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Designing the Future: Integrating Creativity and Innovation Through Design-Based STEAM Learning

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Abstract: *Design-Based STEAM learning emerged as a transformative pedagogical approach aimed at cultivating creativity, innovation, and problem-solving skills among learners. This study examines how Design-Based STEAM learning enhances creative thinking and innovative capacities through an exploratory sequential mixed-method research design. The qualitative phase employed purposive sampling to select STEAM curriculum experts (n = 25) for semi-structured interviews, analyzed using thematic analysis. Insights from this phase informed the design of a quantitative questionnaire administered to trained STEAM teachers (n = 210) by using simple random sampling technique. Quantitative data were analyzed using descriptive statistics. Validity, Reliability, Pilot testing of questionnaire was carried out. Correlation, and regression analysis were applied. It was indicated by results of the study that Design-Based STEAM learning significantly enhances creativity (β = .61, p < .001) and innovation skills (β = .54, p < .001) among learners. Triangulation of qualitative and quantitative findings strengthens the conclusions that Design-Based STEAM education based on prototyping, iterative design, and reflective inquiry is a powerful catalyst for inculcating creativity and innovation. Implications discussed for curriculum developers, teachers, and policymakers seeking to implement STEAM education.*

Introduction

The rapid transformation of global industries requires educational systems that foster creativity, innovation, and integrative problem-solving. STEAM (Science, Technology, Engineering, Arts, and Mathematics) offers a holistic approach to learning by merging scientific thinking with artistic creativity (Yakman & Lee, 2023). However, within STEAM, Design-Based Learning (DBL) has gained prominence for its emphasis on real-world problem solving through iterative design cycles that involve brainstorming, constructing prototypes, testing solutions, and refining ideas (Honey et al., 2022).

Scholars argue that DBL strengthens students' creative fluency, divergent thinking, and capacity to generate innovative solutions (Henriksen & Mishra, 2020). Despite growing interest, empirical evidence on how DBL specifically contributes to creativity and innovation within STEAM education remains fragmented. There is a clear need for research that systematically explores these relationships using

robust methodological approaches.
Thus, this study employs an exploratory sequential mixed-methods research design to first qualitatively explore curriculum experts' perceptions through Semi-structured interviews. then quantitatively investigates by questionnaire survey the educator's opinion about the impact of Design-Based STEAM learning on creativity and innovation among students.

Research Objectives

1. To explore educators' curriculum experts' perceptions of how Design-Based STEAM learning enhances creativity and innovation.
2. To investigates the relationship between Design-Based STEAM learning and students' creativity levels.
3. To analyze the relationship between Design-Based STEAM learning and students' innovation skills.
4. To compare qualitative phase with quantitative phase through triangulation.

Research Questions

1. How do educators and curriculum experts perceive the role of Design-Based STEAM learning in fostering creativity and innovation?
2. What is the impact of Design-Based STEAM learning on students' creativity levels?
3. How does Design-Based STEAM learning influence students' innovation skills?

Hypotheses

1. H1: Design-Based STEAM learning has a significant positive effect on students' creativity.
2. H2: Design-Based STEAM learning has a significant positive effect on students' innovation skills.
3. H3: Creativity significantly leads to innovation within a design-based STEAM environment.

Literature Review

Research on STEAM education has increasingly emphasized the value of integrating science, technology, engineering, arts, and mathematics to foster holistic learning experiences. Scholars argue that STEAM environments cultivate interdisciplinary thinking, creativity, and real-world problem-solving (Land, 2022; Yakman & Lee, 2023). The inclusion of the Arts differentiates STEAM from traditional STEM approaches by allowing learners to engage in expressive, imaginative, and design-oriented tasks that expand cognitive flexibility. This broadening of the learning space is essential for preparing students to address global challenges that require both technical knowledge and creative insight. Design thinking is a human-centered approach to innovation that involves understanding users, challenging assumptions, and redefining problems to identify alternative strategies and solutions. It is widely used in the integration of Arts and engineering in STEAM. Key Proponent of design-based thinking are Kelley and Brown.
However, Design-Based Learning (DBL), a core instructional model within STEAM, provides structured opportunities for students to engage in iterative cycles of ideation, prototyping, testing, and refinement. Honey et al (2022) noted that DBL immerses learners in authentic, hands-on design experiences that mirror real-world engineering and creative industry practices. These iterative activities develop students' capacity for divergent thinking, as they must consider multiple solutions and revise their ideas in response to feedback. Henriksen and Mishra (2020) emphasize that such design tasks stimulate creativity by encouraging learners to think beyond conventional boundaries while integrating knowledge across disciplines.
Creativity, as conceptualized by Runco (2021), involves originality, flexibility, elaboration, and fluency. However, within STEAM education approach, creativity is not limited to the arts but is embedded across

scientific inquiry, technological development, and engineering design. Through open-ended design challenges, students engage in meaning-making processes that strengthen their creative competencies. Additionally, innovation understood as the practical application of creative ideas is a critical outcome of design-based learning. Anderson and Chen (2023) suggest that innovation skills are nurtured when learners apply creative solutions to real-world problems, often using technology, collaboration, and reflective inquiry.

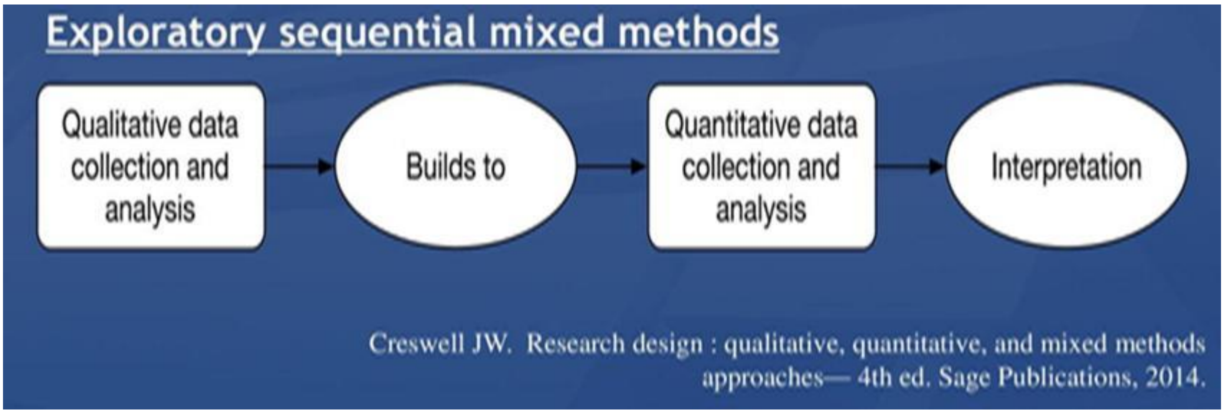
Despite substantial evidence supporting DBL in STEAM education gaps remain in the literature. Most existing studies tend to describe outcomes without deeply exploring how specific design processes contribute to creativity and innovation. Furthermore, earlier studies largely rely on single-method approaches, limiting the triangulation of educator insights and student's experiences. This study addresses these gaps through an exploratory sequential mixed-methods research design that connects qualitative themes with quantitative patterns through triangulation to provide a more comprehensive understanding of the impact of Design-Based STEAM learning.

Research Design

This study employed an exploratory sequential mixed-methods research design guided by a pragmatic research paradigm. Mixed methods approach integrates qualitative and quantitative data to provide a more comprehensive understanding of the research problem (Creswell & Clark, 2018). The qualitative phase was conducted first to explore curriculum experts' perspectives. Qualitative research emphasizes understanding participants' perspectives and meanings within their natural contexts (Patton, 2015). Followed by a quantitative phase to measure teachers' perceptions through questionnaire survey based on five-point Likert scale. Findings from both phases were integrated through triangulation.

Figure 1:

Exploratory Sequential Mixed Methods Research Design Framework



Rationale for using Mixed-methods research design

Comprehensiveness: Mixed-methods research design is based on more comprehensive research methodology and researcher can do a holistic inquiry based on both qualitative and quantitative research phases. (Bryman, 2006). Interdependence: In Mixed-methods research design this term refers to expansion, improvement and interpretation of one phase from the findings of another phase. (Greene, Caracelli & Graham, 1989). Balance or stage of equilibrium: In Mixed-methods research it referred to both qualitative and quantitative phases have their own strength and weakness, by mixing them together research reached to the stage of equilibrium to balance the strength and weakness of both phases by triangulation in order to focus on strengths (Bryman, 2006).

Procedure

Study was carried out in three phases

1. First phase (Qualitative Method).

First Semi-structured interviews with curriculum experts about STEAM curriculum and its implications was conducted.

➢ **Participants:** 15 after Pilot test curriculum experts were selected

➢ **Instrument:** Semi-structured interview protocol

➢ **Duration:** 30–45 minutes per interview

➢ **Location:** online meetings

2. Second Phase (Quantitative Method)

Survey from trained STEAM teachers was carried out to analyze the STEAM curriculum. Questionnaire on five-point Likert scale was used for survey consist of close-ended questions.

➢ **Instrument:** 26-item questionnaire on five-point Likert scale

➢ **Mode:** Paper-based survey administered by researcher

➢ **Completion Time:** 20–25 minutes

3. Third phase (Triangulation)

Findings from teachers' surveys, and curriculum experts' interviews were compared and integrated to ensure credibility and convergence of results. During third phase analysis of both qualitative and quantitative results and integration of all phases was carried out to draw conclusions of the study which is commonly known as triangulation of study (Polit & Beck, 2017).

Population of the study

Population is defined as the entire group of objects, individuals, or events, that a researcher is interested in studying, and to which they intend to generalize the results of their study. Moreover, it is the complete set of elements that share at least one common characteristic that defines the group Creswell, (2014). The target population is also called ideal population. The entire group of individuals or elements that meet the inclusion criteria and to which the researcher wishes to generalize the findings. The accessible population is also called the study population. It is the part of the target population that is practically available to the researcher for participation in the study (Polit, & Beck, 2017).

Target Population of current study were consisting of all (STEAM) teachers of Punjab Pakistan. However, because of limited resources and time constrain it was difficult for the researcher to meet the target population. Therefore, the accessible population was consisting of all trained STEAM teachers (210) from all STEAM integrated schools in Islamabad. For the purpose of this study, a STEAM teacher is defined as a teacher who has received formal training in STEAM pedagogy, including integrated curriculum delivery, project-based learning, and interdisciplinary instructional strategies. These teachers were trained through recognized professional development programs conducted by STEAM based public and private organizations.

Furthermore, for Semi-structured interviews all curriculum experts working in Punjab Pakistan was the target population of study. A curriculum expert refers to an individual with a minimum of five years of professional experience in curriculum development, teacher education, educational leadership, with experience of STEAM and STEM curriculum implementations within public or private educational institutions.

However, again because of limited resources, it was not possible for the researcher to interview all the curriculum experts of Punjab Pakistan. Therefore, the accessible population for Semi-structured interviews consisted of all curriculum experts (25) working in Islamabad Pakistan.

Table 1

Shows population of the study

Curriculum expects	STEAM teachers
25	**210**

Sample of the study and Sampling technique

Purposive sampling is a non-probability sampling technique in which the participants deliberately selected by the researcher based on specific characteristics or qualities that are aligned with the objectives of the study. However, in purposive sampling, the researcher selects individuals who are believed to be knowledgeable and informative about relevant field of study Gay (2012). Moreover, purposive sampling is an advantageous sampling technique in which researcher can use its own knowledge and experience regarding population to ensure that whether the particular sample is the representative of population or not (Vogt, Gardner & Haeffele, 2012).

In the current study, the selection of curriculum experts was made purposively. This involves the presence of only those curriculum experts who have sufficient knowledge, and expertise regarding Designed-Based STEAM curriculum and its implementations. Therefore, by keeping this criterion in view sample of 25 curriculum experts from Islamabad was selected for Semi-structured interview. However, for quantitative phase (survey) simple random sampling technique was used. Simple random sampling technique defined by Gay, Mills, and Airasian, (2012) "it is the process of selecting a sample in such a way that all individuals in the defined population have an equal chance of being selected. Therefore, according to Dr. Jhon Curry (1984) formula of sample selection the sample of 210 trained STEAM teachers was selected for simple random sampling.

Curry proposed:

1. If the population size is between 0–100, sample the entire population (100%).
2. If the population size is between 101–1,000, sample 10%.
3. If the population size is between 1,001–5,000, sample 5%.
4. If the population size is between 5,001–10,000, sample 3%.
5. If the population exceeds 10,000, sample 1%.

Table 2

Shows the sample of the study for content analysis, semi-structured interview and questionnaire

Sample of curriculum experts	Sample of trained STEAM teachers
25	**210**

Instrumentations

Instrumentation of this research study is consisting of qualitative and quantitative research instruments. Thus, for qualitative Phase Semi-structured interviews with experts of STEAM curriculum were also conducted. Semi-structured interviews explored:

- DBL strategies used
- Perceived impact on creativity
- Innovation outcomes
- Challenges and opportunities

Questionnaire will be used as research instrument for quantitative research based on five-point Likert scale on close-ended research questions.

Constructs and Items

1. Design-Based STEAM Learning Scale (10 items)
2. Creativity Scale (8 items)
3. Innovation Skills Scale (8 items)

Likert scale: 1 = Strongly Disagree to 5 = Strongly Agree.

Validity, Pilot Testing, and Reliability of research instruments

1. Validity

It is the extent to which the instrument measures for what it is designed to measure. Content validity was done in this study which ensures that the Questionnaire, and Semi-structured interviews were includes adequate set of items that tap the concept and construct of interest. (Merriam, & Tisdell, 2016). Five points Likert scale was developed and validated. Validation of questionnaire holds three options accept, reject and accept with minor changes; questionnaire was sent to the 15 experts of education along with a covering letter in an envelope packet by the researcher. Consent, dialect and content of the questionnaire was checked and verified by the experts of relevant field. However, during the process of validation all those ambiguous items by experts were excluded and the remaining items with minor changes were included in the research instrument.

2 Pilot testing

After checking the validity of research instruments, the instruments subjected to pilot test. The pilot testing of research instruments was carried out before actual implementation of research tool. The number of participants included in pilot test were excluded from actual sample. A pilot study was conducted with ten trained STEAM teachers and ten curriculum experts of relevant field who were not part of the final sample. Based on pilot feedback, unclear items were revised, redundant statements were removed, and reliability of the instrument was enhanced.

3. Reliability

It was explained by Cypress (2017) that reliability and validity of the study is the process that indicate the research accuracy Creswell (2014), Guba and Lincoln (1994) identified four criteria of reliability: credibility, transferability, dependability, and conformability.

Therefore, to make the research instrument and research process trustworthy and authentic various research sources and methods employed by the researchers. In addition to, Creswell (2012) states that in Mixed-methods research study the triangulation of data from qualitative and quantitative source can maintain and establish the credibility within the research study.

The Reliability Analysis

Table 3:

Shows the Reliability Analysis

Scale	Cronbach's Alpha
DBL	.89
Creativity	.87
Innovation	.85

All scales surpassed the .70 threshold.

Data Collection

The tool which is used to gather the data from specified sample from population is called research instrument or data collection tool. As mentioned above, the study was exploratory sequential mixed-methods. Therefore, two research tools were employed for the collection of data such as for qualitative phase semi structured interviews used as data collection tool. Quantitative tool was consisting of questionnaire survey. Questionnaire was selected as most appropriate tool for conducting survey based on five-point Likert scale.

Data Analysis

Thematic Analysis (Braun & Clarke, 2021)

Six steps were followed: familiarization, coding, theme development, review, definition, and reporting.

Qualitative Themes

Theme1: Iterative Design Spurs Creative Thinking

Teachers reported that cycles of prototype-test-refine improved students' divergent thinking.

Theme 2: Authentic Tasks Drive Innovation

Real-world challenges encouraged students to generate practical solutions.

Theme 3: Collaboration Enhances Idea Generation

Group design tasks increased creativity and problem-solving.

Theme 4: Technology Integration Amplifies Innovation

Digital tools (3D printing, coding) enabled more original product designs.

Phase 2: Quantitative Design

Descriptive Statistics

Table 4

Shows The Descriptive Statistics

Variable	Mean	SD
DBL	3.98	.62
Creativity	4.12	.58
Innovation	4.05	.60

Interpretations:

All variables show relatively high mean scores (around 4 on the scale), which is indicative of fact that respondents reported strong levels of Design-Based STEAM learning, creativity, and innovation. The small standard deviations (.58–.62) suggest that responses were fairly consistent across participants.

Inferential statistics

Correlation Analysis

Table 5

Shows The Correlation Analysis

Variables	1	2	3
1. DBL	1	.61**	.54**
2. Creativity	.61**	1	.69**
3. Innovation	.54**	.69**	1

Interpretations: p < .01, indicating strong correlations.

Regression Analysis

Model 1: DBL → Creativity

- $\beta = .61$
- $t = 10.44$
- $p < .001$
- $R^2 = .37$

Interpretation: DBL explains 37% of variance in creativity. Indicating a substantial effect. The positive beta coefficient shows that increased engagement in Design-Based STEAM learning is associated with higher creativity levels among students.

This supports **H1**.

Model 2: DBL → Innovation

- $\beta = .54$
- $t = 9.12$
- $p < .001$
- $R^2 = .29$

Interpretation: Design-Based STEAM learning has a significant positive effect on students' innovation skills. Hence, 29% of the variance in innovation, signifying a moderate predictive strength. The statistically significant p-value indicates the relationship is highly reliable.

This supports **H2**.

Model 3: Creativity → Innovation

- $\beta = .69$
- $t = 12.03$
- $p < .001$
- $R^2 = .48$

Interpretation: Students' creativity has a strong and significant positive effect on innovation. Creativity explains 48% of the variance in innovation, indicating a strong predictive relationship. This means creativity plays a and important role in developing innovation skills within a Design-Based STEAM learning environment.

This supports **H3.**

Triangulation

Table 6

Shows the Triangulation of both qualitative and quantitative phases

Qualitative Themes	Quantitative Findings	Convergence
Iterative design boosts creativity	DBL → Creativity ($\beta = .61$)	Strong alignment
Authentic tasks foster innovation	DBL → Innovation ($\beta = .54$)	Confirmed
Collaboration enhances idea flow	Creativity strongly predicts innovation	Supported
Technology improves innovation	High innovation means scored	Supported

Interpretations: Triangulation confirms internal consistency across data sources.

Findings

Findings of this study offer critical insights into the role of Design-Based STEAM learning in fostering creativity and innovation among students. Both qualitative and quantitative results converge to show that iterative design processes provide a powerful platform for nurturing creative thinking. Educators emphasized that design tasks stimulate curiosity and allow students to experiment with multiple ideas, which aligns with quantitative data showing that Design-Based Learning significantly predicts creativity ($\beta = .61$). This alignment reinforces theoretical perspectives that creativity thrives in environments that allow exploration, reflection, and revision.

The study also found that innovation is strongly influenced by both DBL ($\beta = .54$) and creativity ($\beta = .69$). This demonstrates that innovation is not an isolated skill but one that emerges from creative processes supported by authentic challenges within STEAM learning. Thematic analysis indicated that real-world problem contexts help students translate creative ideas into functional solutions. For example, educators described how students improved prototypes after iterative testing mirroring authentic engineering practices. The connection between creativity and innovation found here is consistent with Anderson and Chen's (2023) notion that innovation requires both idea generation and feasible application.

Another important finding is the role of technology integration in amplifying innovation. Educators reported that tools such as 3D printers, coding platforms, and digital design software further expanded the creative possibilities for students. This supports research suggesting that technology-rich environments enhance students' capacity to innovate by enabling more complex, original, and interactive designs (Honey et al., 2022). Quantitative patterns also showed higher innovation scores among students exposed to technology-enhanced design tasks.

Discussions

The findings of this study demonstrate that Design-Based STEAM learning is a significant predictor of learners' creativity and innovation, with regression results indicating strong positive effects on creativity ($\beta = .61$, $p < .001$) and innovation skills ($\beta = .54$, $p < .001$). These results are consistent with prior empirical research showing that Design-based and interdisciplinary STEAM approaches enhance higher-order thinking, creative engagement, and innovative problem-solving (Guerra & Smith, 2021; Sung & Hwang, 2020).

The qualitative findings further revealed that prototyping, iterative design, and reflective inquiry are central mechanisms through which creativity and innovation are cultivated. This aligns with Henriksen and Mishra (2020), who emphasized design, processes as foundational to creativity in STEAM education, and with Sawyer's (2022) assertion that creative learning environments must support experimentation, feedback, and revision. The emphasis on iterative design also verifies Mishra et al. (2022), who argued that innovation emerges from cycles of idea generation, testing, and refinement, rather than linear instructional models.

The convergence of qualitative and quantitative findings strengthens the study's conclusions and supports existing mixed-methods STEAM research highlighting the value of triangulation in examining complex educational phenomena (Creswell & Clark, 2018). Moreover, the findings extend the work of Kim and Choi (2022) by providing empirical evidence that creativity and innovation can be systematically developed through structured Design-Based STEAM pedagogy, rather than being treated as incidental learning outcomes.

Overall, this study contributes to the growing body of STEAM education literature by empirically validating Design-Based STEAM learning as an effective framework for fostering creativity and innovation. By integrating design thinking with interdisciplinary learning, the study supports and extends prior research advocating for STEAM curricula that prioritize creative processes, authentic problem-solving and innovation-driven learning outcomes.

Conclusions

Overall, the convergence of qualitative and quantitative findings strengthens the conclusions that Design-Based STEAM learning is an effective approach for fostering creativity and innovation. This study contributes to the literature by demonstrating the mechanisms through which DBL supports these skills and by providing empirical evidence through a robust Mixed-methods framework. The findings underscore the importance of multidisciplinary, hands-on, and technology-supported learning experiences that prepare students for future innovation-driven industries.

Design-Based STEAM learning is an effective approach for cultivating creativity and innovation. Both qualitative and quantitative data support its positive impact. Schools seeking to promote future-ready competencies should integrate DBL into their curricula and provide training for teachers in STEAM Design-Based learning practices.

Recommendations

The findings of this study suggest several important recommendations for enhancing the implementation and effectiveness of design-based STEAM learning.

1. Schools should invest in continuous professional development to build teachers' capacity in Design-Thinking, interdisciplinary instruction, and technology integration.
2. Administrators should allocate flexible time within the curriculum to support extended Design-Cycles, project-based learning, and collaborative problem-solving activities.
3. Equally important is providing access to technological tools and materials that enable students to engage in authentic design work, such as robotics kits, prototyping supplies, and digital fabrication tools.
4. Policymakers should revise assessment frameworks to include creativity, innovation, and Design-Process competencies rather than relying solely on rote knowledge tests.
5. Additionally, schools must foster supportive learning environments that encourage experimentation, risk-taking, and reflection, as these are essential for cultivating creative and innovative mindsets. Partnerships with community organizations, industry professionals, and universities can also enhance the authenticity and relevance of STEAM challenges.
6. To ensure equity, special attention should be given to resource-poor schools by funding essential STEAM infrastructure. Collectively, these recommendations can strengthen DBL practices and ensure that students benefit from STEAM learning that fully develops their creativity and innovation skills.

Challenges in Implementing Design-Based STEAM Learning

Implementing Design-Based STEAM learning in real educational settings presents several challenges. One major challenge is the lack of teacher preparedness, as many educators have limited training in interdisciplinary teaching and design-thinking pedagogy. Teachers often feel uncertain about blending artistic creativity with technical content or managing open-ended tasks that require flexible facilitation. Additionally, resource limitations such as insufficient laboratory space, limited access to technological tools, or lack of materials for prototyping pose barriers to effective implementation, particularly in low-budget or public-school contexts.

Another challenge is curriculum rigidity, where traditional assessment systems prioritize memorization and standardized testing over creativity and design processes. Schools often struggle to allocate time for extended design cycles, iterative projects, and cross-disciplinary collaboration. Student diversity in skill

levels further complicates implementation, as some students may excel in creative ideation while others struggle with the technical aspects of the design process. Moreover, administrative and institutional resistance to change can restrict opportunities for integrating STEAM into existing curricula.
Finally, large class sizes, limited teacher–student interaction, and insufficient professional development opportunities reduce the depth of engagement required for DBL. Without supportive policies, ongoing training, and infrastructural investment, educators face significant obstacles in delivering high-quality design-based STEAM experiences.

Suggestions for the future research

1. **Longitudinal Studies**
   Future research should employ longitudinal designs to examine the long-term impact of Design-Based STEAM learning on creativity and innovation across different educational levels.
2. **Experimental or Quasi-Experimental Designs**
   Researchers may use experimental or quasi-experimental methods to compare Design-Based STEAM learning with traditional instructional approaches to establish stronger causal relationships.
3. **Student-Centered Perspectives**
   Future studies should explore students' perceptions and lived experiences of Design-Based STEAM learning to complement teacher and expert perspectives.
4. **Contextual and Cultural Comparisons**
   Comparative studies across different cultural, national, or institutional contexts would provide deeper insights into how Design-Based STEAM learning functions globally.
5. **Integration of Digital Technologies**
   Further research could investigate how emerging technologies (e.g., AI tools, virtual prototyping, makerspaces) enhance or mediate creativity and innovation within Design-Based STEAM frameworks.

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