394

113. Trisahid TN, Kijkosol D, Corrales CM. Optimization of Biology Learning on Excretory System Material Through Contextual Teaching and Learning Approach. Jou Acd Bio Ed. 2024; https://doi.org/10.37251/jouabe.v1i2.1165

114. Almasri F. Simulations to Teach Science Subjects: Connections Among Students' Engagement, Self-Confidence, Satisfaction, and Learning Styles. Educ Inf Technol (Dordr). 2022; https://doi.org/10.1007/s10639-022-10940-w

115. Chu CE, Wee Cheong GS, Mishra A, Wen Y, Leo CH, Yeo DJ, et al. Enhancing Biology Laboratory Learning: Student Perceptions of Performing Heart Dissection With Virtual Reality. Ieee Access. 2024; https://ieeexplore.ieee.org/document/10509719

116. Hidayah MU, Kuswanto H, Jumadi J, Khotimah K. Integration Review of Project Based Learning in Biology Education: A Systematic Literature Synthesis of Education Levels, Biology Subdisciplines, Research Methodologies and Learning Competencies. International Journal for Multidisciplinary Research. 2024; https://doi.org/10.36948/ijfmr.2024.v06i02.15652

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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