E-Comic Ethnomathematics Based on Bugis-Makassar Culture: PLS-SEM Analysis of Learning Outcomes and Cultural Literacy in Indonesian Primary Education

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Abstract: Background: Mathematics learning in elementary schools requires innovative approaches that not only improve students′ cognitive achievement but also strengthen cultural literacy and identity. Ethnomathematics provides an opportunity to integrate local cultural values into mathematics learning, particularly through digital learning media that are relevant to today′s digital-native students. However, studies integrating Bugis-Makassar culture with interactive digital media and analyzing its impact using Partial Least Squares-Structural Equation Modeling (PLS-SEM) remain limited. This study aimed to analyze the impact of Bugis-Makassar culture-based E-Comic Ethnomathematics on elementary school students learning outcomes and cultural literacy. It also examined the relationships between competence, teacher support, engagement, motivation, self-efficacy, cultural literacy, and learning outcomes using the PLS-SEM approach.

Methods: This study used a quantitative design with SEM-PLS analysis involving 50 fourth-grade students from two elementary schools in Pangkep, South Sulawesi. Data were collected through validated questionnaires and assessments of cultural literacy and mathematics learning outcomes.

Results: The results showed that students′ competence significantly influenced engagement and self-efficacy, indicating that E-Comic Ethnomathematics enhanced students′ confidence and participation in learning. However, teacher support, motivation, and engagement did not significantly affect learning outcomes or cultural literacy.

Conclusions: This study highlights the importance of integrating local wisdom and digital technology through E-Comic Ethnomathematics to support meaningful mathematics learning. Further development of adaptive digital edu-ethnomathematics platforms is recommended to strengthen students′ academic achievement and cultural identity.

Keywords: E-Comic, Ethnomathematics, Bugis-Makassar Culture, PLS-SEM, Learning Outcomes, Cultural Literacy, Primary Education

Introduction

Mathematics is a fundamental subject in elementary school that not only demands logical and analytical thinking skills but also plays a strategic role in shaping students' character and identity (Chen et al., 2024; Kaskens et al., 2020; Kim et al., 2019; Sievert et al., 2019) . Contextual mathematics learning through an ethnomathematics approach can connect abstract concepts with cultural practices of the community so that students more easily understand the relevance of mathematics in everyday life (Batiibwe, 2024; Nugraha et al., 2020; Nur et al., 2020, 2021) . In the Indonesian context, Bugis-Makassar culture contains a wealth of symbols, patterns, and traditions that can be explored as a source of mathematics learning. The integration of local wisdom in learning is also in line with the direction of national education policy which emphasizes strengthening the profile of Pancasila students and cultural literacy from the elementary education level. Therefore, the development of ethnomathematics-based learning media is urgent to create meaningful, contextual, and relevant learning experiences to students' needs in the digital era (Batiibwe, 2024; Hillmayr et al., 2020; Salsabila et al., 2024; Zapata et al., 2024) .

Several previous studies have shown that ethnomathematics is effective in improving students' motivation and understanding of mathematical concepts. However, most studies are still limited to the introduction or application of culturally based materials in conventional forms, such as the use of folklore, traditional games, or simple print media (Salsabila et al., 2024) . The lack of research integrating ethnomathematics with digital technology is a weakness, especially because today's elementary school students are a digital native generation accustomed to interactive media (Munawwaroh et al., 2025) . Furthermore, most previous studies only emphasize cognitive aspects without exploring the complex relationship between learning outcomes and cultural literacy that can be measured through a quantitative approach based on structural equation modeling (PLS-SEM).

A research gap is also found in the limited number of studies focusing on Bugis-Makassar culture as a context for developing mathematics learning media. Although several international studies have highlighted the integration of local culture in digital mathematics learning, studies specifically exploring the use of Bugis-Makassar culture in the form of interactive digital comic media are still rare (Annisa et al., 2024) . Furthermore, the use of PLS-SEM analysis to examine the impact of ethnomathematics- based media on elementary school students' learning outcomes and cultural literacy has also been limited. This research gap is important to fill because it can provide new contributions in connecting students' cognitive and affective dimensions through a culture-based approach and digital technology.

Furthermore, in the context of learning, various previous studies have discussed the concept of ethnomathematics, explaining that cultural elements can be used in mathematics learning and have an impact on improving student understanding (Laurens, 2017) . Research by Sirate, 2012 also explains that the application of ethnomathematics can improve the understanding of abstract mathematical concepts in elementary school students. Ethnomathematics learning can also make a positive contribution in helping students understand abstract mathematical concepts (Razak et al., 2024; Rosida et al., 2018; Yudhi & Septiani, 2024) . These studies only reveal that cultural values in ethnomathematics can be an alternative in providing a contextual understanding of mathematical concepts. However, they do not reach the innovation of ethnomathematics learning that is relevant to current digital technology advances. Meanwhile, digitalization in learning practices is very important to be carried out as an effort to prepare students who are ready in terms of theory and application of learning and are adaptive in facing the rapid development of digital technology (Ahmad et al., 2023; Aziz et al., 2023; Hans & Crasta, 2019; Trends et al., 2020) . Based on the results of the study, the novelty in the research highlights the importance of integration between learning activities, local wisdom values and digitalization of learning through Edu-ethnomathematics based on E-comic Articulate Storyline.

Based on these conditions, this study aims to analyze the impact of the use of Bugis-Makassar culture-based E-Comic Ethnomathematics on learning outcomes and cultural literacy of elementary school students using PLS-SEM. The results of this study not only provide theoretical contributions to the development of ethnomathematics studies, but also recommend the development of an eduetnomathematics model based on Articulate Storyline as a more adaptive, interesting, and applicable interactive media for elementary school contexts. Thus, this study is expected to be a foundation for the development of innovative learning media that are in line with local wisdom while utilizing digital technology to strengthen the quality of elementary education in Indonesia.

Literature Review

2.1 Ethnomathematics and Digital Learning Media

Ethnomathematics has become an increasingly important approach in mathematics education because it connects mathematical concepts with cultural practices, traditions, and local wisdom. Through ethnomathematics, students can develop mathematical understanding based on real-life cultural experiences, making learning more meaningful and contextual. Several recent studies have shown that ethnomathematics contributes positively to conceptual understanding, mathematical literacy, and problem-solving skills because students can relate mathematical ideas to their surrounding cultural environment (Batiibwe, 2024; Nursanti et al., 2024; Pratama & Yelken, 2024).

In primary education, ethnomathematics also plays an important role in strengthening students' cultural identity and appreciation of local heritage. The integration of cultural contexts into mathematics instruction enables learners to simultaneously develop cognitive competencies and cultural awareness. Previous studies conducted in Indonesia have demonstrated that ethnomathematics-based learning improves students' engagement, participation, and mathematical comprehension while preserving local cultural values (Nisa' & Malasari, 2024; Nursanti et al., 2024).

2.2 E-Comic Ethnomathematics as Digital Learning Media

The advancement of digital technology has transformed educational practices by providing innovative learning media that support interactive and student-centered learning. One of the emerging digital learning innovations is educational e-comics, which combine visual storytelling, illustrations, and educational content in a format that is attractive to elementary school students. Educational comics can simplify abstract mathematical concepts and facilitate conceptual understanding through contextual narratives and visual representations (Mamolo & Sugano, 2023).

When ethnomathematics is integrated into e-comic media, students are exposed not only to mathematical concepts but also to local cultural knowledge embedded within learning activities. This integration creates meaningful learning experiences by linking mathematics to cultural realities familiar to students. Research indicates that culturally contextualized digital learning media can significantly improve students' academic achievement, engagement, and self-efficacy in mathematics learning (Mamolo & Sugano, 2023; Batiibwe, 2024).

2.3 Teacher Support, Engagement, and Learning Motivation

Teacher support represents one of the most influential external factors affecting students' learning experiences and academic development. Teacher guidance, encouragement, feedback, and instructional facilitation help students develop confidence and maintain active participation during learning activities. A supportive learning environment created by teachers has been shown to positively influence students' engagement and motivation toward learning tasks (Street et al., 2024).

Student engagement refers to the degree of behavioral, emotional, and cognitive involvement in learning activities. Highly engaged students demonstrate greater concentration, participation, and persistence when completing academic tasks. Previous studies have consistently reported that supportive teacher practices contribute to increased student engagement, which subsequently enhances learning motivation and academic performance (Street et al., 2024; Mamolo & Sugano, 2023).

2.4 Self-Efficacy and Learning Outcomes

Self-efficacy is defined as students' beliefs in their ability to successfully perform learning tasks and achieve desired academic outcomes. According to social cognitive theory, self-efficacy influences students' persistence, effort, learning strategies, and achievement. Students with high self-efficacy tend to demonstrate stronger commitment to learning activities and greater resilience when facing academic difficulties (Street et al., 2024).

Recent educational research has confirmed that self-efficacy is a strong predictor of mathematics achievement and learning outcomes. Interactive digital learning environments that provide positive learning experiences can strengthen students' confidence and improve their academic performance. Therefore, self-efficacy is frequently considered an important mediating variable linking instructional interventions and learning outcomes (Mamolo & Sugano, 2023; Street et al., 2024).

2.5 Cultural Literacy and Learning Outcomes

Cultural literacy refers to the ability to understand, appreciate, and engage with cultural knowledge, values, traditions, and practices within society. In contemporary education, cultural literacy is increasingly recognized as an essential competency because it supports identity formation, cultural awareness, and social cohesion. Integrating local culture into educational activities enables students to develop stronger connections with their cultural heritage while enhancing academic learning (Pratama & Yelken, 2024).

Studies on ethnomathematics suggest that culturally contextualized mathematics instruction positively influences students' cultural literacy and learning outcomes. By connecting mathematical concepts with local cultural practices, students can develop deeper conceptual understanding and stronger appreciation of their cultural identity. Consequently, cultural literacy and learning outcomes are important indicators for evaluating the effectiveness of ethnomathematics-based learning interventions (Batiibwe, 2024; Pratama & Yelken, 2024).

Methodology

3.1 Research Design

This study uses a quantitative approach that aims to analyze the impact of the use of E-Comic Ethnomathematics based on Bugis-Makassar culture on the learning outcomes and cultural literacy of elementary school students. This study was designed through the use of Structural Equation Modeling-Partial Least Square analysis to see the correlation relationship and analysis of factors that influence learning outcomes and understanding of students' cultural literacy. SEM-PLS is effective in analyzing complex data consisting of several research variables.

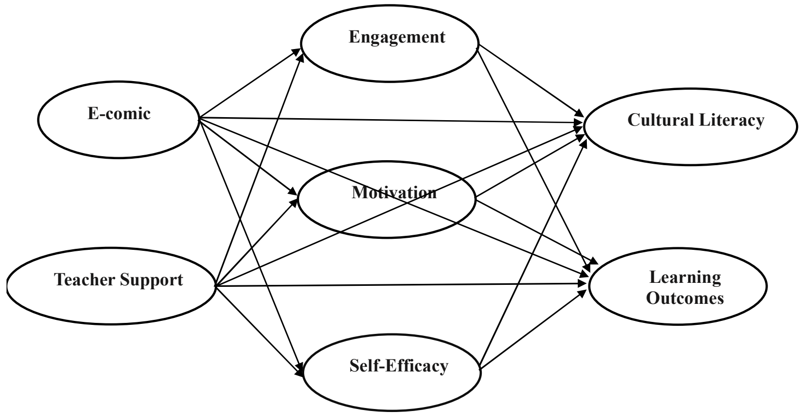

Figure 1. SEM-PLS Model Diagram

The SEM-PLS model diagram in the image above can analyze directly and indirectly the relationship between exogenous and endogenous variables, as well as between exogenous and mediating variables and then to endogenous variables. In this design, the exogenous variables include e-comics and teacher support, the mediating variables include engagement, motivation, and self-efficacy, while the endogenous variables consist of cultural literacy and learning outcomes. This analysis analyzes the factors that influence cultural literacy and learning outcomes of elementary school students

3.2 Population and Sample

The population in this study was determined based on schools that have implemented digital-based learning in fourth-grade elementary schools in Pangkep Regency, South Sulawesi. In the context of this study, the sample was taken comprehensively to ensure that the selected sample had diverse levels of understanding of cultural literacy and mathematics learning outcomes regardless of the background of the students. The sample in this study consisted of 50 fourth-grade students: 31 students at SD 28 Tumampua and 19 students at SD 12 Attassalo.

3.3 Research Instruments

The research instrument was a structured questionnaire that had been developed and further validated by experts supported by literature sources that were in line with the context of this research. This was done to ensure that the data obtained had high accuracy to draw conclusions as research results. This questionnaire was distributed and given to the sample to obtain data on each indicator of the exogenous variables and mediating variables (See Table 1). For data with a structured questionnaire, each indicator was given a weight by the research sample through a Likert scale determination (1 = Strongly Disagree; 2 = Disagree; 3 = Undecided; 4 = Agree; and 5 = Strongly Agree). In addition, data on learning outcomes and cultural literacy were obtained directly based on an evaluation process carried out by teachers to truly ensure the data obtained were accurate with valid indicators as a measurable instrument (Table 2).

Prior to conducting the research, it was ensured that the data collection had gone through the licensing process from the relevant educational institutions, principals, and mathematics teachers at the target schools. The students, who served as the research sample, also understood the research objectives, guaranteed confidentiality of their information, and agreed to participate in the research. This approach ensured that the research process truly applied scientific methods in its research and drawing conclusions.

Table 1. Statements on each research variable measured by a structured questionnaire

Indicator	Statement
Exogenous Variables E-Comic Ethnomathematics	
KOM 1	The illustrations in the e-comic make it easier for me to understand the material.
KOM 2	I am more enthusiastic about learning mathematics with e-comics.
Teacher Support	
DGR 1	The teacher explains the use of e-comics clearly.
DGR 2	The teacher gives a real example of the relationship between Bugis-Makassar culture in mathematics.
DGR 3	The teacher guided me when using e-comics.
DGR 4	The teacher motivated me to actively use e-comics.
Mediating Variables Learning Engagement (ENG)	
ENG 1	I feel happy when I learn with e-comics.
ENG 2	I actively discuss with friends when using e-comics.
ENG 3	I focus more on learning math with e-comics.
Motivation to Learn (MOT)	
MOT 1	I want to learn math because e-comics make it easier.
MOT 2	I tried to solve the problem with enthusiasm after using e-comic.
MOT 3	I feel confident that I can understand the material with e-comics.
Self-Efficacy (SEFF)	
SEFF 1	I am confident that I can master the math material in the e-comic.
SEFF 1	I am confident in answering questions after studying with e-comics.
SEFF 1	I can learn mathematics independently with the help of e-comics.

Table 2. Indicators for assessing learning outcomes and cultural literacy in endogenous variables

Indicator	Statement
Cultural Literacy	
LIT 1	Students have become familiar with Bugis-Makassar culture after studying with e-comics.
LIT 2	Students can connect Bugis-Makassar culture with mathematical concepts.
LIT 3	Students have a sense of pride in learning Bugis-Makassar culture through

	mathematics.
LIT 4	Students are committed to preserving Bugis-Makassar culture after studying it.
Learning outcomes	
HAS 1	Students have understood mathematics material better with e-comics.
HAS 2	Students are able to solve math problems related to culture.
HAS 3	Students can re-explain the material they have learned through e-comics.

Data collection was carried out in a structured manner in the classroom in a controlled system by researchers and competent teachers to ensure that there was no external intervention and interference felt by the sample in the research data collection process/

3.4 Data Analysis

Structural Equation Model (SEM) consists of two parts: a measurement model, which describes the relationship between indicator variables and construct variables, and a structural model, which describes the relationship between construct variables whose results can be analyzed most influentially according to the research (Ruliana et al., 2015) . The structural model is presented in the following equation by Ruliana et al., 2017 .

$$\boldsymbol{\eta} = \mathbf{B}\boldsymbol{\eta} + \boldsymbol{\Gamma}\boldsymbol{\xi} + \boldsymbol{\zeta} \quad \textbf{(1)}$$

Information:

η is the endogenous latent variable d 1

B is the dd coefficient matrix for the influence between endogenous latent variables

Γ is the coefficient matrix dx(qd) for the effect on

ξ is an exogenous latent variable (qd) 1

ζ is the random error dx1, which has an expected value equal to zero.

Assuming the diagonal of matrix B in Equation (2) is 0, it is guaranteed that no element satisfies the function. A sufficient condition for η_i to solve Equation (2) is that (IB) has an inverse (invertible), so that Equation (2) can be solved for endogenous variables by writing it as follows:

$$\boldsymbol{\eta} = (\mathbf{I} - \mathbf{B})^{-1}(\boldsymbol{\Gamma}\boldsymbol{\xi} + \boldsymbol{\zeta}) \quad \textbf{(2)}$$

Next, the measurement model of the exogenous and endogenous constructs is given in the following equation (Ruliana et al., 2017).

$$\mathbf{x} = \boldsymbol{\Lambda}_{\mathbf{x}}\boldsymbol{\xi} + \boldsymbol{\delta} \quad \textbf{(3)}$$

$$\mathbf{x} = \boldsymbol{\Lambda}_{\mathbf{y}}\boldsymbol{\eta} + \boldsymbol{\varepsilon} \quad \textbf{(4)}$$

In Equation (3), x is a vector of p × 1 observations for the exogenous variables, Λ_x is a p × m coefficient matrix for the relationship from x to ξ, and δ is a p × 1 vector for the measurement errors of x. In addition, in Equation (4), y is a vector of q × 1 observations for the endogenous variables, Λ_y is a q × n coefficient matrix for the relationship from y to, and is a q × 1 vector for the measurement errors of y.

In the measurement model, a statistical measure links the latent variable with the indicator, namely the loading factor or lambda (λ). There are two loading factors, namely the loading factor for the exogenous construct, which is written in Equation (5), and the loading factor for the endogenous construct in Equation (6).

$$\hat{\boldsymbol{\lambda}}^{g}_{jk} = \frac{\mathrm{Kov}(x^{g}_{jk}, \xi^{g}_{j})}{\mathrm{Var}(\xi^{g}_{j})^{2}} \quad (5)$$

$$\hat{\boldsymbol{\lambda}}^{g}_{jk} = \frac{\mathrm{Kov}(x^{g}_{jk}, \eta^{g}_{j})}{\mathrm{Var}(\eta^{g}_{j})^{2}} \quad (6)$$

In a structural model, several coefficients connect latent variables called path coefficients. The following is the equation for the path coefficients. 1) The coefficient of the relationship between endogenous latent variables ($\boldsymbol{\eta}$) for each group, namely β with equation (7).

$$\hat{\boldsymbol{\beta}}^{g}_{ji} = ((\boldsymbol{\eta}^{g}_{i})'\boldsymbol{\eta}^{g}_{i})^{-1}(\boldsymbol{\eta}^{g}_{i})'\boldsymbol{\eta}^{g}_{i} \quad (7)$$

2) The coefficient of the relationship between the endogenous latent variable (η) and the exogenous latent variable (ξ) for each group, namely γ, with equation (8)

$$\hat{\boldsymbol{\eta}}^{g}_{ji} = ((\boldsymbol{\xi}^{g}_{i})'\boldsymbol{\xi}^{g}_{i})^{-1}(\boldsymbol{\xi}^{g}_{i})^{-1}(\boldsymbol{\xi}^{g}_{i})'\boldsymbol{\eta}^{g}_{i} \quad (8)$$

RESULT

This section presents the findings obtained from the Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis conducted to examine the relationships among the study variables. The analysis was carried out in two stages, namely the evaluation of the measurement model and the structural model. The measurement model assessment aimed to verify the validity and reliability of the research constructs, while the structural model evaluation examined the hypothesized relationships among competence, teacher support, engagement, motivation, self-efficacy, cultural literacy, and learning outcomes. The results are presented systematically in the following subsections.

4.1 Measurement Model (Outer Loadings)

Measurement model testing was conducted to assess convergent validity through outer loadings. An indicator is considered valid if it has an outer loading value above 0.70, although values between 0.50 and 0.70 remain acceptable when the Average Variance Extracted (AVE) value satisfies the recommended threshold.

Table 3. Outer Loading Results

Construct	Indicator	Loading	T-Statistics
KO	KO3	0.924	13,419
KO	KO4	0.487	1,881
DG	DG1	0.581	2,641
DG	DG2	0.700	3,908
DG	DG3	0.801	4,507
DG	DG4	0.755	4,328
EN	EN1	0.725	3,858
EN	EN2	0.745	6,393
EN	EN3	0.737	7,464
MO	MO1	0.496	1,997
MO	MO2	0.713	3,607
MO	MO3	0.835	3,778
SE	SE1	0.672	5,179
SE	SE2	0.645	2,899
SE	SE3	0.846	9.108
LI	LI1	0.626	3,764
LI	LI2	0.698	6,766
LI	LI3	0.532	3,403

LI	LI4	0.756	6,731
HA	HA1	0.844	15,077
HA	HA2	0.879	11,613
HA	HA3	0.640	4,420

Based on Table 3, most indicators demonstrated outer loading values above 0.70 and were statistically significant (T-Statistics > 1.96), indicating that these indicators adequately represented their respective latent constructs. Indicators such as KO3 (0.924), DG3 (0.801), MO3 (0.835), SE3 (0.846), LI4 (0.756), and HA2 (0.879) showed particularly strong loadings. However, several indicators, including KO4 (0.487) and LI3 (0.532), exhibited loading values below the recommended threshold and should be interpreted cautiously.

4.2 Structural Model Evaluation

Structural model evaluation was conducted to assess the relationships between latent constructs. Significance was determined by looking at the t-statistics (>1.96) and p-value (<0.05).

Table 4. Structural Model Results

Connection	Original Estimate	Mean Subsample	T-Statistics	Information
KO -> EN	0.445	0.444	3,695	Significant
DG -> EN	0.305	0.316	1,918	Not significant
KO -> MO	0.267	0.266	1,494	Not significant
DG -> MO	0.174	0.205	1,075	Not significant
KO -> SE	0.382	0.404	3,518	Significant
DG -> SE	0.200	0.194	1,295	Not significant
KO -> LI	0.179	0.146	1.104	Not significant
DG -> LI	0.107	0.134	0.766	Not significant
EN -> LI	0.159	0.165	0.980	Not significant
MO -> LI	0.278	0.271	1,382	Not significant
SE -> LI	0.248	0.256	1,551	Not significant
KO -> HA	0.060	0.050	0.328	Not significant
DG -> HA	-0.243	-0.234	1,764	Not significant
EN -> HA	0.352	0.392	1,682	Not significant
MO -> HA	0.191	0.164	1,276	Not significant
SE -> HA	0.070	0.088	0.446	Not significant

The results indicate that two structural relationships were statistically significant. The relationship between competence and engagement (KO → EN) was significant ($\beta = 0.445$; $T = 3.695$), while the relationship between competence and self-efficacy (KO → SE) was also significant ($\beta = 0.382$; $T = 3.518$). In contrast, all remaining paths failed to reach statistical significance, including the relationships involving teacher support, motivation, engagement, cultural literacy, and learning outcomes.

4.3 Conceptual Bridges Between Daoist and Western Traditions

These three streams of thought are shown in Figure 3 below as overlapping traditions, that is, a Daoist, a Hindu/Vedic (as found in the Bhagavad Geeta & the Upanishads), and a Western leadership theory approach. The zones of convergence are the ideas that emerged independently from each other and when they are put in dialogue with each other, in the DEL framework, they form a deeper basis for ethical leadership than any tradition alone can provide. These convergence zones are illuminated from within the tradition of the Daoist studies by Chai's (2025) study of Daoist self-consolation and Zaccarini's (2025) work on mindfulness and nonviolent communication.

DISCUSSION

The results of the convergent validity test show that most indicators have outer loading values above 0.70, such as KO3 (0.924), DG3 (0.801), MO3 (0.835), SE3 (0.846), LI4 (0.756), and HA2 (0.879). This confirms that these indicators have a strong contribution in representing their respective latent constructs. However, there are several indicators whose loading values are below the ideal standard, such as KO4 (0.487) and LI3 (0.532). Nevertheless, these indicators can still be maintained if the Average Variance Extracted (AVE) value of the related construct remains above 0.50. This is common in social research because instruments sometimes face contextual variability. Thus, in general, the measurement model can be said to be valid because most indicators show good reliability.

Structural model evaluation showed several significant paths. First, KO → EN (β = 0.445, T = 3.695) and KO → SE (β = 0.382, T = 3.518) were proven to be significant, which means that student competence plays an important role in improving EN and self-efficacy variables. In contrast, the paths DG → EN, DG → MO, and EN → LI were not significant, which indicates that teacher support and other mediating variables have not provided a strong enough influence.

Overall, the research results confirm that competence (KO) is the most consistent factor with a significant influence on both EN and SE. This finding shows that improving student competence through innovative learning media such as E-Comic Ethnomathematics can improve students' self-confidence and understanding. Meanwhile, teacher support (DG), although practically important, does not have a significant effect on most constructs. Furthermore, mediating variables such as motivation (MO), self-efficacy (SE), and EN are not significant on learning outcomes (HA) and cultural literacy (LI). This indicates that the achievement of learning outcomes and cultural literacy is not only determined by internal factors, but also requires the support of a broader learning ecosystem, such as teaching strategies, technology integration, and cultural context.

5.1 Outer and Inner Model

Based on the SEM-PLS model estimation results in Figure 1, it can be seen that the Competence construct (KO) is the variable that most consistently has a significant influence on the endogenous construct. The KO → EN (β = 0.445) and KO → SE (β = 0.382) paths are proven to be significant, indicating that the higher the student's competence, the greater the development of the endogenous variable (EN) and the increase in self-confidence (self-efficacy). Meanwhile, the direct relationship of KO to LI (β = 0.179), MO (β = 0.267), and HA (β = 0.060) is not significant, indicating that student competence does not directly influence cultural literacy, motivation, or learning outcomes, but rather through an indirect path.

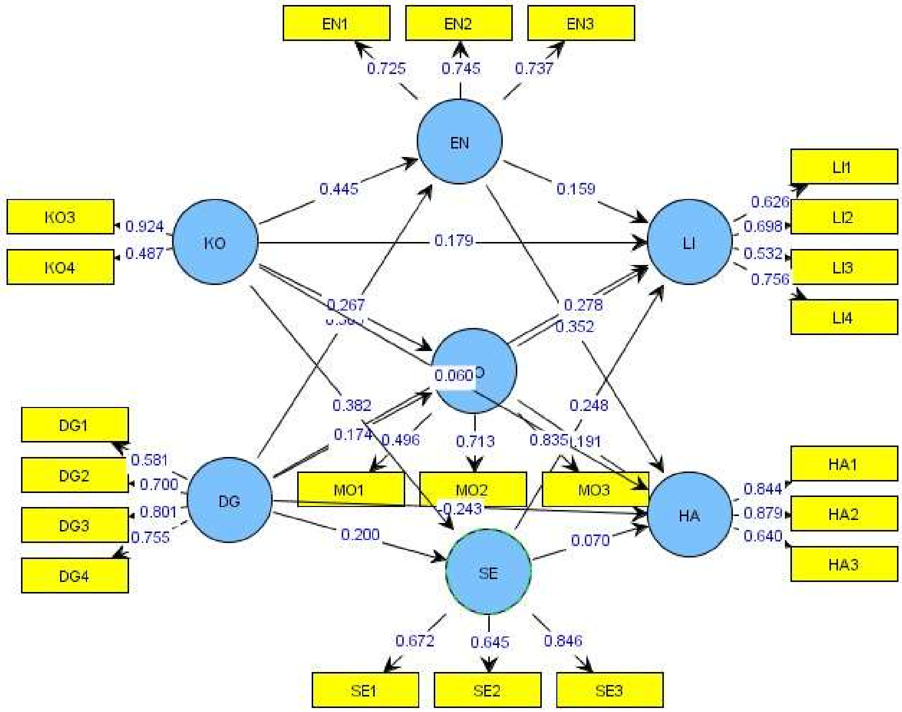

Figure 2. SEM-PLS Structural Model Results

In the Teacher Support (DG) construct, all paths to endogenous variables did not show a significant influence. The paths DG → EN (β = 0.305), DG → SE (β = 0.200), DG → MO (β = 0.174), DG → LI (β = 0.107), and DG → HA (β = –0.243) were in the weak category, even the relationship with learning outcomes (HA) tended to be negative. This indicates that the existence of teacher support alone is not enough to explain variations in learning outcomes or cultural literacy, so that internal student factors become more dominant.

Furthermore, the mediating constructs, namely EN, MO, and SE, have not been proven to play a significant role in bridging the relationship between variables. The paths EN → LI (β = 0.159) and EN → HA (β = 0.352), MO → LI (β = 0.278) and MO → HA (β = 0.191), and SE → LI (β = 0.248) and SE → HA (β = 0.070) were all insignificant. Thus, the achievement of learning outcomes (HA) and cultural literacy (LI) is not solely influenced by competence, motivation, or self-efficacy, but requires the support of a more comprehensive learning ecosystem, including teaching strategies, technology integration, and local cultural context.

The results of this study indicate that student competence (KO) has a significant influence on the constructs of EN and self-efficacy (SE). This finding aligns with previous research confirming that competence is an important internal factor that directly contributes to self-confidence and learning readiness (Huang, 2021; Peng et al., 2024) . Strong competence allows students to have greater control over the learning process, which in turn increases intrinsic motivation and academic success (Santoso et al., 2020) .

In contrast, teacher support (DG) in this research model did not significantly influence endogenous variables, either directly or indirectly. These results demonstrate that while teacher support theoretically plays a role in promoting learning success, in practice, such support is insufficient if it is not accompanied by increased student internal competency. This finding is consistent with research emphasizing the dominance of internal factors such as self-efficacy and metacognition over external factors in influencing academic motivation (Kamila et al., 2024) .

Furthermore, mediating variables such as EN, MO, and SE were not proven significant in bridging the influence between KO and DG on learning outcomes (HA) or cultural literacy (LI). This indicates that although motivational theory places self-efficacy and motivation as important mediators (Arfiandhani & Takeuchi, 2025) , in the context of this study, their mediating role is not optimal. Other factors such as learning strategies, supportive learning environments, and cultural contexts likely play a greater role in influencing learning outcomes and cultural literacy (Sipayung & Kurniawan, 2025) .

These findings can be explained through the Expectancy-Value Theory framework, which emphasizes that the belief in success (expectancy) and the perceived value of a task (value) are the primary drivers of learning engagement (Gonz et al., 2024) . Without a strong perception of competence, teacher support cannot directly drive improved learning outcomes. This aligns with other research findings showing that interventions focused on increasing self-efficacy through successful experiences, providing constructive feedback, and integrating innovative learning media are more effective in improving learning outcomes (Hafizd & Kahar, 2025) .

Overall, this discussion confirms that student competency plays a key role as a predictor in the model, while teacher support and mediating pathways have not proven significant. Therefore, achieving learning outcomes and cultural literacy requires strengthening students' internal competencies, integrated with the support of a more comprehensive learning ecosystem, encompassing pedagogical strategies, technology integration, and local cultural contextualization (Li & Singh, 2023) .

Conclusion

This study shows that the use of Bugis-Makassar culture-based E-Comic Ethnomathematics has a significant influence on improving student competency, particularly in the aspects of learning engagement and self-efficacy. These results confirm that the integration of interactive digital media with local wisdom can be an effective strategy in connecting abstract mathematical concepts with cultural realities close to students' lives. However, teacher support and mediating variables such as motivation and engagement have not been proven to contribute significantly to improving learning outcomes or cultural literacy. This indicates that achieving cultural literacy and learning outcomes requires the support of a more comprehensive learning ecosystem, including innovation in teaching strategies, media digitalization, and systematic strengthening of cultural contexts. Thus, this study recommends further development of digital platform-based edu-ethnomathematics models such as Articulate Storyline to provide a more adaptive, engaging, and relevant learning experience for elementary school students.

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References

Ahmad, S., Umirzakova, S., Mujtaba, G., Amin, M.S., & Whangbo, T. (2023). Education 5.0: Requirements, Enabling Technologies, and Future Directions. *ArXiv Preprint ArXiv* , *2307* (15846), 113–120. http://arxiv.org/abs/2307.15846

Annisa, AM, Wiradharma, G., Anam, K., & Prasetyo, MA (2024). Integration of Ethomathematics in the Social Arithmetic E-Comic, Exploration of Makassar Cultural Products for Elementary School Level. *Journal of Mathematics Education: Judika Education* , *7* (2), 265–277. https://doi.org/https://doi.org/10.31539/judika.v7i2.12167 INTEGRATION

Arfiandhani, P., & Takeuchi, O. (2025). The interplay of grit, enjoyment, and self-efficacy among Indonesian pre-service EFL teachers: an SEM analysis. *Asian-Pacific Journal of Second and Foreign Language Education* , *10*

(23), 1–23. https://doi.org/10.1186/s40862-025-00330-3

Aziz, AT, Desmawati, L., & Muarifuddin. (2023). Implementation of Digitalization in the Course Learning Process at LKP Vision College. *Comm-Edu (Community Education Journal)* , *6* (2), 70–86. http://journal.ikipsiliwangi.ac.id/index.php/comm-edu/article/view/17296

Batiibwe, MSK (2024). The role of ethnomathematics in mathematics education: A literature review. *Asian Journal for Mathematics Education* , *3* (4), 383–405. https://doi.org/10.1177/27527263241300400

Chen, H., Disney, L., & Li, L. (2024). Studying children's motives in mathematical problem-solving during transition from kindergarten to school: A Conceptual PlayWorld approach. *Learning, Culture and Social Interaction* , *48* (August), 100850. https://doi.org/10.1016/j.lcsi.2024.100850

Gonz, V., Chuquin-berrios, J.G., Miguel, F., Pariona-amaya, D., & G, KO (2024). Digital Competencies as Predictors of Academic Self-Efficacy: Correlations and Implications for Educational Development. *Societies* , *14* (226), 1–25. https://doi.org/https://doi.org/10.3390/soc14110226

Hafizd, M., & Kahar, A. (2025). The Influence of Self-Efficacy and Motivation to Enter the Workforce on Job Readiness: A Study of Fourth-Year Diploma Students in Hospitality Management at State University of Padang (Class of 2021). *Journal of Multidimensional Management (JoMM)* , *2* (1), 101–108. https://doi.org/https://doi.org/10.63076/jomm.v2i1.25

Hans, V.B., & Crasta, S.J. (2019). Digitalization in the 21st Century – Impact on Learning and Doing V. *International Journal of Advanced Research* , *7* (6), 994–997. https://doi.org/10.21474/ijar01/9303

Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S.I., & Reiss, K.M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis. *Computers and Education* , *153* (September 2018), 103897. https://doi.org/10.1016/j.compedu.2020.103897

Huang, C. (2021). Using PLS-SEM Model to Explore the Influencing Factors of Learning Satisfaction in Blended Learning. *Educational Sciences* , *11* (249), 1–17. https://doi.org/10.3390/educsci11050249

Kamila, LA, Mahmudin, AS, & Daryono, RW (2024). Self-Intention in Mediating Self-Competence and Memorization Methods on Intensity of Memorizing the Qur'an: PLS-SEM Approach. *Southeast Asian Journal of Islamic Education* , *06* (02), 121–136. https://doi.org/10.21093/sajie.v6i2.8386%0ASelf-Intention

Kaskens, J., Segers, E., Goei, S.L., van Luit, J.E.H., & Verhoeven, L. (2020). Impact of Children's math self-concept, math self-efficacy, math anxiety, and teacher competencies on math development. *Teaching and Teacher Education* , *94* , 103096. https://doi.org/10.1016/j.tate.2020.103096

Kim, DJ, Bae, SC, Choi, SH, Kim, HJ, & Lim, W. (2019). Creative character education in mathematics for prospective teachers. *Sustainability (Switzerland)* , *11* (6), 1–16. https://doi.org/10.3390/su11061730

Laurens, Theresia. (2017). Ethnomathematics Analysis and Its Application in Improving the Quality of Learning. *LEMMA Journal* , *3* (1), 86–96. https://doi.org/10.22202/jl.2016.v1i3.1120

Li, Y., & Singh, C. (2023). Impact of perceived recognition by physics instructors on women's self-efficacy and interest. *Physical Review Physics Education Research* , *19* (2), 20125. https://doi.org/10.1103/PhysRevPhysEducRes.19.020125

Mamolo, L. A., & Sugano, S. G. C. (2023). *Digital interactive app and students' mathematics self-efficacy, anxiety, and achievement in the new normal*. Journal of Computers in Education. https://doi.org/10.1177/20427530231167646

Munawwaroh, DA, Mariana, N., & Ekawati, R. (2025). Analysis of the Need for the Development of Ethnomathematics-Based Flipbook Media to Improve Understanding of Measurement Concepts in Elementary Schools. *Journal of Innovation and Research in Primary Education* , *4* (3), 705–713. https://doi.org/10.56916/jirpe.v4i3.1440

Nisa', I. L. A., & Malasari, P. N. (2024). *Implementasi Etnomatematika Berbasis Alat Kesenian Rebana untuk Memfasilitasi Kemampuan Matematis Siswa: Systematic Literature Review*. https://doi.org/10.21580/square.2024.6.2.21968

Nugraha, T., Maulana, M., & Mutiasih, P. (2020). Sundanese Ethnomathematics Context in Primary School Learning. *Elementary School Forum* , *7* (1), 93–105. https://doi.org/10.17509/mimbar-sd.v7i1.22452

Nur, AS, Waluya, SB, Kartono, K., & Rochmad, R. (2021). Ethnomathematics Perspective and Challenge as a Tool of Mathematical Contextual Learning for Indigenous People. *International Journal on Emerging Mathematics Education* , *5* (1), 1. https://doi.org/10.12928/ijeme.v5i1.17072

Nur, AS, Waluya, SB, Rochmad, R., & Wardono, W. (2020). Contextual learning with Ethnomathematics in enhancing the problem solving based on thinking levels. *JRAMathEdu (Journal of Research and Advances in Mathematics Education)* , *5* (3), 331–344. https://doi.org/10.23917/jramathedu.v5i3.11679

Nursanti, Y. B., Saputra, B. A., & Gibran, G. K. (2024). *Systematic Literature Review: Efektivitas Penerapan Pendekatan Etnomatematika dalam Pembelajaran Matematika*. https://doi.org/10.37081/ed.v12i3.6367

Peng, R., Abdul, R., & Hajar, S. (2024). Heliyon Exploring the role of attitudes, self-efficacy, and digital competence in influencing teachers' integration of ICT: A partial least squares structural equation modeling study. *Heliyon* , *10* (13), e34234. https://doi.org/10.1016/j.heliyon.2024.e34234

Pratama, R. A., & Yelken, T. Y. (2024). *Effectiveness of ethnomathematics-based learning on students' mathematical literacy: A meta-analysis study*. Discover Education, 3, 202. https://doi.org/10.1007/s44217-024-00309-1

Razak, F., Tahmir, S., & Thalib, A. (2024). Optimizing the Existence of Local Culture Through an Ethnomathematics Approach in Mathematics Learning. *Histogram: Journal of Mathematics Education* , *8* (1), 271–280. http://idealmathedu.p4tkmatematika.org/wp-content/uploads/2016/01/4_Nelly-Yuliana.pdf

Rosida, V., Taqwa, M., & Kamaruddin, R. (2018). The Effectiveness of a Local Culture-Based Ethnomatics Approach in Mathematics Learning. *HISTOGRAM: Journal of Mathematics Education* , *2* (2), 97–107. https://doi.org/10.31100/histogram.v2i2.235

Ruliana, Budiantara, IN, Otok, BW, & Wibowo, W. (2017). Estimation of truncated spline in nonlinear structural equation modeling using weighted least squares method. *Journal of Physics: Conference Series* , *893* (1). https://doi.org/10.1088/1742-6596/893/1/012028

Ruliana, R., Budiantara, IN, Otok, BW, & Wibowo, W. (2015). Parameter estimation of nonlinear structural SEM model using spline approach. *Applied Mathematical Sciences* , *9* (149), 7439–7451. https://doi.org/10.12988/ams.2015.510660

Salsabila, NH, Wulandari, NP, & Kurniawan, E. (2024). Ethnomathematics Learning Media Based on Augmented Reality in Geometry to Improve Numeracy Skills. *Journal of Mathematics Education and Learning* , *8* (1), 60–68. https://www.tribunnewswiki.com/2021/08/06/al-khawarizmi

Santoso, PB, Purba, JT, Ugut, GSS, & Budiono, S. (2020). The Role of Transformational Leadership, Self Efficacy and Professional Competence on Knowledge Sharing and Lecture Performance. *Contingencies: Scientific Journal of Management* , *8* (2), 187–201.

Sievert, H., van den Ham, A. K., Niedermeyer, I., & Heinze, A. (2019). Effects of mathematics textbooks on the development of primary school children's adaptive expertise in arithmetic. *Learning and Individual Differences* , *74* (08), 101716. https://doi.org/10.1016/j.lindif.2019.02.006

Sipayung, MS, & Kurniawan, D. (2025). Analysis of Active Learning Methods and Digital Literacy on Student Motivation and Learning Outcomes with SEM-PLS Mauri. *Journal Scientific of Mandalika* , *6* (5), 1401–1421. http://ojs.cahayamandalika.com/index.php/jomla%0AAnalisis

Sirate, FS (2012). Implementation of Ethnomathematics in Mathematics Learning at Elementary School Level. *Lentera Pendidikan: Journal of Education and Teacher Training* , *15* (1), 41–54. https://doi.org/10.24252/lp.2012v15n1a4

Street, K. E. S., Malmberg, L. E., & Schukajlow, S. (2024). *Students' mathematics self-efficacy: A scoping review*. ZDM Mathematics Education, 56, 265–280. https://doi.org/10.1007/s11858-024-01548-0

Trends, N., Analysis, R., Frolova, E. V, Rogach, O. V, Ryabova, T.M., & Federation, R. (2020). Digitalization of Education in Modern Scientific Discourse: New Trends and Risks Analysis. *European Journal of Contemporary Education* , *9* (2), 313–336. https://doi.org/10.13187/ejced.2020.2.313

Yudhi, P., & Septiani, F. (2024). Learning with Ethnomathematics to Improve Understanding of Abstract Mathematical Concepts. *Educational Innovation* , *11* (1), 59–64. https://doi.org/10.31869/ip.v11i1.5649

Zapata, M., Ramos-Galarza, C., Valencia-Aragón, K., & Guachi, L. (2024). Enhancing mathematics learning with 3D augmented reality escape room. *International Journal of Educational Research Open* , *7* (10). https://doi.org/10.1016/j.ijedro.2024.100389