

Needs Analysis of A JOYDATA–STEAM Approach for Data Literacy in Statistics

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Abstract

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Low levels of data literacy and students' reasoning skills in statistics remain a major challenge in senior high school mathematics education. Procedural and decontextualized instructional practices have limited students' engagement in meaningful data analysis activities. This study aims to analyze the needs of students and teachers as a foundation for developing a JOYDATA–STEAM learning model using a design thinking approach up to the ideate phase. A descriptive research method was employed, and data were collected using questionnaires distributed to senior high school students and teachers. The findings indicate that students prefer learning experiences involving real-world data, data visualization, simple project-based activities, and the use of digital media. Meanwhile, teachers reported a gap between current instructional practices and the need to develop students' higher-order reasoning skills and data literacy. Based on the empathize and define stages, key instructional needs were identified, which informed the ideate stage in generating initial concepts for the JOYDATA–STEAM learning model. This model positions data literacy as a core component of learning, encompassing data collection, processing, visualization, and interpretation in a structured and progressive manner. These findings contribute to the development of an integrative and data-driven statistics learning model that supports student engagement and addresses the demands of 21st-century education.

Keywords:

design thinking; JoyData–STEAM; joyful learning; data literacy; statistics education

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INTRODUCTION

Global developments marked by the Fourth Industrial Revolution (Industry 4.0) have driven significant changes in the demands for essential 21st-century skills, including critical thinking, problem-solving, creativity, collaboration, digital literacy, and data literacy (Kalogiannakis et al., 2021; Voogt & Pareja, 2010). In this context, students are required to possess the capacity to access, analyze, and interpret data as a basis for informed decision-making. In line with this global trend, the Indonesian government, through Regulation of the Ministry of Primary and Secondary Education No. 10 of 2025 concerning Content Standards, explicitly identifies data literacy as a core competence in mathematics learning, particularly



within statistics content, thereby reinforcing the need for innovative and digitally relevant instructional approaches (Kemendikbudristek, 2025). This regulation indicates that strengthening data literacy at the senior high school level is not only a global demand but also a mandate of the national curriculum.

Despite these policy directions, international assessment results indicate that Indonesian students' mathematics literacy achievement remains significantly below the OECD average. According to the Programme for International Student Assessment (PISA) 2022, released in 2023, the average mathematics score of Indonesian students was 366 points, which remains considerably below the OECD average of approximately 472 points (OECD, 2023a). Moreover, the trend in Indonesian students' mathematics literacy across the last three PISA cycles shows a gradual decline, as illustrated in Figure 1. Indonesia's mathematics literacy scores reached 386 points in 2015, decreased to 379 points in 2018, and further declined to 366 points in 2022, reflecting persistent challenges in developing students' mathematical competencies (GoodStats, 2023; OECD, 2023b, 2023c). This downward trend suggests that students' abilities in mathematical problem solving, logical reasoning, and applying mathematical concepts to real-world contexts have not shown significant improvement, despite these skills constituting core components of the PISA mathematics literacy framework (OECD, 2023b).

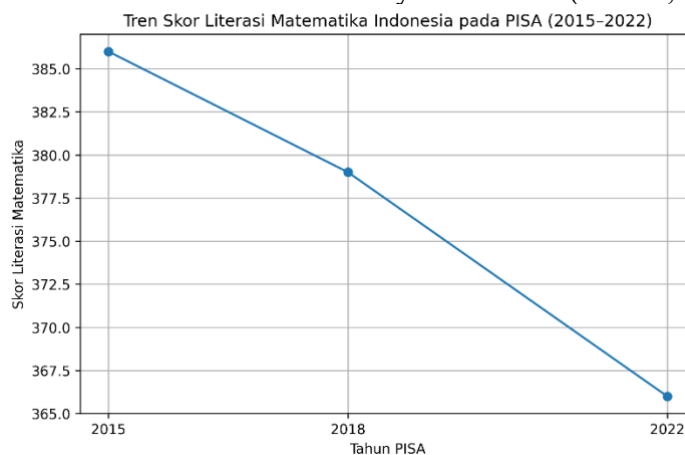


Figure 1. Trends in Indonesian Mathematics Literacy Scores in PISA from 2015 to 2022

These international findings are consistent with various national studies indicating that Indonesian senior high school students show limited proficiency in developing a deep understanding of data literacy and statistics. A study by Putri et al. (2023) revealed that students frequently make errors at the stages of data interpretation and reasoning when solving statistical literacy tasks similar to those used in the Minimum Competency Assessment, particularly in interpreting graphs, tables, and contextual numerical information (Kartika Putri et al., 2023). In addition, other studies have shown that senior high school students' levels of statistical literacy are predominantly at the lower levels of the Watson framework, especially when data are presented in real-world contexts that require reasoning and data-driven decision making (Setio & Baiduri, 2023).

These findings emphasize that data literacy challenges are not merely individual in nature but are also closely related to instructional approaches that have

not yet optimally fostered conceptual understanding, statistical reasoning, and higher-order thinking skills in statistics learning. This is evident in classroom practices in several senior high schools that still predominantly rely on traditional approaches such as lectures and routine problem-solving exercises, thereby limiting opportunities for conceptual exploration, data analysis, and real-life application (Mustaqfiroh et al., 2024). As a result, many students struggle to interpret contextual data and provide adequate justification, particularly when required to express uncertainty in solving statistics-based problems (Groth & Choi, 2023).

Furthermore, students' critical thinking profiles in solving contextual mathematics problems vary across different levels of learning motivation. In particular, students with lower motivation tend to experience greater difficulties in understanding and handling data within real-world contexts (Pratama et al., 2020). This condition indicates that, although the curriculum has formally mandated data literacy, instructional practices in classrooms have not yet been able to adequately address these requirements. Therefore, the development of instructional strategies in mathematics teaching, particularly in statistics, is therefore essential to ensure that learning becomes more meaningful and contextual, while equipping students with essential data literacy skills required in the digital era.

The results of the questionnaires administered to senior high school students and teachers indicate that the dynamics of mathematics learning continue to face complex challenges, both in terms of students' learning experiences and teachers' instructional practices. From the students' perspective, more than half of the respondents reported experiencing negative emotions such as fear of making mistakes, confusion, or anxiety when learning mathematics. This condition is consistent with findings showing a strong negative correlation between mathematics anxiety and conceptual understanding, whereby students with higher levels of anxiety tend to demonstrate lower levels of conceptual comprehension (Khairat et al., 2024). Students also demonstrated low levels of self-confidence in understanding mathematical concepts and processing data, further reinforcing previous research findings indicating that many learners struggle to interpret graphs and basic quantitative information (Dipalaya et al., 2022).

Based on teachers' responses to the questionnaire, the most frequently reported challenges included students' difficulties in understanding basic concepts (92.9%), low learning motivation, and limited abilities in reading and interpreting graphs, tables, and data. Although teachers have attempted to create positive learning environments through engaging interactions and collaborative activities, instructional practices that explicitly foster data literacy remain infrequently implemented. This condition is consistent with previous studies indicating that the integration of real-world data and data analysis based activities in mathematics instruction is still limited, which in turn contributes to low levels of statistical literacy (Kurnia et al., 2024; Obunge & Omeodu, 2024). Furthermore, teachers expressed a strong need for contextual learning resources, project-based student worksheets, and interactive digital media, underscoring the importance of innovative instructional approaches that support problem solving and higher order thinking skills—competencies widely recommended in the development of 21st-century learning (Purnomo et al., 2025).

Existing literature highlights a gap between the demands of data literacy competencies in the digital era and current mathematics instructional practices in senior high schools, which continue to rely on traditional approaches such as lectures and routine problem-solving exercises. As a result, opportunities for conceptual understanding, data exploration, and real-life application remain limited. This condition aligns with national studies indicating that conventional instruction has not been optimal in fostering students' higher-order thinking skills, particularly in the context of mathematical problem solving and reasoning, whereas problem-based learning approaches have proven more effective in actively and contextually engaging students (Simanjuntak et al., 2021; Tambunan, 2019).

Furthermore, previous research highlights that learning designed within a joyful learning environment can enhance students' motivation and engagement, thereby positively influencing their conceptual understanding of mathematics (Nuruzzaman & Kurniawan, 2025). At the same time, the integration of the STEAM approach in mathematics learning has been shown to broaden students' learning experiences through interdisciplinary, contextual, and applied activities, thus supporting the development of data literacy and critical thinking skills in statistics education (Oktavian et al., 2025; Siti Barkah, 2024). Therefore, the development of a JOYDATA–STEAM learning model is considered a promising alternative, as it is intended to integrate joyful learning, data interpretation skills, and the principles of Science, Technology, Engineering, Arts, and Mathematics into senior high school statistics instruction.

Considering the identified challenges, this study focuses on developing a learning model that is systematically designed to address the actual needs of students and teachers in statistics learning. Low levels of data literacy, the emergence of mathematics anxiety, the limited use of data-based learning activities, and the suboptimal integration of real-world contexts in statistics instruction indicate that existing instructional approaches have not fully addressed students' learning needs. This condition is consistent with previous studies highlighting that the development of educational innovations benefits from a user-centered design process to ensure that the resulting solutions are relevant to the actual characteristics and needs of classroom learning (Utomo et al., 2024).

Therefore, based on the needs analysis of students and teachers, the design thinking framework was selected as the foundation for developing the learning model, as it emphasizes instructional design processes that focus on users' experiences and needs. This framework encompasses the empathize stage of the design thinking process to gain a deep understanding of students' learning experiences and teachers' challenges; the define stage to systematically formulate learning problems based on empirical findings; the ideate stage to generate contextual learning solutions; the prototype stage to develop an initial instructional design as a representation of the proposed solution; and the testing stage to evaluate and refine the design based on user feedback. The application of design thinking in educational development has been shown to be effective in producing learning solutions that are relevant, adaptive, and aligned with authentic classroom needs (Utomo, Muhtarom, & Dwijayanti, 2024). This line of reasoning leads the present study to formulate an initial design of the JOYDATA–STEAM learning model as an alternative approach to statistics instruction that is engaging, contextual, and

oriented toward strengthening students' data literacy. The conceptual framework of this study is presented in Figure 2.

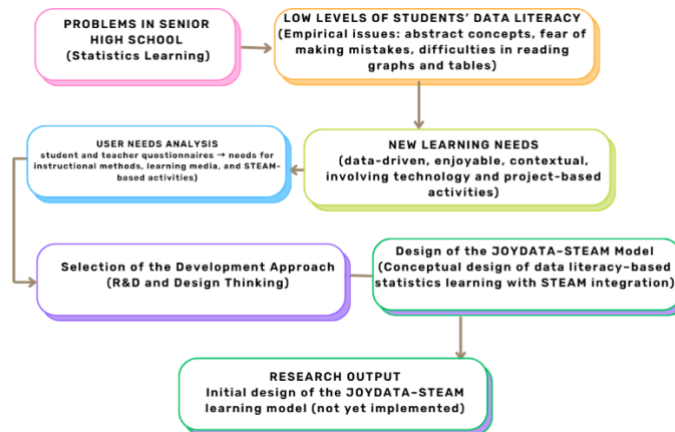


Figure 2. Conceptual Framework for the Development of the JOYDATA-STEAM Learning Model

Figure 2 illustrates the conceptual framework for the development of the JOYDATA-STEAM learning model. The framework begins with the identification of problems in senior high school statistics learning, particularly the low levels of students' data literacy, as reflected in difficulties in understanding abstract concepts, interpreting data, and reading graphs and tables. These issues lead to the identification of new learning needs that emphasize data-driven, contextual, and technology-supported learning experiences.

Based on these needs, a user needs analysis is conducted through student and teacher questionnaires to identify gaps in instructional practices and learning preferences. The findings then inform the selection of an appropriate development approach, namely the integration of research and development (R&D) and the design thinking framework. This process subsequently leads to the design of the JOYDATA-STEAM learning model, which integrates data literacy, joyful learning, and STEAM principles. The final output of this framework is an initial design of the learning model that has not yet been implemented, serving as a conceptual foundation for further development and validation.

This study aims to conduct an in-depth examination of mathematics learning conditions in senior high school statistics, particularly with regard to students' learning constraints and teachers' needs in developing data literacy. Through an analysis of questionnaire and interview data, the study seeks to identify key components, characteristics, and fundamental requirements for designing a learning model capable of addressing the demands of 21st-century education. Furthermore, this study aims to produce an initial design of the JOYDATA-STEAM learning model that integrates a data literacy approach, elements of joyful learning, and the principles of Science, Technology, Engineering, Arts, and Mathematics through the empathize, define, and ideate stages of the design thinking framework. Accordingly, this study is expected to provide a conceptual foundation for the development of more innovative, meaningful, and contextual learning models to enhance the quality of statistics instruction and senior high school students' data literacy competencies.

METHODS

This study employed a Research and Development (R&D) approach integrated with a design thinking framework to design a JOYDATA–STEAM learning model aligned with the needs of students and teachers in statistics instruction. The R&D approach was selected because it facilitates the systematic development of educational products through a user needs–based process, encompassing needs analysis, model design, and the formulation of an initial prototype that is ready for further development and testing. This approach is widely recommended in educational research, as it not only focuses on evaluating instructional practices but also emphasizes the design of contextual, innovative learning solutions oriented toward improving the quality of the learning process (Plomp, Nieveen, & Folmer, 2013; Reeves, 2006).

In line with this orientation, the present study adopted the design thinking framework as a guiding model for instructional design. The design thinking approach emphasizes a creative, user-centered process, ensuring that the developed learning model is grounded not only in theoretical considerations but also in the authentic needs and lived experiences of its users (Alvarado, 2025).

The research procedures in this study were conducted up to the ideate phase, comprising three main stages: empathize, define, and ideate. During the empathize stage, data were collected using questionnaires administered to 408 students from three public senior high schools in Semarang City, as well as 14 mathematics teachers. These instruments were designed to elicit information regarding students' learning experiences, learning constraints, media needs, and teachers' readiness to integrate data literacy and the STEAM approach into statistics instruction. The distribution of respondents based on school affiliation is presented in Tables 1 and 2.

Table 1. Distribution of Teacher Respondents

School of Origin	Number (n)	Percentage (%)
SMAN 2 Semarang	10	71,4
SMAN 10 Semarang	2	14,3
SMAN 15 Semarang	2	14,3
Total	14	100

Table 2. Distribution of Student Respondents

School of Origin	Number (n)	Percentage (%)
SMAN 2 Semarang	197	48,3
SMAN 10 Semarang	177	43,4
SMAN 15 Semarang	34	8,3
Total	408	100

During the define stage, questionnaire data were analyzed using descriptive quantitative analysis to identify patterns of learning needs and instructional constraints, while interview data were examined through qualitative analysis to explore users' learning experiences and perceptions in greater depth. This combined use of quantitative and qualitative data enabled a more comprehensive understanding of the learning context, allowing the core problems requiring

intervention to be articulated more accurately. Such an analytical strategy is recommended in educational research oriented toward user needs, as it effectively integrates numerical findings with the contextual meanings derived from participants' experiences (Lee, 2019).

During the ideate stage, various alternative instructional solutions were formulated, and an initial design of the JOYDATA–STEAM learning model was developed based on the problems and needs identified in the preceding stages. This initial design serves as a conceptual framework for the learning model, encompassing the instructional syntax, characteristics of students' learning activities, the role of teachers in facilitating learning, and the types of learning resources required to support the development of data literacy through the integration of Science, Technology, Engineering, Arts, and Mathematics.

The development of a conceptual design at the ideate stage represents a critical step in the design thinking process, as it enables developers to systematically formulate instructional solutions before they are realized in the form of prototypes. Consequently, the resulting design is grounded in a strong understanding of user needs and is well prepared for further development during the prototyping and testing stages in subsequent research (Dell'Era et al., 2020; Liedtka, 2020; Utomo & Dwijayanti, 2025).

The research instruments were validated through expert judgment conducted by mathematics education experts to ensure that each item was aligned with the measurement objectives and accurately represented the constructs under investigation. Furthermore, data trustworthiness was strengthened through methodological triangulation by combining questionnaire and interview data, ensuring that the research findings were not solely quantitative but were also supported by contextual interpretations of teachers' and students' experiences. The use of triangulation in educational research is widely recommended to enhance the reliability of findings and minimize interpretive bias, particularly in developmental studies and learning needs analyses (Nurfajriani & Ilhami, 2024; Utomo et al., 2024).

Through this methodological approach, the study not only provides a comprehensive portrayal of learning needs and challenges in mathematics instruction but also produces an initial design of the JOYDATA–STEAM learning model with the potential to enhance students' data literacy through more contextual, engaging, and innovative learning experiences.

RESULTS & DISCUSSION

The analysis of questionnaire data from 408 senior high school students indicates that data literacy skills and understanding of statistics concepts remain major challenges in mathematics learning. A summary of the key indicators derived from the questionnaire, particularly those related to the need for data-based learning and the readiness for implementing the JOYDATA–STEAM learning model, is presented in Table 3.

Table 3. Summary of Key Findings from Student and Teacher Questionnaires Related to Data Literacy and Statistics Learning

Findings Aspect	Percentage (%)
Difficulties in data analysis	56,3
Difficulties in data interpretation	44,7
Difficulties in understanding abstract concepts	51,6
Difficulties in reading graphs and tables	45,9
Need for real-world data-based learning modules	71,5
Interest in project-based learning	43,2
Need for visual and digital learning media	57
Teachers' identification of students' difficulties in understanding basic concepts	92,9
Teachers' need for STEAM integration in learning	57,1
Teachers' need for data-based learning approaches	64,3

A total of 56.3% of students reported difficulties in understanding word problems that require data analysis, while 44.7% experienced challenges in processing and interpreting data presented in the form of tables, graphs, or diagrams. These findings indicate that the majority of students are not yet accustomed to engaging in data-based thinking processes, even though such competencies constitute a fundamental foundation of data literacy within the context of 21st-century learning. This result is consistent with the findings of Putri et al. (2024), which indicate that senior high school students tend to make errors during the stages of data interpretation and numerical information analysis, particularly when confronted with real-world contexts.

In addition, 51.6% of students reported difficulties in understanding abstract mathematical concepts without contextual examples, while 45.9% indicated challenges in independently reading and interpreting data presented in graphs or tables. These results suggest that current instructional practices continue to place greater emphasis on procedural problem-solving rather than on conceptual meaning-making and learning experiences that enable students to construct understanding through data exploration. However, statistics learning requires students to be able to interpret, connect, and make decisions based on quantitative information. These findings further reinforce the OECD PISA 2022 report, which indicates that Indonesian students remain in the lower performance category in terms of their ability to use data to solve contextual problems (OECD, 2023).

From the perspective of learning needs, students demonstrated a strong preference for instructional approaches that involve authentic activities and visual media. A total of 71.5% of students expressed the need for modules or worksheets containing real-world data examples, 43.2% were interested in creating simple projects, and 45% preferred learning through real-life phenomena in their surrounding environment. These findings are consistent with previous studies in Indonesia indicating that mathematics learning grounded in contextual and authentic problem situations can enhance student engagement and conceptual understanding (Kasmiasi, 2021).

In addition, 57% of students expressed a preference for the use of videos or animations, while 24.1% indicated the need for data-processing applications such as spreadsheets to support their understanding of statistics content. Prior research has shown that student engagement in statistics learning through activities that

utilize real-world data, visualization, and digital technologies can contribute to improved statistical literacy and conceptual understanding (Kurnia et al., 2024). Taken together, these findings suggest that students not only require more contextual explanations but also seek active involvement in learning processes that encourage data exploration, visual analysis, and the use of technology as a tool for developing data literacy.

Findings from the teacher questionnaire further reinforce the existence of a substantial gap in mathematics instruction. A total of 92.9% of teachers expressed concern regarding students' difficulties in understanding fundamental mathematical concepts, while 50% reported that students were not yet able to solve problems requiring higher-order reasoning. This condition is consistent with previous studies in Indonesia indicating that low conceptual understanding and limited higher-order thinking skills remain major challenges at the secondary education level (Ashari et al., 2022; Waluyo & Nuraini, 2021).

Although teachers have implemented cooperative learning strategies and classroom discussions, only a small proportion have integrated data-based learning activities and the use of datasets in statistics instruction. These findings corroborate earlier research suggesting that statistics teaching in schools tends to remain procedurally oriented and has not yet optimally engaged students in authentic data exploration and contextual reasoning. Several studies have reported that mathematics instruction, including statistics, is still dominated by conventional approaches emphasizing formula mastery and algorithmic procedures, resulting in limited opportunities for students to interpret data meaningfully and relate it to real-life situations (Sari & Adirakasiwi, 2025; Waluyo & Nuraini, 2021).

Furthermore, teachers expressed need for instructional approaches that integrate STEAM elements and enable students to process and interpret data progressively highlights the urgency of developing an integrative learning model oriented toward data literacy and the strengthening of students' mathematical reasoning. Research in Indonesia has emphasized the important role of STEAM integration in enhancing 21st-century skills and mathematical reasoning competencies (Ajir et al., 2025; Bariyah & Hamimi, 2025).

Findings from the analysis of student and teacher questionnaire data indicate that statistics instruction in senior high schools has not yet fully developed the data literacy competencies required in the digital era. Students require learning experiences that are contextual, enjoyable, and enable data exploration through project-based activities. Meanwhile, teachers need a clear and structured instructional model capable of integrating data literacy, creative activities, digital media, and interdisciplinary approaches such as STEAM. Accordingly, the development of the JOYDATA–STEAM learning model is considered relevant as a solution that addresses the needs of both stakeholders while providing data-driven, creative, and problem-oriented learning experiences. The conceptual framework of the JOYDATA–STEAM learning model is illustrated in Figure 3.

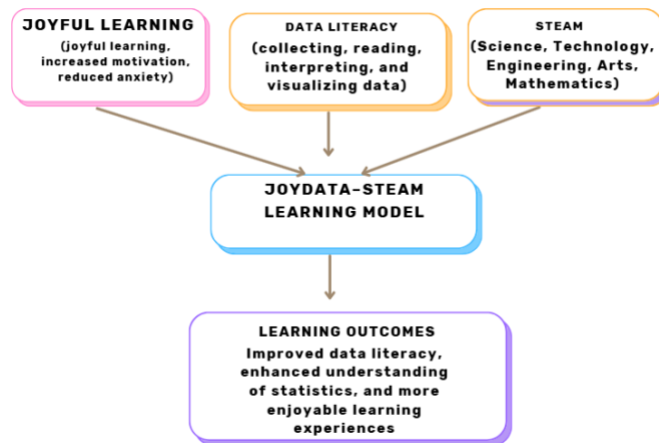


Figure 3. Conceptual Model of JOYDATA-STEAM

Design of The Joydata-STEAM Learning Model

The JOYDATA-STEAM learning model is designed to address the demands of statistics instruction in senior high schools that require the development of data literacy, problem-solving skills, and active student engagement within real-life contexts. This design is informed by the findings from the needs analysis, which indicate that students require contextual, engaging, and data-driven learning experiences, while teachers need structured instructional guidance that integrates data literacy and interdisciplinary approaches. This model integrates three main foundations, namely joyful learning, data literacy, and the STEAM approach, so that the learning process is not solely oriented toward conceptual mastery but also toward meaningful and enjoyable learning experiences that are relevant to the dynamics of 21st-century education. Previous studies have demonstrated that mathematics learning designed within a joyful learning environment can reduce learning anxiety, enhance students' interest, and positively influence learning outcomes (Dewi & Prihatnani, 2022; Nabila et al., 2025).

The first component, joyful learning, functions as an affective foundation that fosters students' comfort, self-confidence, and engagement in learning mathematics. Learning environments that are low in pressure and provide positive experiences enable students to ask questions more confidently, attempt problem-solving strategies, and actively participate in discussions without fear of making mistakes. Research has shown that the implementation of joyful learning strategies through interactive activities, educational games, and simple projects can increase student participation while also improving mathematics learning outcomes (Nabila et al., 2025). Accordingly, the joyful learning aspect within the JOYDATA-STEAM model is integrated through interactive and collaborative activities that value and appreciate students' thinking processes.

The second component, data literacy, serves as the core of this model's development, as statistics learning requires students to be able to collect, read, visualize, interpret, and use data as a basis for decision making. Within the JOYDATA-STEAM framework, data literacy is not positioned as an additional skill but rather as the central process integrated into every statistic learning activity.

This perspective aligns with studies in Indonesia that emphasize data literacy as an essential competence in mathematics and statistics education, as it encourages students to develop conceptual and contextual understanding of data (Ritmayanti et al., 2025).

Through direct engagement with real-world data, the construction of visual representations, and evidence-based reasoning, students are guided to develop critical thinking and problem-solving skills. This approach is consistent with the demands of international assessments and recent research trends that highlight the importance of data-based learning as a means of strengthening 21st-century skills in the digital era (Muhaimin & Fadiana, 2025).

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These three components interact synergistically within the JOYDATA STEAM model. Joyful learning provides a supportive and motivating learning climate, data literacy offers a cognitive focus on data processing and interpretation, while STEAM serves as an activity framework that connects mathematics with real-world phenomena and creative projects. Through this integration, students are not merely positioned as recipients of information, but as active data processors, problem solvers, and evidence-based decision makers. Ultimately, the JOYDATA STEAM model is expected to enhance students' data literacy, deepen their conceptual understanding of statistics, and provide learning experiences that are more engaging and relevant to students' real-life contexts.

CONCLUSION

Based on the analysis of senior high school students' and teachers' needs, this study indicates that statistics instruction in senior high schools has not yet fully supported the development of students' data literacy competencies, particularly reflected in low levels of data literacy, mathematics learning anxiety, limited data-based learning activities, and the suboptimal integration of real-world contexts and interdisciplinary approaches. These findings suggest the need for a learning model that is systematically designed and aligned with the actual needs of students and teachers.

Based on the design thinking framework, an initial design of the JOYDATA–STEAM learning model was developed, integrating the principles of joyful learning, data literacy, and the STEAM approach within statistics instruction. This initial model design is expected to serve as a foundation for further development and empirical testing aimed at improving the quality of statistics learning and enhancing senior high school students' data literacy in more contextual, meaningful, and innovative ways.

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