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The influence of creativity, communication, and digital literacy on understanding scientific culture and problem solving skills of biology students

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ABSTRACT

Understanding scientific culture (USC) and developing problem-solving skills (PSS) are important elements in facing complex global challenges in the digital era. This study examines the effects of creativity (CRV), communication (CMN), and digital literacy (DGL) on USC and PSS in biology students at Universitas Negeri Makassar, Universitas PGRI Sumatera Barat, and Universitas Pendidikan Mandalika in Indonesia. A cross-sectional quantitative survey approach was used with a structured online questionnaire, and data were analyzed using the Structural Equation Modeling (SEM) method. The results showed that CRV had a significant direct effect on USC and PSS. CMN also had an effect on USC. However, the direct effect of CMN on PSS was not significant, indicating that its role in improving problem-solving skills was mediated by USC. In contrast, DGL showed a weaker direct effect on PSS and USC, indicating a less dominant role than creativity and communication. These findings emphasize the importance of a synergistic educational approach that integrates CRV, CMN, and DGL to support USC and PSS. Emphasis on creativity as a transformative tool and communication as a collaborative medium in scientific contexts is highly recommended, while DGL needs to be further developed to effectively complement these competencies. Future research needs to explore these relationships in different contexts to refine educational strategies and address evolving challenges.

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INTRODUCTION

The ability to understand scientific culture and develop problem-solving skills are crucial elements in facing increasingly complex global challenges in the digital era (Alrakhman, 2023; Güner & Erbay, 2021). Understanding scientific culture involves integrating scientific concepts into evidence-based mindsets, developing critical thinking skills, and being aware of the role of science in everyday life (Ade et al., 2018). On the other hand, problem-solving skills enable individuals to recognize, analyze, and create innovative solutions in various contexts, both academic and practical (Amalia, 2024). These two abilities complement each other in building relevant competencies for the dynamic world of work and life. In this context, creativity, communication, and digital literacy become important pillars that support each other to form individuals who are not only able to understand scientific concepts in depth, but also apply them in innovative and sustainable problem solving (Sudarto et al., 2021). These competencies are very relevant in supporting the understanding of scientific culture and problem-solving skills, which are essential to facing increasingly complex societal challenges.

Creative ability is identified as a key driver in understanding scientific concepts and translating them into practical applications (Jamaluddin et al., 2021; Redó et al., 2021). In the context of learning, creativity not only functions as the ability to generate new ideas but also as a catalyst for innovative problem solving and the development of critical thinking (Gladushyna, 2019; Tran, 2024). In addition, creativity plays an important role in learning by encouraging students to think beyond conventional boundaries and find innovative solutions to various problems. Education that is oriented towards developing creativity allows students to explore various approaches in understanding complex concepts, including in the field of science. Musengimana et al (2021)and Ernesto et al. (2022) highlighted that developing creativity through innovative learning activities can improve students' ability to connect abstract scientific concepts with real-world contexts.

At the same time, effective communication skills are also key to conveying scientific ideas clearly, both in academic discussions and cross-disciplinary collaborations (Smedinga et al., 2023). In addition, communication skills can also strengthen more deeply about scientific culture and collaboration in problem solving (Wrighting et al., 2021). According to Yasmawan (2020) and Wicaksono et al (2022), students who have good communication skills tend to be more able to express their thoughts clearly, both in academic discussions and in collaborative contexts, thus facilitating a deeper understanding of the learning material. Furthermore, effective communication skills also encourage the development of social skills, empathy, and the ability to work in teams, which are essential in the modern workplace (Jacob et al., 2019; Munohsamy & Muniandy, 2023).

Digital literacy complements both creativity and communication skills competencies by ensuring that learners are able to access, evaluate, and use information wisely in an era dominated by digital technology. Digital literacy not only facilitates the understanding of academic concepts through access to diverse learning resources, but also encourages the development of analytical, creativity, and problem-solving skills (Martinez Zayas & Rofi'ah, 2022; Özeren, 2023). Digital literacy also enables learners to actively participate in technology-based learning, such as online and project-based learning, which reflects the needs of a world of work that is increasingly integrated with digital technology (Kailani et al., 2021; Wu et al., 2021). Research by Mufidah et al., (2023) confirms the important role of digital literacy in equipping individuals to engage effectively with science and approach problems systematically. As noted by Zhang et al., (2021) and Klochko & Prokopenko, (2023), digital literacy plays a vital role in equipping learners to explore and evaluate scientific information in the digital environment, encouraging more informed decision-making. Creativity, communication skills, and digital literacy form a framework of mutually supportive capabilities to enhance learner engagement in the learning process and enable learners to understand science concepts in a more meaningful way.

While existing literature highlights the importance of creativity, communication skills, and digital literacy separately, there is a significant research gap in understanding their combined effects. Previous research has shown that creativity plays an important role in driving innovation and problem solving, especially in dynamic and knowledge-based environments (Syamsiah et al., 2024). On the other hand, communication skills have been shown to enhance collaboration, strengthen interpersonal relationships, and support effective delivery of ideas in various contexts, including in biology students' academic and practicum activities (Murphy & Kelp, 2023; Troy et al., 2022). Meanwhile, digital literacy has been identified as key to efficiently accessing, evaluating, and utilizing technology-based information, which is highly relevant for biology students in facing the latest developments in science and technology (Jamaluddin et al., 2025; Yasmawan, 2020).

Very few studies have examined how these competencies interact collectively to enhance learners' understanding of scientific culture and problem-solving skills. A study by Guaman-Quintanilla et al., (2022) showed that a synergistic approach integrating creative thinking, digital tools, and effective communication yielded superior outcomes in complex problem-solving scenarios. However, these findings are often limited to a specific scope and do not address the broader implications of integrating these competencies into mainstream education systems, creating opportunities for further exploration. For example, a study by Liu, (2023) revealed that traditional teaching methods often fail to address the dynamics of interactions between these skills. These limitations underscore the importance of empirical research to investigate how these competencies collectively impact learners' ability to understand scientific culture and solve problems effectively.

In addition, the facts on the ground also show that there is a lack of empirical evidence regarding the synergistic effects between creativity, communication skills, and digital literacy in improving students' understanding of scientific culture and problem-solving skills. To address this issue, this study proposes a comprehensive investigation of the interactions between these competencies, providing evidence-based insights into their roles in modern education. The novelty of this study lies in its emphasis on the interactions of the three competencies, rather than their effects separately, in a local context. By focusing on education in Indonesia, this study also addresses the contextual gap in the existing literature. The scope of this study includes the evaluation of these competencies on students with a mixed approach, providing quantitative and qualitative insights into their interactions and educational implications. The research hypothesis states that there is a synergistic relationship between the influence.

1. H1 creativity towards understanding scientific culture,
2. H2 creativity towards problem-solving skills,
3. H3 communication skills towards understanding scientific culture,
4. H4 communication skills towards problem-solving skills,
5. H5 digital literacy towards understanding scientific culture,
6. H6 digital literacy towards problem-solving skills,
7. H7 understanding scientific culture towards problem-solving skills.
8. H8 creativity towards problem-solving skills through understanding scientific culture,
9. H9 communication skills towards problem-solving skills through understanding scientific culture,
10. H10 digital literacy towards problem-solving skills through understanding scientific culture.

METHODS

Types and Design of Research

This study uses a quantitative approach with a cross-sectional survey design (Syamsiah et al., 2024). This method was chosen to evaluate the relationship between creativity, communication, and digital literacy on students' understanding of scientific culture and problem-solving skills at a certain time. This study utilized a survey technique with a structured online questionnaire to collect data from students from various locations and levels of education. The data obtained were analyzed using Structural Equation Modeling (SEM) to evaluate the direct and indirect relationships between independent and dependent variables. This method is expected to provide empirical insight into the synergistic influence between creativity, communication, and digital literacy in supporting students' understanding of scientific culture and problem-solving skills. The SEM model diagram is presented in Figure 1.

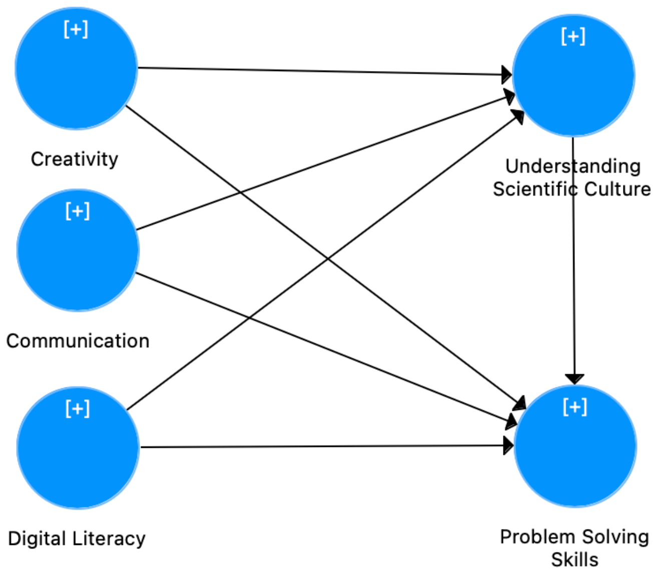

Figure 1. SEM Model Diagram

Research Subject

Participants were biology students from Universitas Negeri Makassar, Universitas PGRI Sumatera Barat, and Universitas Pendidikan Mandalika in Indonesia. The students selected were students in the second semester of 2023-2024. The sample was selected using a stratified sampling technique to ensure equal representation from the three selected cities (Table 1). Therefore, out of 439 students in three different cities, only 270 met the qualifications to continue the data collection process. Students who participated in this study had agreed to participate in the study and filled out the instruments used during the study. The number of samples was calculated based on the criteria of 10 times the number of indicators in the SEM analysis, as recommended in the literature.

Table 1
Demographics of research subjects

University	Male	Female	Percentage (%)
Universitas Negeri Makassar	46	67	41.85
Universitas PGRI Sumatera Barat	35	44	29.26
Universitas Pendidikan Mandalika	38	40	28.89
Total	119	151	100

Data Collection Instruments and Techniques

The instrument is a questionnaire that has been developed by researchers using a 4-point Likert scale that includes dimensions of creativity, communication skills, digital literacy, understanding of scientific culture, and problem-solving skills. Data were collected online during the learning period, ensuring that participants understood the purpose of the study and provided voluntary consent for participation. Initial trials were conducted to ensure the clarity of the questionnaire items and reduce the potential for bias in student interpretation. The instrument is presented in Table 2.

Table 2
Statement of each variable item in the research instrument

Variable Items	Survey Item Statement
CRV1	I often find new ideas when working on learning assignments.
CRV2	The learning that I follow encourages me to think creatively in solving problems.
CRV3	I am able to create innovative solutions to challenges faced during the learning process.
CRV4	Learning activities encourage me to think outside the box and seek new approaches.
CRV5	I am motivated to explore new ways to complete learning assignments.
CRV6	I am able to convey my ideas or opinions clearly during learning discussions.
CMN1	The learning that I follow helps me improve my speaking skills in front of classmates.
CMN2	I feel confident to actively participate in group or class discussions.

CMN3	Teachers often give me the opportunity to express my thoughts related to learning materials.
CMN4	I am able to construct logical and structured arguments when answering questions or explaining ideas.
CMN5	The learning provided encourages me to communicate effectively both orally and in writing.
DGL1	I can easily access learning information through digital sources.
DGL2	The learning that I follow helps me understand how to use digital technology to support the learning process.
DGL3	I am able to evaluate the credibility of information that I obtain from digital sources.
DGL4	Learning activities encourage me to use digital devices in working on assignments or projects.
DGL5	I feel skilled in using digital applications or devices to support learning.
DGL6	The learning provided helped me understand the importance of ethics in using digital resources.
USC1	I understand how science contributes to solving problems in society.
USC2	The learning I took encouraged me to think critically in understanding scientific phenomena.
USC3	I can explain the relationship between science and everyday life based on the material taught.
USC4	I feel capable of evaluating scientific information with an evidence-based approach.
USC5	The learning helped me understand the importance of integrity and ethics in the application of science.
PSS1	I understand the importance of evidence-based thinking in the learning process.
PSS2	The learning I took encouraged me to use the scientific method in solving problems.
PSS3	I am skilled in analyzing the causes of a problem before trying to solve it.
PSS4	I can use the information obtained to find effective solutions to a problem.
PSS5	The learning provided encouraged me to use a creative approach in solving problems.
PSS6	I feel more confident in making decisions after going through the problem-solving process during learning.

Data Analysis Techniques

Data analysis was performed using SmartPLS 3 software to test the measurement and structural models. Data validity was measured from outer loading (<.70), and instrument reliability was tested through construct validity test (AVE> 0.50) and internal consistency through Cronbach's Alpha (> 0.70), Rho A (> 0.70), Composite Reliability (> 0.70) (Barclay & Thomson, 1995; Hair et al., 2019). Discriminant validity was assessed using the Fornell-Larcker criteria (Fornell & F. larcke, 1981), while significance testing was performed using the bootstrapping method at a 95% confidence level ($p < 0.05$) (Henseler, 2012). Evaluation of the coefficient of determination (R^2) was used to measure the predictive power of the model against the dependent variable.

RESULTS AND DISCUSSION

The results of the reflective measurement model analysis (Table 3) show that all constructs have indicators with outer loading above the threshold value of 0.70, indicating that each item has a significant contribution to the measured construct. Specifically, the "Understanding Scientific Culture" construct shows the highest Cronbach's Alpha value (0.923) with a Composite Reliability of 0.942 and an Average Variance Extracted (AVE) of 0.765, indicating very good measurement quality in absorbing variations in its indicators. These results reflect that the construct has strong internal coherence, indicating that understanding scientific culture is a well-structured aspect in the context of the measurement carried out. In the "Communication" construct, it has the highest AVE value (0.703) compared to other constructs, although its Cronbach's Alpha and Composite Reliability are relatively lower than other constructs such as "Understanding Scientific Culture." This shows that the communication indicator makes a significant contribution to the total variance.

Table 3.
The Results of The Reflective Measurement Model Analysis

Variable/Construct	Variable Items	Outer Loading	Cronbach's Alpha	Rho_A	Composite Reliability	AVE
Creavity	CRV1	0.892	0.902	0.908	0.925	0.675
	CRV2	0.769				
	CRV3	0.852				
	CRV4	0.795				

Variable/Construct	Variable Items	Outer Loading	Cronbach's Alpha	Rho_A	Composite Reliability	AVE
	CRV5	0.732				
	CRV6	0.877				
Communication	CMN1	0.737				
	CMN2	0.888				
	CMN3	0.891	0.893	0.900	0.922	0.703
	CMN4	0.877				
	CMN5	0.786				
Digital Literacy	DGL1	0.765				
	DGL2	0.750				
	DGL3	0.864	0.887	0.894	0.914	0.642
	DGL4	0.756				
	DGL5	0.879				
	DGL6	0.781				
Understanding Scientific Culture	USC1	0.898				
	USC2	0.835				
	USC3	0.873	0.923	0.925	0.942	0.765
	USC4	0.863				
	USC5	0.902				
Problem Solving Skills	PSS1	0.868				
	PSS2	0.758				
	PSS3	0.882	0.909	0.913	0.930	0.691
	PSS4	0.768				
	PSS5	0.864				
	PSS6	0.837				

Table 4 shows the results of the Fornell-Larcker criteria, which are used to test the discriminant validity between constructs. These results indicate that the diagonal value (AVE root) for each construct is higher than the correlation value between other constructs, indicating that discriminant validity is met. A unique finding from this table is seen in the relationship between "Communication" (CMN) and "Digital Literacy" (DGL), which has the highest correlation value of 0.838. This shows that there is a strong relationship between communication skills and digital literacy, which may indicate a close interrelationship in the context of this study. In contrast, the relationship between "Creativity" (CRV) and "Digital Literacy" (DGL) has the lowest correlation value of 0.709, indicating that creativity stands alone rather than being related to digital literacy. This finding provides insight that certain dimensions may have a more independent role, while others show stronger synergy in influencing overall outcomes.

Table 4

Descriptive Fornell-Larcker Criterion

Variable	CRV	CMN	DGL	USC	PSS
CRV	0.952				
CMN	0.924	0.933			
DGL	0.709	0.838	0.871		
USC	0.812	0.929	0.900	0.917	
PSS	0.722	0.819	0.724	0.805	0.831

Table 5 presents the cross-loading results for each item in the CRV, CMN, DGL, USC, and PSS variables. The findings show that all items have higher loading values on their main constructs compared to other constructs, indicating adequate discriminant validity. This indicates that each item is more relevant to its main construct and can be relied upon to measure the dimension.

Table 5.
Item Variable Cross-Loading

Variable Items	CRV	CMN	DGL	USC	PSS
CRV1	0.880	0.818	0.779	0.770	0.720
CRV2	0.870	0.799	0.742	0.751	0.696
CRV3	0.889	0.918	0.791	0.822	0.735
CRV4	0.876	0.842	0.774	0.810	0.707
CRV5	0.870	0.823	0.906	0.831	0.731
CRV6	0.886	0.419	0.433	0.376	0.474
CMN1	0.834	0.949	0.857	0.874	0.780
CMN2	0.825	0. 937	0.843	0.925	0.770
CMN3	0.823	0.906	0.792	0.778	0.737
CMN4	0.806	0.896	0.777	0.773	0.722
CMN5	0.889	0.918	0.791	0.822	0.735
DGL1	0.735	0.766	0.849	0.715	0.673
DGL2	0.770	0.787	0.883	0.774	0.713
DGL3	0.745	0.723	0.890	0.682	0.675
DGL4	0.837	0.815	0.916	0.790	0.733
DGL5	0.870	0.823	0.906	0.831	0.731
DGL6	0.856	0.719	0.823	0.918	0.756
USC1	0.585	0.576	0.571	0.737	0.533
USC2	0.660	0.657	0.644	0.835	0.609
USC3	0.764	0.752	0.762	0.880	0.675
USC4	0.875	0.937	0.843	0.925	0.770
USC5	0.645	0.625	0.630	0.616	0.875
PSS1	0.588	0.592	0.611	0.581	0.839
PSS2	0.646	0.614	0.634	0.613	0.858
PSS3	0.587	0.573	0.555	0.549	0.802
PSS4	0.694	0.667	0.659	0.654	0.891
PSS5	0.894	0.949	0.857	0.874	0.780
PSS6	0.586	0.419	0.433	0.376	0.774

The results of the analysis in Table 6 show several unique findings related to the direct and indirect relationships between variables. In the direct effect, the relationship between CRV and USC (β = 0.320; p < 0.001) *(H1)* and CRV and PSS (β = 0.467; p < 0.001) *(H2)* have very high significance, indicating that CRV plays a significant role in influencing both USC and PSS. In addition, the relationship between CMN and USC (β = 0.504; p < 0.001) *(H3)* also shows a strong and significant effect, confirming that CMN is an important predictor of USC. In contrast, the relationship between CMN and PSS is not significant (p = 0.672) *(H4)*, indicating that CMN does not contribute directly to PSS, so its effect on PSS may be mediated by other variables. This reflects a different dynamic compared to other constructs, which directly contribute significantly to PSS.

In the indirect effect, the relationship between CMN and PSS through USC showed a significant effect (β = 0.156; p = 0.002) *(H9)*, indicating that USC is an important mediator in linking CMN to PSS. In contrast, the indirect effect of DGL on PSS was not significant (p = 0.240) *(H10)*, although the direct effect of DGL on PSS was significant (p = 0.017). These findings indicate that the contribution of DGL to PSS is more direct than through a mediation pathway. In addition, CRV showed a significant indirect effect on PSS (β = 0.099; p = 0.009) *(H8)*, emphasizing the importance of CRV in influencing perceived stress (PSS) through other pathways, such as USC. These results highlight the specific roles of different mediation pathways and the unique relevance of each construct in the research model..

Table 6.
Direct and Indirect Impacts (Hypothesis Test)

Variable	Original Sample (β)	Sample Mean	Standard Deviation	T Statistics	P Values
Direct Effects					
CRV -> USC	0.320	0.317	0.085	3.763	0.000
CRV -> PSS	0.467	0.465	0.070	6.683	0.000
CMN -> USC	0.504	0.510	0.109	4.635	0.000
CMN -> PSS	0.036	0.036	0.084	0.424	0.672
DGL -> USC	0.140	0.137	0.111	1.261	0.207
DGL -> PSS	0.187	0.190	0.078	2.387	0.017
USC -> PSS	0.310	0.308	0.077	4.008	0.000
Indirect Effects					
CRV -> PSS	0.099	0.098	0.038	2.624	0.009
CMN -> PSS	0.156	0.156	0.050	3.098	0.002
DGL -> PSS	0.043	0.042	0.037	1.175	0.240

The structural model shown in Figure 2 shows the relationship between constructs, with interesting unique findings. Creativity shows a significant direct effect on Understanding Scientific Culture (USC) with a value of $\beta = 0.320$, indicating that creativity plays an important role in improving the understanding of scientific culture. In addition, the direct effect of Creativity on Problem Solving Skills (PSS) has a value of $\beta = 0.467$, which is stronger than the effect of Digital Literacy (DGL) on PSS ($\beta = 0.187$). This indicates that creativity makes a more substantial contribution to problem-solving skills compared to digital literacy, highlighting the role of innovation and creative ideas in the context of solving complex problems.

In contrast, another finding is the significant contribution of Communication (CMN) to USC ($\beta = 0.504$) which is one of the strongest paths in this model. However, the direct effect of Communication on PSS has a very small and insignificant value ($\beta = 0.036$), indicating that communication skills do not directly affect problem-solving skills. In contrast, the effect of Communication on PSS appears to be mediated by USC, as indicated by the significant β value in the USC to PSS path ($\beta = 0.310$). This underscores that understanding scientific culture may be an important mediator that strengthens the relationship between communication and problem-solving skills, creating a more complex causal pathway in this model.

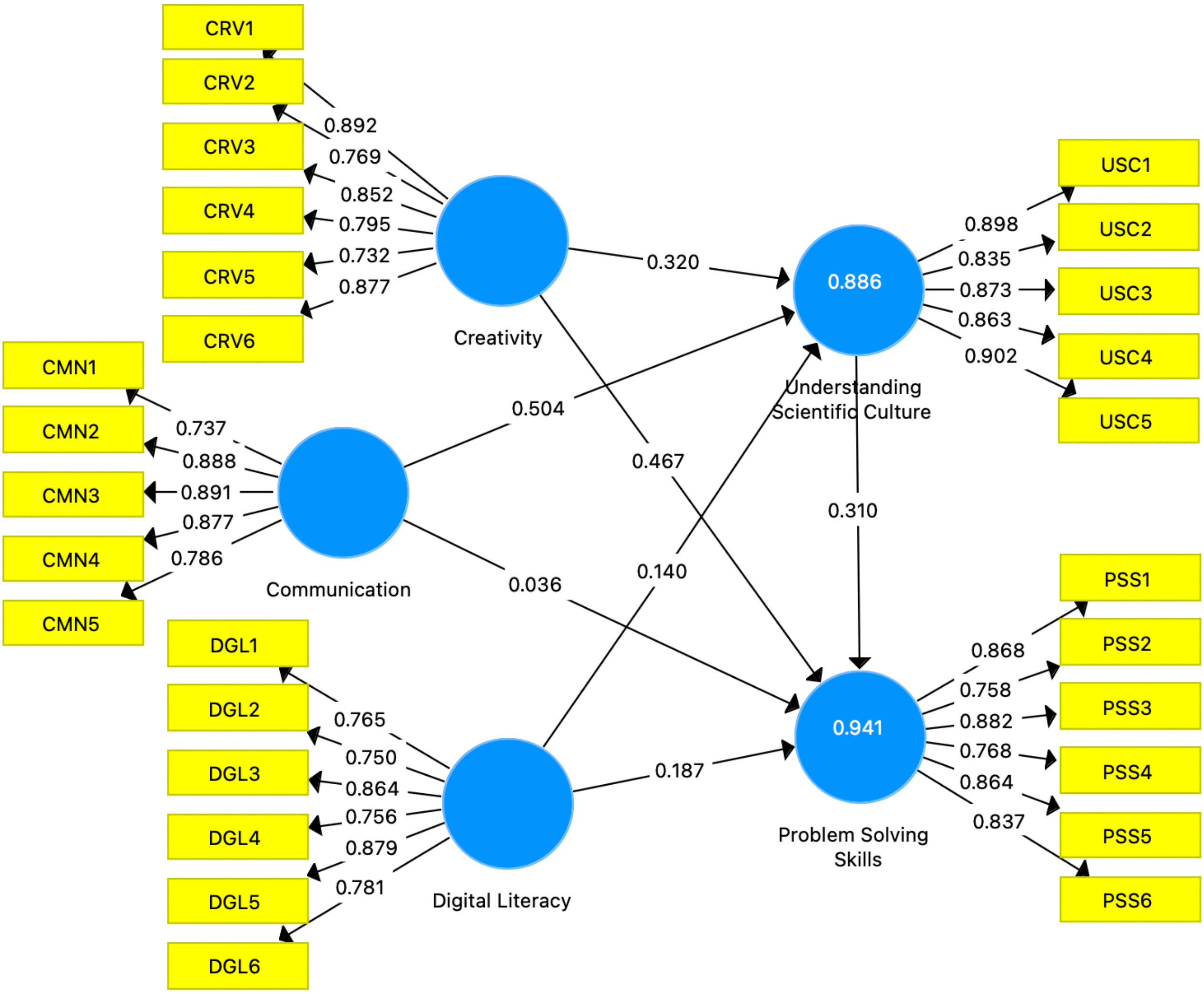

Figure 2. SEM Analysis Results

This result is in line with previous studies that emphasize the importance of creativity in improving problem-solving abilities through innovative thinking and the application of scientific principles. (Redó et al., 2021). Likewise, the significant effect of communication on USC supports the findings of Wrighting et al., (2021), which highlight the importance of communication in fostering collaboration and understanding of complex scientific concepts. However, the absence of a direct effect of CMN on PSS ($p < 0.672$) contradicts previous studies (e.g., Karim, 2025) which show that good communication skills directly facilitate problem solving. Communication skills cannot directly shape problem-solving skills because communication functions more as a tool to convey, elaborate, and share ideas, rather than as a core mechanism in the analysis or solution of the problem itself (Winarto et al., 2022). In the context of problem solving, analytical and cognitive processes, such as problem identification, data analysis, and development of innovative solutions, require critical thinking and creativity as the main core. In contrast, communication plays a supporting role by ensuring that ideas can be communicated clearly to others, facilitating collaboration, and enabling constructive feedback (Kadir, 2023; Obi et al., 2020). However, communication has an indirect contribution through mediating pathways, such as understanding scientific culture (USC), which provides a conceptual framework for connecting information and building an evidence-based approach to problem solving. This is in line with the literature emphasizing that effective communication encourages team coordination and idea exchange rather than independent problem solving (Wrighting et al., 2021).

In understanding scientific culture, the effect of DGL is weaker compared to CRV and CMN, which is in line with the observation of Mufidah et al., (2023), who highlighted that although digital literacy is important, it does not independently drive significant gains in scientific understanding without integration with other skills, such as creativity and communication. Digital literacy mainly focuses on the ability to access, evaluate, and utilize digital information, which, although important, is more supportive than central to generating creative ideas or building conceptual connections through communication (Kesici, 2022; Martinez Zayas & Rofi'ah, 2022; Syefrinando et al., 2022). In contrast, creativity directly contributes to innovation and the development of new solutions, while communication plays a role in strengthening collaboration and shared understanding, both of which are key elements in solving complex problems. Furthermore, the impact of DGL can be limited if it is not accompanied by the critical ability to integrate digital information into relevant contexts, which often relies on creative skills or effective communication. This is in line with research by Pangrazio et al., (2020), Azzahro et al., (2023), and Halim, (2024)., which shows that digital literacy, although crucial for accessing scientific resources, has a greater impact when integrated with other skills such as critical thinking and creativity, which are more dominant in determining learning outcomes and problem solving.

These findings emphasize the importance of the synergistic relationship between creativity, communication, and digital literacy in shaping scientific cultural understanding and problem-solving skills. In particular, creativity emerged as the most influential factor, confirming its potential as a key focus in educational strategies aimed at fostering innovation. The mediating role of USC in the relationship between communication and problem-solving suggests the need to design curricula that not only enhance communication skills but also place them in the context of scientific inquiry and critical thinking. Although digital literacy contributes to this competency, its relatively weaker influence suggests that its effectiveness depends on its integration with other skills, such as creativity and communication. These results highlight the need for a holistic approach in education, where these competencies are developed synergistically to prepare individuals for the complex problem-solving demands of the modern era.

CONCLUSION

This study demonstrated the significant roles of creativity (CRV), communication (CMN), and digital literacy (DGL) in influencing scientific culture understanding (USC) and problem-solving skills (PSS). Among these factors, creativity emerged as the most influential, exerting a direct impact on both USC and PSS. Communication proved crucial in enhancing USC, but its effect on PSS was mediated through USC, reflecting the importance of scientific culture in bridging conceptual understanding and problem-solving skills. In contrast, digital literacy showed a weaker effect compared to creativity and communication, emphasizing its more instrumental nature that complements, rather than independently drives, cognitive processes and problem solving. These findings highlight the need for a synergistic approach in education that integrates creativity, communication, and digital literacy to build critical competencies for the 21st century. Specifically, creativity should be emphasized as a transformative tool in educational strategies, while communication and digital literacy need to be developed in tandem with critical thinking and contextual application. This holistic approach is essential to prepare individuals for the complexities of modern problem solving, ensuring relevance and adaptability in an increasingly dynamic world. Future research needs to explore these relationships further in a variety of contexts to refine educational interventions and address the evolving challenges in science education and other fields.

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