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STEAM Pedagogy and Student Competency Development: A Comparative Mixed-Methods Study of Institutional Contexts in Pakistan and Japan

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Abstract

Purpose

This study analyzed the relationship of STEAM Pedagogical practices with students STEAM competency development in higher education and how contextual constraints and institutional culture shape their implementation in Japan and Pakistan.

Design/methodology/approach:

A comparative concurrent mixed-methods design was adopted, integrating quantitative and qualitative data collected concurrently. Quantitative data captured using adopted survey questionnaire total of 293 (Pakistan 151 and Japan 142) students' perceptions of STEAM practices and their competencies, while qualitative interviews with students and faculty (total of 10 students and 6 teachers; 5 students and 3 teachers from each country) provided insights into institutional and contextual factors influencing STEAM pedagogy. Quantitative analyses included nonparametric tests to compare perceptions across countries and hierarchical regression to assess the predictive and moderating roles of STEAM practices followed by thematic analysis of qualitative part of the study.

Findings:

The study found that STEAM pedagogical practices strongly predict student competency development, and this relationship is largely consistent across both national contexts. While differences in students' perceptions of STEAM practices and competencies were observed, institutional and contextual factors, rather than national context per se, influence the translation of pedagogy into effective learning outcomes.

Research limitations/implications:

The study is limited to selected higher education institutions and convenience sampling, which may affect generalizability. Nonetheless, it highlights the importance of context-sensitive professional development and curriculum design for successful STEAM implementation.

Practical implications:

Findings offer guidance for educators and policymakers on enhancing student competencies through structured STEAM pedagogical practices while adapting to local institutional conditions.

Originality/value:

By integrating quantitative outcomes with qualitative insights, this study provides a cross-national perspective on STEAM pedagogy, emphasizing the interplay between instructional practices, institutional culture, and contextual constraints.

Introduction

STEAM (Science, Technology, Engineering, Arts, and Mathematics) learning has become one of the most prominent pedagogical interventions in implementing 21st century skills in critical thinking, creativity, collaboration, and technological literacy development (Bybee, 2013; Papadopoulou, 2024). Combining disciplinary learning with practical problem-solving, STEAM transforms the idea of the higher education institution to the development of competencies in addition to academic success and labor market preparation (Mynbayeva and Maigeldiyeva, 2024; Spyropoulou and Kameas, 2023). In addition, successful implementation of STEAM requires that teachers combine pedagogy, content and technology. The Technological Pedagogical Content Knowledge (TPACK) framework offers a framework to comprehend meaningful technology integration (Chai, 2019), with recent extensions including competency-based TPACK and DPACK, focusing on context-regulated digitally mediated pedagogy (Dolgopolovas and Dagiene, 2024; Thyssen et al., 2023). Empirical evidence suggests that organized models of STEAM support the competence of projects among the students, their motivation, and problem-solving abilities, with the professional development of the teacher being an important factor in maintaining the high quality of instruction (Lin and Tsai, 2021; Morales et al., 2020; Martins and Baptista, 2024). Though becoming more prevalent, the implementation of STEAM is frequently limited by the inflexibility of curricula, lack of resources, cultural attitudes towards interdisciplinarity, and disproportionate readiness among the faculty (Wu, 2022; Vosnjak et al., 2023). These situational aspects are not well-researched in the comparative studies of higher education, which continues to be dominated by studies conducted in individual countries (Yim et al., 2025). Therefore, by comparing Pakistan and Japan, it can provide useful information, pitting a technologically advanced system against an environment that encounters challenges associated with structure and capacity (Rehman et al., 2025). The research fills the existing gaps by investigating how the use of STEAM pedagogies influences students to develop competencies, comparing the perceptions of various contexts, and outlining the possible institutional challenges with a mixed-methods approach (combining findings of quantitative outcomes and qualitative insights) (Abdullah and Mahmud, 2024; Widiyatmoko et al., 2024).

Research Objectives

1. To examine the extent to which STEAM pedagogical practices influence the development of students' STEAM competencies in higher education institutions in Pakistan and Japan.
2. To compare students' perceptions of STEAM pedagogical practices and competency development across the two national contexts.
3. To identify the key contextual and institutional challenges affecting the implementation of STEAM pedagogical practices in higher education.
4. To generate comparative insights that inform the improvement and contextual adaptation of STEAM pedagogical practices in diverse higher education systems.

Literature Review

Foundations and Principles of STEAM Education

STEAM education has become the development of the old forms of STEM education, and the focus on the combination of arts with science, technology, engineering, and mathematics to promote creativity and critical thinking and holistic problem solving (Mynbayeva and Maigeldiyeva, 2024; Papadopoulou, 2024). In contrast to content-based STEM programs, STEAM is an interdisciplinary program that enables students to establish links among the disciplines and apply their knowledge to real-world problems (Thyssen et al., 2023). Constructivist pedagogies form a significant part of the theoretical basis of STEAM and put a strong focus on inquiry-based learning, experiential learning, and the collaborative construction of knowledge (Lin and Tsai, 2021). The principles of STEAM are also very similar in the Japanese context, where the lesson study culture and reflection in the school environment are widespread, and the principles of inquiry, experimentation, and project collaboration are inherent to the regular school curriculum (Matsuura and Nakamura, 2021). Japanese STEAM models are process-centered and problem-solving approaches are more important than content memorization. On the other hand, the incorporation of STEAM in Pakistan is immature. Policy systems and pilot programs have begun to promote interdisciplinary methods, but the education system is predominantly exam-based, and integration of arts is very low, making the holistic application of STEAM pedagogy impossible (Rehman et al., 2025; Mahmood et al., 2025). On the whole, STEAM education can be discussed as the paradigm shift to the learning approach based on competencies rather than rote memorization focused on training students to solve complex problems in the 21st century by making them creative, collaborative, and capable of critical thinking (Spyropoulou and Kameas, 2023).

STEAM Pedagogical Practices and Classroom Instruction

STEAM Pedagogical practices in STEAM education focus on student-centered and project-based learning, such as inquiry-based and design-thinking learning, and experiential learning (Lin and Tsai, 2021; Anito Jr et al., 2019). The successful application depends on the incorporation of Technological Pedagogical Content Knowledge (TPACK) frameworks, which can help a teacher combine content knowledge with pedagogy and digital tools to conduct interdisciplinary teaching (Thyssen et al., 2023; Chai et al., 2019). According to the latest research, STEAM classrooms are associated with facilitating collaborative problem-solving, engaging in the authentic project, and reflecting, which altogether contribute to the development of student competencies (Spyropoulou and Kameas, 2023; Morales et al., 2021). In Japan, there is high teacher autonomy and institutional support of STEAM practices. Collaborative and inquiry-based lessons are common in Japanese education supported by constant professional growth and lesson study, which facilitates continuous improvement of teaching methods (Matsuura and Nakamura, 2021; Milara et al., 2020). Conversely, in Pakistan, a lack of resources, inflexible curricula, and even large classroom sizes contributes toward systemic and structural barriers when it comes to full implementation of STEAM pedagogies. Although project-based and inquiry-oriented approaches have been tried in some cities and private schools, they are not yet widely adopted as teachers are not adequately prepared and teachers focus on exams (Rehman et al., 2025; Mahmood et al., 2025). Also, Professional development is identified as a decisive element that make the use of STEAM pedagogical practices possible. TPACK-oriented teacher training, co-created learning laboratories and technology-enhanced collaborative learning environments have proven to enhance the quality of instruction and teacher self-confidence in STEAM disciplines (Martins and Baptista, 2024; Max et al., 2020; Meletiou-Mavrotheris and Paparistodemou, 2024). Cross-disciplinary collaboration is also promoted with the help of such initiatives, as it is a key to the successful implementation of STEAM curricula in culturally diverse settings (Wu, 2022; Lyu et al., 2024).

Student Competency Building through STEAM

The creation of 21st century skills is one of the major objectives of STEAM learning: critical thinking, problem-solving, creativity, teamwork, and communication (Mynbayeva and Maigeldiev, 2024; Lin and Tsai, 2021; Morales et al., 2019). Development of competencies is highly related to pedagogical practices that foster active learning, formative feedbacks and authentic evaluation. Research has shown that learners in STEAM-based classes have shown greater project competence, intrinsic motivation, and interdisciplinary reasoning (Lin and Tsai, 2021; Morales et al., 2020).

In Japan, structured project cycles, reflective learning practice and an educational culture that places emphasis on process over performance are some of the aspects that facilitate competency development. Japanese learners are challenged to participate in problem-solving and iteration of designs and this contributes to the development of cognitive and socio-emotional skills (Matsuura and Nakamura, 2021; Milara et al., 2020). Competency development of students in Pakistan is not evenly distributed because of the traditional pedagogical restrictions. Although STEAM initiatives of private and urban schools demonstrate encouraging results of creativity and problem-solving improvement, the public schools' environment is typically characterized by the lack of resources, teacher readiness, and examination priority, which influence the overall results in developing competencies in students (Rehman et al., 2025; Mahmood et al., 2025).

According to emerging studies, the digital tools and computational thinking also play a crucial role in improving the competency development. The effectiveness of STEAM education directly depends on the competence of teachers who can use technology in the classroom, lead inter-disciplinary projects, and build interactive learning environments (Sun et al., 2023; Psycharis et al., 2020). Technological infrastructure is used by the Japanese educators to

strengthen process-oriented competency in cross cultural comparisons and in Pakistan, technology adoption is inconsistent which underscores contextual inequities in competency outcomes.

Institutional Culture and its effect on Pedagogy

The institutional culture is central to the effectiveness of the STEAM pedagogical practices. The impact of school norms, leadership, teacher autonomy, and professional development opportunities on STEAM implementation in classrooms is combined (Morales et al., 2021; Chai, 2019). When a culture of support exists in the institutional culture, experimentation, collaboration, and reflective teaching are promoted, and teachers can change interdisciplinary strategies efficiently (Martins and Baptista, 2024; Meletiou-Mavrotheris and Paparistodemou, 2024). On the other hand, the innovation might be constrained by hierarchical or inflexible institutional settings, and the implementation of student-centered pedagogies could be limited (Vosnjak et al., 2023).

The culture of Institutional cultures in Japan is described by organized lesson study cycles, professional learning communities, and the emphasis on the continuous professional development of teachers. These aspects offer a consistent approach to the implementation of STEAM pedagogies into everyday life, which promotes risk-taking and reflective teaching (Matsuura and Nakamura, 2021; Milara et al., 2020). The Japanese teachers enjoy the freedom of these frameworks and hence they are able to put the STEAM projects into context and also meet the requirements of education.

Moreover, centralized curriculum, hierarchies in schools' administration and lack of teacher autonomy tend to affect institutional culture in Pakistan (Rehman et al., 2025; Mahmood et al., 2025). Even with the policy measures that foster the 21st century competencies, most schools find it hard to offer settings that support innovative pedagogy. Professional development programs are present and not equally distributed and teachers are often under pressure at systemic level to focus on examination results rather than competency-based STEAM learning (Abbas et al., 2024).

The Cross-Cultural and Comparative Analysis of Japan and Pakistan

Comparative studies present the impact of cultural values, historical processes, and institutional configurations on the adoption and achievement of STEAM. Cross-cultural studies show that the variation in the beliefs of teachers, classroom norms, and expectations of the society influence the way of competencies development and the implementation of pedagogy (Chu, 2021). Attitudes toward collaboration, student autonomy, and experimentation are the cultural factors that have a direct impact on the teacher practices and student engagement.

The success of the integration of STEAM approaches in Japan is favored by the culture of reflective practice and collaborative learning, as well as process-oriented assessment (Matsuura and Nakamura, 2021; Milara et al., 2020). The students will also work to solve problems iteratively, complete collaborative assignments, and seek interdisciplinary answers, which leads to increased competence development in the areas of creativity, critical thinking, and communication abilities. There are great professional networks, feedback, and institutional support of pedagogical innovation in the teachers. Cultural and systemic factors, including hierarchical classroom interactions, learning based on examinations, and teacher-centered methods, are comparative studies that indicate a challenge to STEAM implementation in Pakistan (Rehman et al., 2025; Mahmood et al., 2025). As urban and privately run schools start moving towards student-based and technology-enhanced learning, unequal distribution of resources, teacher skills and flexibility in curriculum creates unequal learning outcomes. Cross-cultural comparison shows that instead of implementing the models of high-performing countries, it is necessary to modify STEAM strategies to the local contexts (Abdullah and Mahmud, 2024; Abbas et al., 2024).

Gaps and Need for This Research

Although there is increasing interest in STEAM education, there are some gaps in conceptualizing the practice and its effectiveness in higher education. To begin with, most of the available work is either country-specific or institution-specific, tending to either address student achievement or the readiness of teachers, with very little incorporation of both sides (Yim, Su, and Wegerif, 2025). This disjointed practice is a constraint to holistic and contextually oriented STEAM strategies. Second, frameworks like TPACK and DPACK are commonly applied to conceptualize technology-integrated pedagogy (Chai, 2019; Thyssen et al., 2023; Dolgopolovas and Dagiene, 2024), yet there is a limited quantity of empirical studies that have linked these frameworks with STEAM competency development of students, especially in higher education. The literature does not focus on university students (Lin and Tsai, 2021; Morales et al., 2020), though the content of the study is mostly focused on preservice educators or school-level situations. Third, contextual and institutional factors such as the rigidity of the curriculum, the resources, the capacity of the faculty, and the cultural disposition to interdisciplinarity are not studied thoroughly in comparative literature (Wu, 2022; Morales et al., 2022; Vosnjak et al., 2023). There is limited literature on how such factors influence the implementation of STEAM as cross-national research. Lastly, little research combines quantitative competency results with qualitative situational analysis, which limits knowledge on the success or failure of STEAM practices in different environments (Abdullah and Mahmud, 2024). It is especially important to address these gaps in terms of contrasting cultures like that of Pakistan and Japan.

Theoretical Synthesis of STEAM Pedagogical Practices

The literature reveals that STEAM pedagogy at the higher-level education is internationally based on the constructivist and socio-cultural learning theories, which focus on the interdisciplinary integration, the authentic problem-solving, and the learner-centred learning. The ability to develop critical thinking, creativity, and applied problem-solving skills, which are among the main aspects of developing STEAM competencies, is well-known among core pedagogical practices, including project-based learning, inquiry-based learning, and collaborative learning (Bybee, 2013; Morales et al., 2020). These strategies are progressively facilitated by technology-encompassed pedagogies, which conform to the TPACK framework, and go ahead to affirm the effective combination of technological, pedagogical, and content knowledge as the pivotal component of meaningful STEAM learning experiences (Chai et al., 2019). Although this

is an international agreement, the literature shows that there is much inconsistency on the operationalization of STEAM pedagogical practices in the national and institutional settings. STEAM pedagogy has deep roots in institutional cultures that facilitate interdisciplinary curriculum development, design thinking, and authentic assessment practices in technologically advanced systems like Japan that are supported by long-term faculty professional growth and infrastructure investment (Wu, 2022; Yim, Su, and Wegerif, 2025). The mentioned conditions enable development of student competencies in a systematic way as a result of organized teamwork, practical participation in real-world problems, and evaluation based on performance.

Conversely, research in developing and transitional settings, such as Pakistan, indicates the existence of structural and cultural barriers that do not allow the systematic adoption of STEAM pedagogical strategies. Despite the growing support of policy speech towards interdisciplinary and technology-enhanced learning, its practical implementation is often limited by a limited curriculum, examination-based assessment, faculty education, and unfair distribution of technological facilities (Morales et al., 2022; Vosnjak et al., 2023). Therefore, STEAM activities in these settings tend to be subjective and disjointed in terms of their possible effects on comprehensive competency learning. Table 1 shows the STEAM pedagogical practices globally, and a comparative look of Pakistan and Japan in higher education context.

Table 1
STEAM Pedagogical Practices Applied Globally, in Pakistan, and in Japan (Higher Education Focus)

STEAM Pedagogical Practice	Global Application (Literature-Based)	Application in Pakistan	Application in Japan	Key Supporting Literature
Project-Based Learning (PBL)	Widely adopted as a core STEAM strategy to promote problem-solving, collaboration, and real-world application of interdisciplinary knowledge.	Implemented unevenly; often constrained by rigid curricula, assessment systems, and limited institutional support.	Strongly embedded in university courses, especially engineering and applied sciences, emphasizing real-world societal problems.	Bybee (2013); Morales et al. (2020); Wu (2022)
Inquiry-Based Learning	Used globally to foster critical thinking, scientific reasoning, and learner autonomy within STEAM contexts.	Limited adoption due to exam-oriented teaching cultures and large class sizes.	Systematically incorporated, with emphasis on structured inquiry and guided exploration.	Lin & Tsai (2021); Vošnjak et al. (2023)
Technology-Integrated Pedagogy (TPACK-aligned)	Common globally, focusing on the integration of digital tools with pedagogy and content knowledge.	Adoption is emerging but inconsistent; technology use often remains surface-level rather than pedagogically integrated.	Highly developed, with institutional investment in digital platforms and faculty training.	Chai et al., (2019); Thyssen et al. (2023)
Interdisciplinary Curriculum Design	Promoted globally as the foundation of STEAM, encouraging integration across science, technology, engineering, arts, and mathematics.	Often limited to policy rhetoric; practical implementation remains fragmented across departments.	Actively practiced through cross-departmental courses and collaborative modules.	Bybee (2013); Morales et al. (2022)
Design Thinking & Creative Problem Solving	Increasingly emphasized worldwide to develop innovation, creativity, and user-centered problem-solving.	Rarely institutionalized; mostly dependent on individual instructors' initiatives.	Widely practiced, particularly in engineering, robotics, and innovation programs.	Wu (2022); Yim, Su & Wegerif (2025)
Collaborative & Team-Based Learning	Globally recognized for enhancing communication, teamwork, and interdisciplinary competence.	Applied inconsistently; collaboration is often informal rather than pedagogically structured.	Strong cultural and institutional support for structured teamwork and collective problem-solving.	Morales et al. (2020); Vošnjak et al. (2023)
Authentic Assessment Practices	Used globally to assess applied competencies through projects, portfolios, and performance tasks.	Predominantly replaced by traditional exams; competency-based assessment remains limited.	Integrated into course design, emphasizing performance and applied learning outcomes.	Bybee (2013); Widiyatmoko et al. (2024)
Faculty Professional Development for STEAM	Recognized globally as critical for sustainable STEAM implementation.	Limited access to structured professional development and STEAM-specific training.	Institutionalized through continuous professional development and research-informed teaching.	Chai et al. (2019); Abdullah & Mahmud (2024)

Research Methodology

This paper embraced a comparative mixed-method research design with a convergent parallel design, where both the quantitative and qualitative data were gathered at the same time, analyzed independently, and combined with the interpretation phase (Creswell and Creswell, 2014). It was such a design that allowed a thorough investigation of not only measurable student outcomes but also contextual aspects that define STEAM pedagogical practices in two national settings of Pakistan and Japan. The research was based on pragmatic research paradigm, which promotes the application of various methods in researching on complex educational phenomena (Hall, 2013). Pragmatism was well suited to this study since it enabled combination of both quantitative data on the development of student competencies and qualitative data on the issue of institutional cultures, pedagogical realities, and constraints of the context of STEAM implementation. The focus was also on producing findings of practical relevance and context sensitivity as opposed to following the methodological singularity.

The target population comprised undergraduate and post graduate students pursuing a program in STEAM related programs and faculty members teaching a course in STEAM oriented courses in selected institutions of higher education in Pakistan and Japan. The institutions were enlisted according to the involvement in interdisciplinary or technology-based pedagogical activities that are adjusted to the STEAM education. This population was deemed appropriate both in studying the results of the learners and institutional factors influencing the STEAM pedagogy. The sampling strategy was convenience

based because of the constraints in accessibility and because the study was cross-national. In case of the quantitative stage, a survey by way of Google Forms was circulated. Pakistani students who are already studying in Japanese universities were asked to share out the questionnaire with their academic circles in Japan and the same approach was employed in Pakistani universities. A total of 293 valid responses were gained, 142 and 151 responses of Japan and Pakistan respectively, that offers a sufficient sample to conduct a comparative quantitative analysis.

The survey tool was based on already existing frameworks of STEAM and technology-integrated pedagogy and specifically on Technological Pedagogical Content Knowledge (TPACK) framework (Chai et al., 2019) and the model of STEM/STEAM skills by Bybee (2013). The questionnaire assessed the perceptions of the students toward STEAM pedagogical practices and their contribution to significant competencies, such as critical thinking, creative problem-solving, collaboration, communication, technological literacy, and interdisciplinary integration. There were a few contextual changes that were done to guarantee the cultural relevance in both nations. Instrument validity was determined with the relatedness to the theoretical frameworks, and reliability was determined by means of Cronbach alpha used to verify the scales of acceptable internal consistency. Further, semi-structured interviews were used to gather qualitative data in order to have a more in-depth understanding of contextual and institutional issues that influenced the implementation of STEAM. Five students and three teachers of each country were chosen to form the qualitative sample, making ten interviews of students and six interviews of teachers. The participants were chosen according to their personal experience in teaching and learning that is based on STEAM. Interventions on the institutional support, flexible curriculum, faculty readiness, resource provision, and cultural understanding of interdisciplinary learning were conducted in terms of interviews. The interviews were about 30–45 minutes on a face-to-face or online basis. Audio-recorded informed consent was used to interview all interviewees and the field notes were kept.

To summarize the perceptions and competency development of the students, quantitative data were analyzed using statistical software to create descriptive statistics, i.e., means, standard deviations, frequencies, etc. To test the impact of STEAM pedagogical practice on the student competencies and compare the results in Pakistan and Japan, inferential statistical tests were performed. It was followed by reliability analyses before inferential testing. Nonparametric tests were used as quantitative analyses to compare the perceptions across countries whereas Mann Whitney U test and hierarchical regression were also conducted to elaborate differences and predictive relationships between pedagogical practices and the student competency outcomes.

Thematic analysis was used in analyzing qualitative data (Braun and Clarke, 2006). Inductive coding of interview transcripts was done in order to determine recurring patterns in terms of institutional and contextual challenges. Thematic analysis helped to narrow down themes through coding and cross-context analysis to ensure that both the common and country-specific limitations of STEAM pedagogy were taken into account. Additionally, triangulation was done at the interpretation level by integrating the quantitative and qualitative results. To understand how STEAM pedagogy influences the development of competencies, quantitative outcomes were discussed with reference to the qualitative insights to explain the factors beyond the scope of the discussed instrument, which are influenced by the circumstances. This research follows ethical standards, participants were placed in the awareness of the objective of the study, their confidentiality and anonymity were ensured, and they were told that *they had the right to withdraw at any given time*. The information was safely saved and only applied to academic purposes. Although the convenience sampling and the selection of institutions restricts the generalizability, the comparative mixed-methods design will have transferable information on the implementation of STEAM in different contexts of higher education.

Results and Findings

Interpretation of Descriptive Statistics of STEAM Pedagogical Practices

The descriptive statistics indicate that STEAM pedagogical practices are implemented at a moderately high level (M ≈ 3.58–3.88 on a 5-point scale). Among these, *inquiry-based learning* (M = 3.88) and *cross-disciplinary knowledge application* (M = 3.85) show relatively higher prevalence, while *authentic competency-focused assessment* (M = 3.58) and *innovation practices* (M = 3.62) are comparatively lower. Standard deviations (≈ .76–1.00) suggest moderate variability in responses. Similarly, students' STEAM competencies are also reported at a moderate to high level (M ≈ 3.44–3.83). Higher scores are observed for *interdisciplinary learning confidence* (M = 3.83) and *future career readiness* (M = 3.82), whereas *applied scientific and mathematical literacy* (M = 3.44) is relatively lower. The variability remains moderate (SD ≈ .79–1.03), indicating some diversity in students' competency levels. Overall, the findings suggest that both STEAM practices and student competencies are reasonably well-developed, though certain areas require further strengthening.

Table 2
Descriptive Statistics of STEAM Pedagogical Practices

Interdisciplinary STEAM Integration	N	Minimum	Maximum	Mean	Std. Deviation
	293	**1.0**	**5.0**	**3.690**	**.9815**
Cross-Disciplinary Knowledge Application	293	1.0	5.0	3.845	.7683
Creativity and Arts Integration	293	1.0	5.0	3.774	.8552
Inquiry-Based Learning Environment	293	1.0	5.0	3.881	.9366
Real-World Contextual Learning	293	1.0	5.0	3.798	.9541
Project/Design-Based Learning Approach	293	1.0	5.0	3.726	.9738
Innovation and Iterative Problem Solving	293	1.0	5.0	3.619	.9806
Technology-Enhanced Deep Learning	293	1.0	5.0	3.750	1.0045
Collaborative Learning Practices	293	1.0	5.0	3.786	.9323
Authentic Competency-Focused Assessment	293	1.0	5.0	3.583	.9720
Valid N (listwise)	293				

Table 3
Descriptive Statistics

Analytical Problem-Solving Competence	N	Minimum	Maximum	Mean	Std. Deviation
	293	**1.0**	**5.0**	**3.560**	**1.0338**
Applied Scientific and Mathematical Literacy	293	1.0	5.0	3.440	1.0102
Creative Thinking Skills	293	1.0	5.0	3.702	.9791
Engineering Design Competence	293	1.0	5.0	3.655	.8711
Interdisciplinary Learning Confidence	293	1.0	5.0	3.833	.8335
Digital and Technological Literacy	293	1.0	5.0	3.798	.9285
Communication Skills in STEAM Contexts	293	1.0	5.0	3.798	.9022
Collaborative Teamwork Competence	293	1.0	5.0	3.643	.8308
Critical Evaluation and Evidence-Based Reasoning	293	1.0	5.0	3.679	.8803
Future STEAM Career Readiness	293	1.0	5.0	3.821	.7940
Valid N (listwise)	293				

Mann-Whitney U Test

A Mann–Whitney U test was conducted to examine differences between Pakistan and Japan. The results indicated significant differences in STEAM practices (U = 628, p = .023) and students' STEAM competencies (U = 643, p = .032). However, no significant differences were observed for interaction-related variables.

Table 4. Test Statistics[a]

	STEAM_Practices	Students_STEAM_Competencies	SPractices_Cent	SCompetencies_Cent	SPractice_x_SComp	STEAMxCountry
Mann-Whitney U	628.000	643.000	628.000	643.000	697.000	693.500
Wilcoxon W	1574.000	1589.000	1574.000	1589.000	1643.000	1639.500
Z	-2.278	-2.140	-2.278	-2.140	-1.654	-1.689
Asymp. Sig. (2-tailed)	.023	.032	.023	.032	.098	.091

a. Grouping Variable: Country

Hierarchical Multiple Regression

The hierarchical regression results show that STEAM pedagogical practices are a strong and significant predictor of the outcome variable. In Model 1, STEAM practices had a high positive effect (β = .776, $p < .001$), explaining 60.7% of the variance ($R^2 = .607$), while country was non-significant (β = −.068). In Model 2, STEAM practices remained significant (β = .657, $p < .01$), but the interaction term was non-significant (β = .125, $p > .05$). The change in explained variance was minimal ($\Delta R^2 = .002$; total $R^2 = .609$). Overall, the results indicate that STEAM practices strongly predict outcomes, with no significant differences between Pakistan and Japan.

Table 5. Hierarchical regression predicting students' STEAM competencies

Predictor	Model 1 β	Model 2 β
STEAM Practices (centered)	.776***	.657**
Country	−.068	−.071
STEAM Practices × Country	—	.125
R^2	.607	.609
ΔR^2	—	.002
F	62.58***	41.50***

Notes:

- $p < .05$*, $p < .01$*, **$p < .001$
- Country coded: 0 = Pakistan, 1 = Japan

Table 6. Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Country, SPractices_Cent[b]	.	Enter
2	STEAMxCountry[b]	.	Enter
a. Dependent Variable: Students_STEAM_Competencies			
b. All requested variables entered.			

Table 7. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.779[a]	.607	.597	.42304	.607	62.584	2	81	.000
2	.780[b]	.609	.594	.42475	.002	.346	1	80	.558
a. Predictors: (Constant), Country, SPractices_Cent									
b. Predictors: (Constant), Country, SPractices_Cent, STEAMxCountry									

Qualitative Findings: Thematic Analysis of Contextual and Institutional Challenges

To respond to the third research question, to find out what contextual and institutional challenges influence the application of STEAM pedagogical practices in higher education, thematic analysis of qualitative data collected in the form of semi-structured interviews with students and faculty representatives in Pakistan and Japan was performed. The underpinning of the analysis was inductive and led to the formulation of five overarching themes that describe common as well as context-specific obstacles to STEAM pedagogy.

Weakened institutionalization of STEAM Pedagogy

One of the most prominent themes of the Pakistani interviews was that there were no formal institutional frameworks to facilitate the STEAM pedagogy. The respondents added that STEAM activities were often based on the personal enthusiasm of the teachers, and not implemented in systematic curriculum or department plans.

A Pakistani faculty gave the following explanation:

"There is no formal structure of STEAM in this case. When a teacher wishes to experiment with something interdisciplinary, he or she is left on their own. It is not supported or guided by the system itself". (PT2)

This perception was also reflected by students who reported differences in the exposure to the practice of STEAM in courses:

"Some educators attempt to use project-based tasks or integrated but some stick to lecture format all the way. It is based on the teacher, rather than the university". (PS3)

Japanese respondents on the other hand reported more explicit curricular alignment in relation to interdisciplinary and technology-based learning. This structuring was however, at times viewed as being rigid:

"The curriculum contains STEAM ideas, which are pre-determined in terms of results and schedules. The space in which anything can be altered is minimal than what is already scheduled to be done". (JT1)

This indicates that institutionalization is present in Japan but it can also limit the flexibility of pedagogy.

Resource and Infrastructure Constraints

One of the important contexts that formed the implementation of STEAM is the availability of resources. Access to laboratories, digital resources, and interdisciplinary education places were also a common issue mentioned by Pakistani participants.

A Pakistani student noted:

"We study the idea of STEAM, but in reality, we do not have sufficient equipment and laboratories to implement these ideas. Majority of the activities are theoretical". (PS1)

Faculty members stressed the fact that restricted resources influenced the quality and the number of practical STEAM experiences:

"STEAM should be experimented and designed, but the lack of appropriate facilities makes it hard to get beyond the discussion stage". (PT1)

The Japanese respondents mostly indicated an increased availability of the technological infrastructure. Nevertheless, they specified other resource-specific limitations, especially, time and workload:

"The amenities exist but time is the actual problem. Planning STEAM classes is more cumbersome, and faculty do not have extra time to spend". (JT3)

Therefore, resources limitation in Pakistan were a limiting factor to STEAM pedagogy, whereas time and usage limitations in Japan were restrictive to its performance.

Professional Development Gaps and Preparedness of the Faculty

Faculty readiness to STEAM pedagogy. Pakistani teachers often complained that they have not been formally trained in interdisciplinary instruction, measurement of STEAM skills and technology.

One faculty member stated:

"We had been schooled in our disciplines. STEAM involves integration of disciplines, yet minimal professional development is on that". (PT3)

This gap was considered by students to influence classroom practices:

"The teachers would like to do the STEAM, though at times they are not sure how to use technology or how to cope with interdisciplinary projects". (PS4)

Faculty members were comparatively better prepared to pedagogical training in Japan but noted that they experienced difficulties with maintaining professional learning:

"There are workshops and yet, there is no continuous development of STEAM due to time constraint and institutional priorities". (JT2)

It means that, though the level of preparedness varies, the issue of professional development is one of the most serious in both settings.

Assessment-oriented Assessment Culture

The practice of assessment was also seen as contrary to the objectives of STEAM pedagogies especially in Pakistan. The participants highlighted those systems concentrated on examinations are not conducive to creativity, teamwork, and problem-solving because they are based on rote learning.

One of the Pakistani students commented:

"In the end, skills do not count as much as grades. STEAM activities are fun yet exams do now test memorization". (PS2)

This tension was confirmed by the faculty members:

"We supposedly finish the syllabus and train learners to exams. STEAM is time consuming and does not necessarily fit in the assessment system". (PT2)

The Japanese participants also reported the constraints associated with assessments, but in a varied variant:

"Assessment is encouraged Project-based on the one hand, it is difficult to grade interdisciplinary work on equal terms, with larger classes the more challenging". (JT1)

Such results indicate that the culture of assessment in both countries determines the extent to which STEAM pedagogy can be adopted.

Learning Expectations and Cultural Norms of the students

The attitude of a culture toward teaching and learning was an indicator of a small but powerful theme. Hierarchical classroom norms in Pakistan were viewed to restrict student autonomy and inquiries-based learning.

A student explained:

"We are accustomed to having teachers who give clear instructions. Open-ended tasks are initially confusing since we are not conditioned to do it". (PS5)

In Japan, group-based STEAM activities were encouraged by collaborative norms, yet students were reluctant to show non-conformity:

"Group work is typical, and students might not want to confront the ideas of others openly and this may limit creativity". (JS2)

These cultural processes demonstrate that sociocultural demands can empower and restrict STEAM pedagogy.

The qualitative data show that the idea of STEAM pedagogy is conditioned by the multi-level interaction of the institutional frameworks, resources, assessment systems, and cultural imperatives. These contextual aspects can be seen as an explanation of cross-national differences recorded in the quantitative results and as the necessity to rely on context-sensitive approaches to facilitate the sustainable implementation of STEAM in higher education.

Integrated Findings of the Study

Integration of quantitative and qualitative findings was done through a joint display. Quantitative findings revealed that student perceptions of STEAM pedagogical practices and competency development should not be compared in cross-national terms, and the regression analysis model revealed that STEAM pedagogy and competencies are highly interconnected and stable in the two settings. These patterns were explained by qualitative results that identified the ways in which institutional framework, resources, assessment culture, and sociocultural norms influence implementation of STEAM pedagogy hence putting into perspective the quantitative differences. Table 8 show the integrated findings of the study.

Table 8. Integration of Quantitative and Qualitative Findings Across Contexts

Quantitative Findings	Qualitative Themes	Illustrative Verbatim Evidence	Integrated Interpretation (Meta-Inference)
Pakistani students reported significantly higher mean ranks for STEAM pedagogical practices than Japanese students (U test results).	**Institutional Structuring of STEAM**	"If a teacher wants to do STEAM, it depends on personal effort. There is no official structure guiding it." (PT2)	Higher reported STEAM practices in Pakistan appear to be driven by **individual teacher initiative**, rather than formal institutional systems, leading to variability but strong perceived engagement.
Pakistani students also showed higher mean ranks for STEAM competency development.	**Resource Constraints vs. Pedagogical Adaptation**	"We don't have enough labs, so teachers adapt activities using available tools." (PS1)	Despite limited infrastructure, **adaptive pedagogical strategies** may strengthen students' perceived competency development in Pakistan.
Regression analysis showed STEAM pedagogical practices strongly predict student competencies across both countries ($R^2 = .607$, $p < .001$).	**Faculty Role in Competency Development**	"When STEAM is used properly, students clearly develop problem-solving and collaboration skills." (JT3)	Quantitative strength of the relationship is explained qualitatively by **faculty mediation**, confirming STEAM pedagogy as a robust mechanism across contexts.
The interaction effect (STEAM × Country) was non-significant ($\Delta R^2 = .002$, $p = .558$).	**Cross-Context Pedagogical Consistency**	"The teaching methods may differ, but STEAM helps students think more critically everywhere." (JS2)	Although levels differ, the **core pedagogical mechanism of STEAM remains stable** across Pakistan and Japan, explaining the absence of moderation effects.
Japanese students reported lower mean ranks for STEAM practices and competencies.	**Curricular Rigidity and Standardization**	"STEAM is part of the curriculum, but there is little freedom to modify activities." (JT1)	Formal inclusion of STEAM in Japan may **limit pedagogical flexibility**, reducing students' perception of engagement and impact.
Quantitative differences exist despite similar pedagogical effects.	**Assessment-Oriented Academic Culture**	"STEAM activities are interesting, but exams still test memorization." (PS2)	Misalignment between **assessment systems and STEAM goals** constrains deep implementation, particularly affecting how students value competencies.
Strong main effects of pedagogy regardless of country.	**Cultural Norms in Learning**	"Students hesitate to share unconventional ideas during group work." (JS1)	Cultural norms subtly shape **how STEAM is enacted**, influencing expression, creativity, and perceived outcomes without altering the core pedagogy–competency link.

Discussion

This study highlighted the effect of STEAM pedagogical practice on higher education students in relation to STEAM competencies, perception comparisons between Pakistan and Japan, and the contextual and institutional barriers of implementing STEAM. The findings enhance the existing research of STEAM scholarship because it provides cross-national empirical data of two opposite educational systems, as well as combines competency-based and pedagogical knowledge frames.

STEAM Pedagogical Practice and Competences Development

The quantitative results show that there is a significant positive correlation between pedagogical practices related to STEAM and STEAM competencies in students, which proves that learner-centered, interdisciplinary, and inquiry-based methods are closely related to the increased level of problem-solving, creativity, collaboration, and integrative thinking. This is consistent with the previous empirical and conceptual research focusing on competency-based STEAM learning (Lin and Tsai, 2021; Spyropoulou and Kameas, 2023; Mynbayeva and Maigeldiyeva, 2024). The findings also support the idea that STEAM education needs to be interpreted not only as the combination of content, but as a pedagogical approach that would help to develop transferable 21st-century skills (Papadopoulou, 2024; Ulbrich et al., 2025). Theoretically, the findings serve competency-based extensions of the TPACK framework. In response to the challenges of introducing the complexity of STEAM learning environments, recent scholarship has emphasized the weaknesses of traditional TPACK, which resulted in models like DPACK (Thyssen et al., 2023) as the teachers need more digital competence beyond only technology use, and competency-based STEM-TPACK (Dolgopolovas and Dagiene, 2024). The high predictive validity of STEAM practices to predict student competencies observed in the given research indicates that efficient STEAM pedagogy involves not only integrating technology and pedagogy, but also the purposeful correspondence to competency frameworks, including those that involve computational thinking and interdisciplinary problem-solving (Psycharis et al., 2020; Sun et al., 2023).

Pakistan and Japan Cross-National Differences

The comparative analysis has shown that there is a statistically significant difference in the perceptions of STEAM pedagogical practices and competency development between students in Pakistan and Japan, with Pakistani students recording the presence of higher mean ranks. Although it is intuitively contrary to this fact given the more established STEM infrastructure in Japan, qualitative results furnish valuable background explanations. As in the case of Matsuura and Nakamura (2021), Japanese STEAM is frequently integrated with formal curricula and standardized outcomes, which might limit pedagogical agencies and student agency. Pakistani STEAM projects, which are less institutionalized, on the contrary, seem to enable more experimentation and teacher-based innovation, which is similar to emerging STEM settings (Abbas et al., 2024; Rehman et al., 2025). These findings confirm the claim by Chu (2021) that the implementation of STEAM in the Asia-Pacific region is quite situational and cannot be measured only based on the level of infrastructural preparedness. Instead, pedagogical culture, assessment regimes and institutional expectations are mediating factors that are significant in influencing the experiences and outcomes of students.

Contextual Challenges to STEAM Implementation

The qualitative results indicate that both settings have several systemic obstacles to STEAM implementation, such as inadequate institutional structures, inappropriate assessment systems, disequilibrium in faculty readiness, and culturally aligned learning standards. These are common issues in global STEAM literature (Vosnjak et al., 2023; Wu, 2022; Morales et al., 2022), yet this research introduces certain nuances of comparison by demonstrating how each country approaches these issues differently. In Pakistan, the lack of official policies on STEAM, lack of access to laboratories, and academic cultures based on exams were defined as key limitations. These results are aligned with the national-level studies on STEM preparedness that indicate the lack of teacher training, policy consistency, and resource distribution (Rehman et al., 2025; Widiyatmoko et al., 2024). In Japan, participants highlighted the time issue, strict assessment frameworks, and workload-related issues, which agrees with previous studies in Japanese STEAM education despite less problematic infrastructure and curricula alignment (Matsuura and Nakamura, 2021). The preparation of faculty was also identified as a cross-cutting problem of concern. Although Japanese educators typically exhibited more pedagogical competence at the baseline, both settings indicated the necessity of professional development over a period of time, which is context-dependent. This is much in line with global experience that has shown that successful STEAM implementation requires ongoing professional learning that is based on TPACK and its emerging variants (Chai, 2019; Martins and Baptista, 2024; Meletiou-Mavrotheris and Paparistodemou, 2024). New models like makerspaces, teaching-learning laboratories, and AI-powered professional development models can provide a direction to fill these gaps (Max et al., 2020; DeWallace-Marenholz, 2025).

Conclusion

This mixed-methods study examined how STEAM pedagogical approaches influence competency development in higher education in Pakistan and Japan, considering contextual and institutional factors. Quantitative findings indicate that STEAM practices significantly predict student competencies, with notable differences in perceptions across countries. Qualitative results reveal that institutional readiness, faculty expertise, curriculum design, and policy alignment shape effective implementation. The integrated analysis suggests that STEAM effectiveness depends not only on pedagogy but also on broader educational systems. While Japan demonstrates consistent implementation due to strong institutional support, Pakistan shows promising pedagogical intent constrained by limited resources and uneven professional development, highlighting the context-dependent nature of STEAM education.

Theoretical and Practical Implications

In theory, the study empowers competency-based and TPACK-based STEAM frameworks by showing that the relationship between institutional conditions and student outcomes mediates through practices of pedagogy. The findings justify the transition to ecological and systems-based approaches to STEAM implementation, which should close the gaps in studies that are mostly single-context. In practice, the results have shown that consistent professional development, curriculum flexibility, and alignment of policies are necessary to maintain STEAM programs. Faculty capacity and institutional support are

strategic investments that are very important in Pakistan, whereas more curricular adaptability can increase innovation in Japan. The study, in general, provides evidence-based recommendations on context-responsive higher education STEAM reforms.

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