

Comparative STEAM Competency Profiles of Secondary School Teachers in Riau, Indonesia

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ABSTRACT. This study addresses the need to strengthen teachers' competencies in implementing the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach to support 21st-century skills in secondary education. The main problem is that STEAM implementation remains uneven across school types and teacher competency dimensions, especially in interdisciplinary planning, digital literacy, and project-based assessment. This study aims to analyze the comparative STEAM competency profile of secondary school teachers in Riau Province and to identify priority areas for professional development. A cross-sectional explanatory survey involved 42 teachers from SMA, MA, and SMK selected through proportional sampling. Data were collected using a 35-item Likert-scale questionnaire covering seven competency dimensions. The instrument was validated through expert judgment and construct testing, with a Cronbach's Alpha coefficient of 0.87. Data were analyzed using descriptive statistics and one-way ANOVA. The findings show that overall STEAM implementation is in the high category, with mean scores ranging from 3.31 to 3.54. Collaboration (3.54) and project-based assessment with 4C (3.52) scored highest, while digital literacy and technology (3.31) scored lowest. Comparative analysis indicates significant differences among school types, with SMA and MA generally scoring higher than SMK ($p < 0.05$). Theoretically, this study constructs a regional STEAM teacher competency profile that links 21st-century skills, ethno-STEAM, and project-based pedagogy. Practically, it identifies training priorities in digital pedagogy, interdisciplinary planning, and authentic assessment. In policy terms, it supports differentiated STEAM capacity building for SMA, MA, and SMK teachers.

Keywords: STEAM, Teacher Competence, 21st-Century Skills, Secondary Education.

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INTRODUCTION

The transformation of 21st-century education has created increasing demands for secondary school teachers to develop students' competencies beyond subject mastery. Schools are now expected to cultivate creativity, collaboration, critical thinking, communication, and digital literacy as essential competencies for future society and workforce readiness (Aprilianto et al., 2025; Budiartini et al., 2025; Ridlo et al., 2026; Sa'ad et al., 2025; Trilling & Fadel, 2009).

In Indonesia, this transformation has become more urgent following the implementation of the Merdeka Curriculum, which encourages interdisciplinary learning, project-based instruction, and contextual educational practices (Kartiko et al., 2025; Salabi & Muharramah, 2026). Consequently, teachers are no longer positioned merely as transmitters of knowledge, but as facilitators who integrate technology, innovation, and authentic problem-solving into classroom

learning. Within this context, the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach has gained increasing attention because it promotes integrative, inquiry-based, and project-oriented learning experiences that align with 21st-century educational goals (Fitriyani et al., 2026; Jannah et al., 2026; Leal Filho et al., 2016). However, the implementation of STEAM in Indonesian secondary schools remains uneven, particularly across different institutional contexts such as SMA, MA, and SMK. In Riau Province, this challenge becomes more complex because teachers are also expected to integrate local Malay cultural values and contextual learning practices into STEAM-oriented pedagogy.

Previous studies consistently report that STEAM education contributes positively to students' creativity, scientific literacy, collaboration, and higher-order thinking skills when supported by effective pedagogical practices and authentic learning projects (Dimitrova, 2025; Hsu et al., 2023; H.-C. Kuo, 2025). Research has also highlighted the importance of interdisciplinary learning design, inquiry-based activities, and project-based assessment in strengthening meaningful learning outcomes (Amemasor et al., 2025; Beneroso & Robinson, 2022; H.-C. Kuo, 2025). Furthermore, recent studies emphasize that teacher competence is a determining factor in successful STEAM implementation because teachers must be capable of integrating technology, collaborative learning, creativity, and reflective assessment simultaneously (Bassachs et al., 2020; Spyropoulou & Kameas, 2023; Sun et al., 2023; Wu, 2022). Nevertheless, several empirical studies reveal persistent problems in teachers' readiness, especially in digital pedagogy, interdisciplinary planning, and authentic assessment practices (Falloon, 2020; Huriyah et al., 2025; Ziyabekova & Zhumabaeva, 2025). Existing studies in Indonesia also tend to focus primarily on elementary education, pre-service teachers, or conceptual reviews rather than comparative competency mapping among secondary school teachers (Anam et al., 2025; Andriyani & Leksono, 2024; Chang et al., 2025; Nugraha et al., 2023; Syahrudin & Agus, 2026). Although ethno-STEAM studies have begun to emerge, most still examine local culture integration at the primary education level and rarely investigate how secondary school teachers integrate local wisdom within STEAM pedagogy across different school orientations (Deesongkram, 2025; Hermita et al., 2024; Imron et al., 2025).

Based on these conditions, this study aims to analyze the comparative STEAM competency profiles of secondary school teachers in Riau Province across SMA, MA, and SMK institutions. Specifically, the study seeks to identify dominant and weak competency dimensions in STEAM implementation and examine how school orientation influences teachers' pedagogical readiness in integrating 21st-century skills. The study also aims to provide empirical evidence regarding the dimensions that require priority intervention in teacher professional development programs, particularly in digital literacy, interdisciplinary planning, and project-based assessment.

This study addresses several important research gaps. First, previous studies have predominantly discussed STEAM implementation conceptually or focused on student outcomes, while empirical profiling of teacher competencies in secondary education remains limited. Second, comparative investigations examining STEAM competencies across SMA, MA, and SMK contexts using measurable 21st-century skill indicators are still scarce, particularly in Indonesian regional contexts. Third, studies integrating teacher competency profiling, ethno-STEAM perspectives, and project-based pedagogy within one analytical framework remain underexplored. Therefore, this study offers both theoretical and practical contributions. Theoretically, it develops a contextual STEAM teacher competency profile that connects 21st-century skills, ethno-STEAM integration, and project-based pedagogical orientation within secondary education. Practically, the findings provide evidence-based recommendations for differentiated teacher training, digital pedagogy development, and institutional policy formulation according to school characteristics. In addition,

the study strengthens the discourse on contextual STEAM implementation in developing-country educational settings, particularly within culturally diverse Indonesian secondary schools

METHOD

This study employed a non-experimental quantitative approach using a cross-sectional explanatory survey design to obtain an empirical picture of STEAM learning implementation among teachers at the senior high school (SMA), Islamic senior high school (MA), and vocational high school (SMK) levels in Riau Province. The survey design was chosen because this study describes current implementation and compares teachers' perceptions, experiences, and pedagogical readiness in developing 21st-century skills through STEAM across different school types (Permanasari et al., 2021).

The study population consisted of teachers in science, mathematics, technology, informatics, language, social science, arts, and vocational subjects who taught at SMA, MA, and SMK levels in Riau Province. The sample was selected using proportional sampling by considering school type and administrative representation. A total of 42 teachers participated in the study. All respondents had experience in implementing or participating in STEM/STEAM-based learning programs. The sample profile is presented in Table 1.

Table 1 Profile of Participating School Types and Respondents

Type	School Orientation	n	STEAM and Data Context
SMA	General academic	21	Cross-disciplinary projects; student data not analyzed
MA	Islamic academic	6	Islamic and local culture; student data not analyzed
SMK	Vocational	15	Industry-oriented projects; instrument trial data N = 65
Total	Secondary schools in Riau	42	Teacher survey as primary data source

Note. The primary unit of analysis was teacher competence. Student data were used only for instrument trial information where available, not for comparative student outcome analysis.

The research instrument was a Google Form-based questionnaire consisting of 35 items using a 4-point Likert scale (1 = strongly disagree to 4 = strongly agree) (Koo & Yang, 2025). The instrument was developed based on STEAM competency indicators, including pedagogical planning, technology integration, creative learning design, cross-disciplinary collaboration, communication, critical thinking, and project-based assessment. The constructs were adapted from established frameworks in STEM, STEAM, and 21st-century education research (Imron et al., 2025; Mehddi et al., 2025).

The questionnaire items were organized into seven STEAM teacher competency dimensions, as shown in Table 2.

Table 2 STEAM Teacher Competency Dimensions and Item Distribution

Dimension	Items	Measurement Focus
STEAM learning planning	1-5	Objectives, materials, media, activities, and STEAM integration
Creativity and innovation	6-10	Student ideas, alternative solutions, and creative products
Critical thinking and problem solving	11-15	Analysis, evidence use, argument, and contextual problem solving

Collaboration	16-20	Group work, role distribution, peer support, and team contribution
Communication	21-25	Presentations, reports, discussions, and justification of ideas
Digital literacy and technology	26-30	Digital media, simulations, LMS, and ethical technology use
Project evaluation and 4C	31-35	Assessment of process, product, rubric, and 4C skills

Before final data collection, the questionnaire was examined through validity and reliability procedures to ensure that the instrument measured the intended competency dimensions.

Instrument validity was examined through expert judgment and construct review. Three experts in science education and educational technology reviewed the relevance, clarity, and coverage of the items. Construct validity was examined by checking item alignment with the seven STEAM competency dimensions. Items that needed wording improvement were revised before distribution.

Table 3 Summary of Instrument Validity and Reliability

Procedure	Evidence	Result	Decision
Content validity	Expert judgment	Items aligned with STEAM indicators	Accepted after wording revision
Construct review	Item mapping to seven dimensions	All constructs represented	Adequate coverage
Internal consistency	Cronbach's Alpha	0.87	High reliability
Final decision	Validity and reliability review	35 items retained	Suitable for data collection

The validity and reliability results indicate that the questionnaire was appropriate for measuring teacher competency profiles in STEAM implementation. The Cronbach's Alpha coefficient of 0.87 shows high internal consistency among the items.

Reliability was reported narratively because the purpose of this section is to show the consistency of the overall instrument, not to present item-by-item scoring. Therefore, the validity and reliability explanation was integrated into one continuous methodological description. This approach was used to make the presentation of the research method more systematic, concise, and easier to understand. In addition, the narrative presentation helps emphasize that the instrument met the required criteria of validity and consistency as a reliable data collection tool in the study (Jarraya et al., 2025; Zhang et al., 2025).

The data were analyzed using descriptive statistics and one-way ANOVA. Descriptive statistics were used to calculate the mean score of each STEAM competency dimension. One-way ANOVA was used to examine differences in STEAM implementation among the three school types, namely SMA, MA, and SMK. The use of one-way ANOVA was selected because the comparative analysis involved more than two independent school groups. The analysis focused on differences in average competency scores across school types, while the significance level was set at 0.05.

Data analysis was conducted using IBM SPSS Statistics 26. The school type was coded as the grouping variable, while the seven STEAM competency dimensions were treated as comparison variables. If the significance value was less than 0.05, the difference among school types was interpreted as statistically significant. This analysis was expected to provide a consistent description of teachers' readiness to integrate 21st-century skills, including creativity, communication, collaboration, critical thinking, and digital literacy (Ilma et al., 2023; Rahayu et al., 2023).

RESULTS AND DISCUSSION

Results

The observation instrument involved 42 teachers who taught at SMA, MA, and SMK levels in Riau Province. The sample consisted of 21 SMA teachers, 15 SMK teachers, and 6 MA teachers. This composition shows that the study represented general academic schools, vocational schools, and Islamic senior secondary schools. Although the MA group was smaller, its inclusion was important because Islamic schools have started to adopt STEAM-based learning within religious and local cultural contexts.

The respondents came from science, mathematics, Indonesian, English, history, arts and culture, technology, and vocational subjects. This diversity shows that STEAM implementation in secondary schools is no longer limited to science and technology teachers. It has started to operate as a cross-disciplinary approach that can be integrated into academic, social, humanities, arts, and vocational learning.

The instrument used a score range of 1-4 for each indicator. A higher score indicates stronger and more consistent implementation of STEAM-related practices. For example, a score of 1 in planning indicates that the learning plan was not STEAM-oriented, while a score of 4 indicates that the plan consistently integrated interdisciplinary principles, projects, and 4C skills. All items were grouped into seven teacher STEAM competency dimensions. These dimensions reflect the theoretical construction of this study and connect STEAM implementation with 21st-century skills. The dimensions are presented in Table 4.

Table 4 Teacher STEAM Competency Dimensions and Measurement Focus

No.	STEAM Competency Dimension	Measurement Focus
1	STEAM learning planning	The extent to which teachers design objectives, materials, methods, media, and learning activities that integrate science, technology, engineering, arts, and mathematics
2	Creativity and innovation	The extent to which teachers provide opportunities for students to generate new ideas, explore alternative solutions, and express ideas through creative products
3	Critical thinking and problem solving	Teachers' ability to design activities that encourage analysis, evidence comparison, logical argument, and contextual problem solving
4	Collaboration	Teacher practice in organizing group work, role distribution, peer support, and assessment of team contribution
5	Communication	Teacher facilitation of students' oral and written presentation, discussion, reporting, posters, and other STEAM communication media
6	Digital literacy and technology	Teachers' use of digital media, simulations, LMS, collaborative applications, and ethical technology integration in STEAM projects

7	Project evaluation and 4C	Assessment of project processes and products, including creativity, critical thinking, collaboration, and communication through structured rubrics
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Each dimension was calculated as the mean score of several related items. This aggregation made it possible to compare the relative strength of STEAM implementation across teacher competency dimensions. It also helped identify whether teachers were stronger in collaboration, planning, assessment, or digital technology integration.

Overall, the mean score across the seven dimensions ranged from 3.31 to 3.54 on a maximum scale of 4. This finding indicates that STEAM implementation was generally in the high category, although meaningful variation appeared across dimensions.

Table 5 Distribution of Collaboration Responses

Scale	Frequency	Percentage	Category
Strongly disagree	2	2.2	Low
Disagree	2	2.2	Low
Moderately agree	20	22.0	Medium
Agree	44	48.4	High
Strongly agree	23	25.3	High
Total	91	100.0	

The collaboration dimension obtained the highest mean score in the STEAM implementation profile (3.54). This result aligns with the response distribution in Table 2, where 48.4% of respondents agreed and 25.3% strongly agreed that collaborative STEAM activities improved group discussion and joint learning design. This indicates that group-based projects and teacher collaboration are already familiar practices in secondary school learning.

Table 6. Distribution of Communication Responses

Scale	Frequency	Percentage	Category
Strongly disagree	2	2.2	Low
Moderately agree	31	34.1	Medium
Agree	42	46.2	High
Strongly agree	16	17.6	High
Total	91	100.0	

The communication dimension obtained a mean score of 3.43. Table 3 shows that 46.2% of respondents agreed and 17.6% strongly agreed that STEAM activities strengthened communication. However, the proportion of moderate responses (34.1%) indicates that scientific presentation, argumentation, and systematic explanation of ideas still require further training.

Table 7. Distribution of Creativity Responses

Scale	Frequency	Percentage	Category
Strongly disagree	1	1.1	Low
Disagree	1	1.1	Low

Moderately agree	27	29.7	Medium
Agree	42	46.2	High
Strongly agree	20	22.0	High
Total	91	100.0	

The creativity and innovation dimension reached a mean score of 3.49. Table 4 shows that 46.2% of respondents agreed and 22.0% strongly agreed that STEAM encouraged innovative and interesting ideas. This result confirms that STEAM workshops and project-based learning can create space for exploration. The moderate response group (29.7%) also shows that creativity has not developed evenly among teachers.

Table 8. Distribution of Critical Thinking Responses

Scale	Frequency	Percentage	Category
Strongly disagree	3	3.3	Low
Disagree	3	3.3	Low
Moderately agree	30	33.0	Medium
Agree	41	45.1	High
Strongly agree	14	15.4	High
Total	91	100.0	

The critical thinking and problem-solving dimension also reached a mean score of 3.49. Table 5 indicates that 45.1% of respondents agreed and 15.4% strongly agreed that STEAM activities supported analysis of student needs and technology-based solutions. The 33.0% moderate response suggests that problem-based learning design and strategic use of technology still need deeper support.

Table 9. Distribution of Digital Literacy Responses

Scale	Frequency	Percentage	Category
Strongly disagree	3	3.3	Low
Disagree	2	2.2	Low
Moderately agree	24	26.4	Medium
Agree	40	44.0	High
Strongly agree	22	24.2	High
Total	91	100.0	

Digital literacy and technology obtained the lowest mean score (3.31). Table 6 shows that 44.0% of respondents agreed and 24.2% strongly agreed that they understood 21st-century digital competence, but 26.4% remained in the moderate category. This means that motivation to use technology has not fully translated into pedagogical digital competence. This means that teachers' motivation and interest in using technology are relatively high, but these have not been fully accompanied by the ability to integrate technology effectively into the teaching and learning process. In other words, teachers may already be familiar with digital tools, yet they still face challenges in applying them pedagogically to support meaningful learning outcomes (Ju et al., 2025; Ollonen & Kangas, 2025).

The comparative findings also show differences in STEAM implementation among SMA, MA, and SMK. SMA and MA scored higher than SMK in most dimensions, especially digital literacy, communication, critical thinking, and STEAM planning. This finding confirms that school type and institutional orientation shape how teachers implement STEAM learning.

Overall, the response distribution supports the main competency profile. Teachers showed strength in collaboration, creativity, and project orientation. However, digital literacy, scientific communication, and strategic technology use need continued development through sustained training, direct practice, and cross-subject collaboration.

Table 10. Average STEAM Implementation Score per Dimension (n = 42)

No.	STEAM Competency Dimension	Average Score (1-4)
1	Collaboration	3.54
2	Project evaluation and 4C	3.52
3	Creativity and innovation	3.49
4	Critical thinking and problem solving	3.49
5	Communication	3.43
6	STEAM learning planning	3.41
7	Digital literacy and technology	3.31

Table 7 shows that all dimensions were in the high category. Collaboration scored highest (3.54), which indicates that teachers were relatively strong in managing group work and shared project activities. Project evaluation and 4C (3.52) also scored high, showing that teachers had started to assess project processes and student competencies beyond final products.

Creativity and innovation (3.49) and critical thinking and problem solving (3.49) show positive implementation, but these dimensions still require stronger authentic tasks, open-ended questions, and problem-based learning. Communication (3.43) and STEAM learning planning (3.41) scored lower than the top dimensions, indicating the need to improve lesson design and scientific communication strategies.

Digital literacy and technology received the lowest score (3.31). This finding identifies technology integration as the main priority for improvement. Teachers need stronger access to digital resources, application mastery, digital project design, and pedagogical use of technology in STEAM learning.

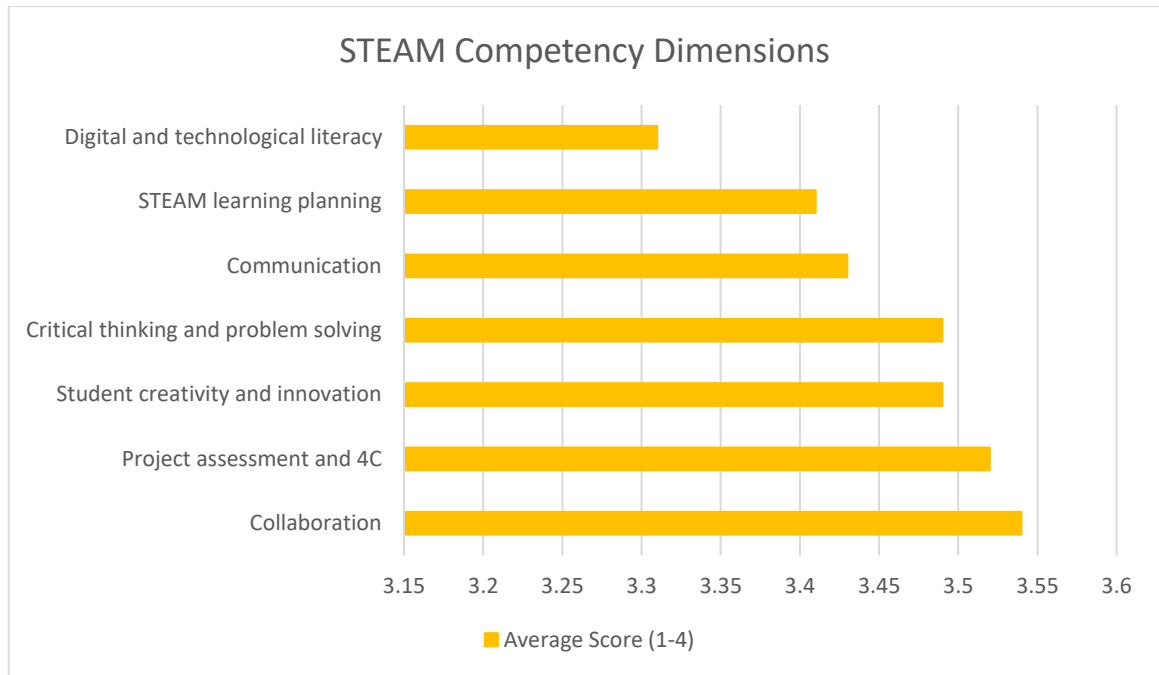


Figure 1. Bar Chart of STEAM Implementation per Dimension (n = 42)

Comparative descriptive analysis shows different patterns of STEAM implementation among SMA, MA, and SMK. The comparison is presented in Table 8 and Figure 2.

Table 11. Average Score of STEAM Implementation per Dimension and School Type

School	Plan	Creat	Critical	Collab	Comm.	Digital	Project
MA	3.50	3.67	3.50	3.70	3.60	3.47	3.77
SMA	3.54	3.68	3.69	3.73	3.59	3.54	3.66
SMK	3.20	3.17	3.20	3.20	3.13	2.92	3.24

The comparative data show that SMA obtained the highest scores in most dimensions, followed by MA, while SMK obtained the lowest scores. This pattern suggests that academic school contexts may provide more flexibility for interdisciplinary and inquiry-based STEAM learning than vocational contexts that focus on occupational competence and industry standards.

In STEAM planning, SMA scored highest (3.54), followed by MA (3.50), while SMK scored 3.20. Creativity and innovation were also higher in SMA (3.68) and MA (3.67) than in SMK (3.17). Critical thinking showed the same trend, with SMA scoring 3.69, MA 3.50, and SMK 3.20. These results indicate that SMK learning still tends to emphasize technical practice rather than integrated inquiry, analysis, and design reflection.

Collaboration was strong in SMA (3.73) and MA (3.70), while SMK scored 3.20. Communication was also lower in SMK (3.13) than in MA (3.60) and SMA (3.59). The largest gap appeared in digital literacy and technology. SMA scored 3.54, MA 3.47, and SMK only 2.92. This is important because vocational education is expected to be close to technological and industrial practices, yet teachers still face challenges in using technology as a pedagogical tool.

Overall, SMA and MA showed more consistent STEAM implementation than SMK. The lower SMK scores indicate a need to strengthen digital pedagogy, project-based assessment, communication, and critical thinking in vocational learning. STEAM training for SMK teachers should connect industry-oriented practice with interdisciplinary inquiry and 4C-based assessment.

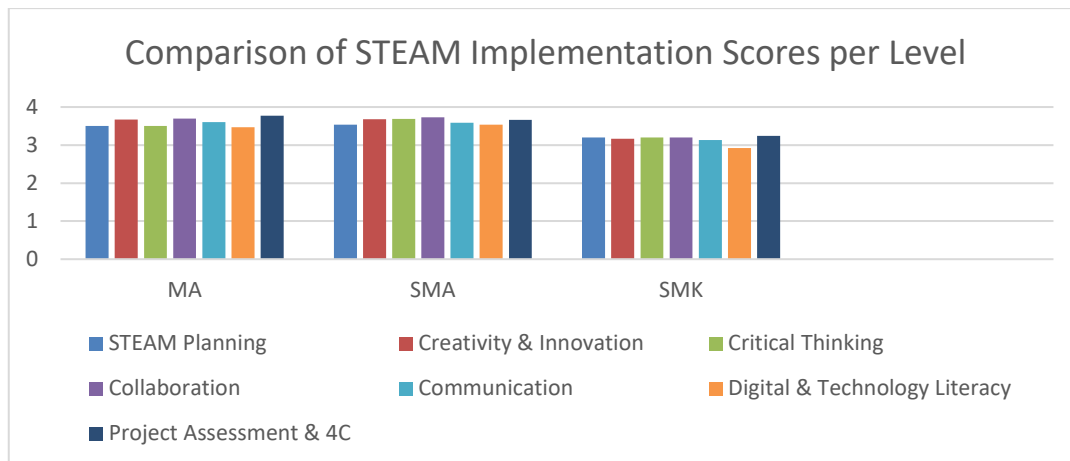


Figure 2. Comparative Bar Chart of STEAM Implementation by School Type

Discussion

The results of this study can be explained through the perspective of the grand theory of constructivism and project-based learning which places students as the center of learning through authentic, collaborative, and contextual experiences. In the constructivist approach, competencies are not formed through one-way transfer of information, but rather through a process of exploration, reflection, problem solving, and social interaction that enables students to construct knowledge independently (Ah-Nam & Osman, 2017). The STEAM approach is fundamentally aligned with this theory because it integrates science, technology, engineering, art, and mathematics into project-based activities that demand creativity, communication, collaboration, and critical thinking. The research findings show that the collaboration dimension scored the highest at 3.54, followed by project evaluation and the 4Cs at 3.52. This demonstrates that teachers in senior high schools (SMA), Islamic high schools (MA), and vocational high schools (SMK) in Riau Province have begun implementing learning practices aligned with constructivist principles, particularly in group work activities, project discussions, and problem-based learning. The dominance of the collaboration dimension indicates that teachers are no longer merely delivering material but are beginning to act as learning facilitators, providing space for active interaction between students. In the context of 21st-century education, this is crucial because social competence, communication, and the ability to work in teams are key demands of the global workplace and digital society. Therefore, the results of this study strengthen the theoretical argument that the success of STEAM implementation is strongly influenced by teachers' ability to build collaborative and authentic learning environments that encourage students to build understanding through direct experience.

In addition to constructivism, the results of this study can also be analyzed using the 21st century learning theory developed by Trilling and Fadel regarding the importance of mastering the 4C skills, namely critical thinking, creativity, collaboration, and communication. (Trilling & Fadel, 2009). This theory explains that the modern education system must move from rote-based learning to competency-based learning that is able to prepare students to face global social, economic and technological changes (Hieng et al., 2026). The research findings show that all STEAM competency dimensions are in the high category with a score range of 3.31–3.54. These results indicate that teachers at the secondary education level have begun to integrate 21st-century skills into their learning processes. The high scores for the creativity and innovation dimension (3.49) and critical thinking (3.49) indicate that STEAM learning has encouraged teachers to develop more exploratory, open-ended, and problem-solving-based activities. However, the digital literacy dimension received the lowest score of 3.31, indicating a gap between STEAM conceptual understanding and teachers' digital pedagogical skills. This condition indicates that the transformation of 21st-century education has not been fully optimal, particularly in the integration of technology as a pedagogical tool. Teachers may be familiar with digital devices, but are not yet fully capable of using them to effectively support inquiry learning, digital simulations, authentic

assessments, and project-based learning. Therefore, the results of this study confirm that the implementation of 21st-century skills theory requires ongoing digital training support so that pedagogical transformation does not stop at the mere administrative use of technology.

The alignment between STEAM theory and the research findings is clearly evident in the collaboration and project evaluation dimensions, which scored the highest compared to other dimensions. In STEAM theory, learning is designed to create interdisciplinary learning experiences that encourage students to collaborate in solving contextual problems through real-life projects. The results showed that teachers were relatively strong in managing group work, role distribution, and joint project activities. These findings indicate that a collaborative learning culture has begun to form in secondary schools in Riau, especially in senior high schools (SMA) and Islamic senior high schools (MA). Theoretically, this situation suggests that the STEAM approach is easier to implement in the social and collaborative aspects because these activities are already close to everyday learning practices. Teachers do not require highly complex technology to implement group work and class discussions. However, the communication dimension scored lower than collaboration, at 3.43. This indicates that although students are accustomed to working in groups, scientific presentation skills, academic argumentation, and data-based communication still need to be strengthened. In STEAM theory, scientific communication is crucial because project results must not only be produced but also be logically and systematically accounted for. Thus, the results of this study show that the implementation of STEAM in secondary schools still tends to be strong in the collaborative activity aspect, but is not yet fully optimal in strengthening the culture of scientific argumentation and scientific communication.

The results of this study also demonstrate a gap between the theory of technology integration in STEAM and the reality of its implementation in the field. Within the framework of digital pedagogy theory, technology should not only be used as an administrative tool, but also as a medium for exploration, simulation, virtual collaboration, and the development of student creativity. However, this study shows that digital and technological literacy is the dimension with the lowest score, especially in vocational high schools (SMK), which only scored 2.92. This condition indicates a paradox in vocational education, where schools that should be closest to industrial technology actually experience weaknesses in the integration of pedagogical technology. This finding can be explained because vocational learning tends to focus on technical skills and industry targets, thus limiting the space for exploration of inquiry-based learning. Furthermore, limited digital infrastructure, internet access, learning tools, and teacher training also exacerbate this gap. From the perspective of TPACK theory and digital competence, teachers need the ability to integrate knowledge of technology, pedagogy, and content simultaneously. Low digital literacy scores indicate that teachers have not fully achieved the integration of these three aspects. Therefore, the results of this study reinforce the view that successful STEAM implementation is not achieved through curriculum changes alone, but must be accompanied by strengthening teachers' digital competencies, providing infrastructure, and transforming the overall culture of technology-based learning.

When compared with research in other countries, the findings of this study show a pattern that is relatively consistent with global trends in STEAM implementation. Research in Finland, South Korea, and Singapore generally shows that collaboration and creativity are the fastest growing dimensions in STEAM implementation because these two aspects are easier to integrate into project-based learning. Kuo's research in Taiwan also found that project-based learning was able to significantly increase students' creativity and collaborative inquiry (Chen et al., 2022; Y.-C. Kuo & Lee, 2026; Rafiq-uz-Zaman & Malik, 2025). The results of the Riau study show a similar pattern, with higher scores for collaboration and creativity compared to other dimensions. This suggests that conceptually, teachers in Indonesia have begun to move toward a global learning paradigm that emphasizes creativity and active student participation. However, a key difference between the Indonesian context and developed countries is seen in the digital literacy dimension. In countries with mature digital education infrastructure, the use of virtual simulations, artificial

intelligence, and LMS-based learning has become common practice in STEAM. In contrast, the results of this study indicate that technology integration in Indonesian secondary schools is still in a transitional stage. Thus, although STEAM implementation in Indonesia has aligned with international trends, the quality of technology integration and digital pedagogy still requires strengthening to meet global implementation standards.

Comparison with other developing countries also shows that the challenges of implementing STEAM in Indonesia have almost the same characteristics. Research in Pakistan, India, and several Southeast Asian countries shows that teachers often experience difficulties in integrating technology and authentic assessment due to limited professional training and educational infrastructure (Aslam et al., 2023; Habib & Naureen, 2025; Hasyim et al., 2026; Rafiq-uz-Zaman & Malik, 2025; Rohmadi et al., 2024). The findings of this study support this situation, particularly in the dimensions of digital literacy and project evaluation. Although teachers demonstrate high motivation in using technology, their ability to integrate it pedagogically remains limited. In some developing countries, STEAM implementation is often oriented towards simple project activities without strong digital inquiry support. The results of this study indicate that a similar situation also occurs in secondary schools in Riau, particularly in vocational high schools (SMK). However, this study is unique in that it involves SMA, MA, and SMK simultaneously within a single comparative analysis framework. This approach is rarely found in international research, which generally focuses on only one type of school or one specific field of study. Therefore, this study makes an important contribution to understanding how institutional orientation influences teacher readiness to implement STEAM in diverse secondary education contexts.

The findings of this research also show the influence of institutional orientation on STEAM implementation. SMA and MA scored higher than SMK on almost all competency dimensions, especially on communication, critical thinking, and STEAM planning. Theoretically, this condition can be explained through the institutional learning environment theory which states that school academic culture influences the learning patterns of teachers and students. Academically oriented high schools and MAs tend to provide greater space for conceptual discussions, reflection and cross-disciplinary learning. In contrast, SMK places more emphasis on technical skills and achieving industrial competency so that learning is more product-oriented rather than the inquiry process. This condition makes it relatively difficult for vocational school teachers to integrate art, reflection, scientific communication and critical inquiry into learning. This finding is important because it shows that STEAM implementation cannot be uniform across all types of schools. The STEAM approach must be adapted to the characteristics of the institution, curriculum goals, and learning culture of each school. Thus, this research confirms that STEAM-based education policies require a differentiated approach, not a single approach that is applied generally without considering the school's institutional context.

The main novelty of this research lies in the development of comparative STEAM teacher competency profiles between SMA, MA, and SMK in the context of Indonesian secondary education based on 21st century skills and ethno-STEAM. Most previous research has focused more on the implementation of STEAM at the elementary school level, student teachers, or conceptual studies without conducting empirical mapping of teacher competencies across school types. This research provides a new perspective by connecting STEAM competencies, local Riau Malay culture, project-based pedagogy, and 21st century skills in one analytical framework. The integration between local cultural contexts and STEAM is an important contribution because it shows that modern learning does not have to abandon regional cultural identities. In the MA context, for example, the STEAM approach can be integrated with Islamic values and local culture, resulting in more contextual learning. Another novelty is the identification of specific priority dimensions of teacher development based on school type (Abidin et al., 2025; Fajri et al., 2025; Husni et al., 2026). This research not only describes the level of teacher competency, but also provides strategic direction regarding dimensions that need to be strengthened in each educational

institution. Therefore, this research has a strong theoretical contribution in the development of contextual STEAM implementation models in developing countries.

CONCLUSION

The conclusion of this study indicates that STEAM implementation among secondary school teachers in Riau Province is at a high level, but still shows disparities across competency dimensions and school types. The most surprising finding is the low digital and technological literacy dimensions in vocational high schools (SMK) compared to senior high schools (SMA) and Islamic high schools (MA), even though vocational schools should be structurally closer to technological practices and industry needs. These results highlight a pedagogical paradox that has not been widely addressed in previous research: that an institution's proximity to industrial technology does not automatically result in strong digital pedagogical competencies for STEAM implementation. This study also found that senior high school (SMA) and Islamic high school (MA) teachers are better able to integrate inquiry learning, scientific communication, and interdisciplinary collaboration compared to vocational high school (SMK) teachers, who tend to be more focused on technical practices and job competency targets. Furthermore, this study presents a novel approach in the form of a comparative mapping of STEAM competencies in SMA, MA, and SMK teachers simultaneously within the context of Indonesian secondary education based on 21st-century skills, project-based learning, and ethno-STEAM, a previously limited area of international and national empirical research.

This research's contribution offers important implications for the development of educational policy, particularly in designing teacher competency strengthening programs based on school institutional differentiation. The results confirm that STEAM implementation cannot be achieved through a single policy approach because each type of school has different pedagogical characteristics, academic culture, and learning needs. Therefore, the government and educational policymakers need to develop a more contextual STEAM training model, particularly in the areas of digital pedagogy, interdisciplinary project design, authentic assessment, and the integration of the 4C skills. In the context of vocational high schools (SMK), educational policy needs to be directed at strengthening the integration of industry needs with inquiry learning and pedagogical digital literacy, not just operational technical skills. Meanwhile, senior high schools (SMA) and Islamic high schools (MA) require strengthening research-based project evaluation, scientific communication, and the integration of local cultural values through an ethno-STEAM approach. Therefore, this research makes a strategic contribution to supporting the transformation of 21st-century education that is more adaptive, contextual, and relevant to global needs and the characteristics of Indonesian education.

However, this study has several academic limitations that should be considered. The study only involved 42 teachers from one province, thus limiting the generalizability of the results to all secondary education contexts in Indonesia. Furthermore, the study used a self-report-based quantitative survey approach, so the data relied heavily on teacher perceptions without direct classroom observations or analysis of student learning outcomes. This study also failed to integrate other important variables such as school infrastructure quality, institutional leadership support, curriculum readiness, and socioeconomic factors that likely influence the success of STEAM implementation. Therefore, future researchers are advised to use a mixed methods approach with classroom observations, in-depth interviews, and analysis of actual learning practices to obtain a more comprehensive picture of STEAM implementation. Future research should also expand the scope of research areas across provinces and countries, link teacher competencies with student

learning outcomes, and explore the integration of artificial intelligence, digital learning ecosystems, and local culture-based ethno-STEAM models in 21st-century secondary education.

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