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Digitized Project-Based Learning in Senior High School Statistics: An Integration of Mathematics and Climate Change Education

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This study explored the development and validation of a digitized project-based learning material. This is guided by the cross-disciplinary approach in teaching senior high school statistics using local climate concepts. Anchored on Constructivism Learning Theory, this study was conducted using developmental research design, which comprised three sequential and interdependent stages: analysis, design and development, and validation and evaluation. For the analysis and design development stages, two science teachers, two statistics teachers, two climate change experts, one educational technology expert, and one project-based learning expert were purposively selected and participated in the two stages of interview. Using Braun and Clarke's six-phase thematic analysis, seven themes emerged: integrated statistics and climate competence for informed action, active, collaborative, and technology-enhanced project-based approaches, comprehensive, authentic, and reflective project-based assessment, purposeful and scaffolded project-based learning, interactive and visual interface design, usability and accessibility features, and real-time feedback and support systems. Based on the insights from the interviews, the project-based learning material was developed and underwent expert validation and evaluation with five purposively selected experts in the field of educational technology and project-based learning. The digitized material received an overall mean score of 4.16, indicating that the developed project-based learning material anchored on the emerging themes possessed high level of pedagogical-technological consistency and functionality. The findings reveal that the intertwining framework of constructivist instructional design and interactive digital design upholds the development of inquiry-based, project-based, and contextualized learning materials which are pedagogically and technologically reliable and operational.

Keywords: mathematics education, senior high school statistics, project-based learning, climate change education, digital learning

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INTRODUCTION

Technology-enhanced, project-based, and contextualized learning materials that combine statistical literacy and local climate concepts at the senior high school level remain scarce. Recent studies (e.g., Tesfamicael & Enge, 2024; Lucas & Paulo, 2024) highlighted this gap, noting that sustainability and mathematics are viewed as isolated within the curriculum. This suggests a lack of integration between the two critical concepts. The dire exploration of these topics further indicates a potential issue on unavailability of materials and limited existing resources (Li, 2025). In fact, various empirical studies (e.g., Bărbulescu et al., 2025; Septiana et al., 2023) have shown that mathematics curriculum continue to face inadequate innovative and project-based learning materials. This implies that if project-based learning materials are unavailable, the collaborative, critical thinking, and problem-solving skills of students are hampered (Rehman et al., 2024).

On a global scale, research indicates that various educational settings face challenges in providing and accessing adequate project-based learning resources that integrate climate change concepts into mathematics education. For instance, Syahdia et al. (2024) identified that developed countries face challenges not only in the availability of resources but also in how project-based systems are designed, managed, and utilized. Finland, for example, encounters disparities in accessibility across regions. Meanwhile, the USA's infrastructure landscape is characterized by variability emerging across states and sectors. Although the UAE exhibits highly developed and rapidly advancing infrastructures, challenges to its effectiveness are attributed to the country's implementation and sustainability considerations. Meanwhile, Nepal faces resource shortages and a need for context-specific project-based learning materials (Dhungana, 2025). Furthermore, countries in Sub-Saharan Africa, South Asia, and Latin America experience limited digital literacy, inadequate infrastructure, and inequitable access to educational resources needed for project-based learning (Albakri & Wood-Harper, 2025). Indeed, current educational resources from various countries frequently overlook the provision and equitable access to project-based learning materials.

In the Philippines, one of the teaching standards is to integrate content within and across curriculum teaching areas but recent empirical evidence shows that this is often ignored because of limited teaching time and compartmentalized approach to teaching different learning areas (Ignacio et al., 2024). In addition, teachers do not receive adequate resources and training that upholds inquiry-based and project-based learning (Carcellar-Abrencia, 2025). Furthermore, Filipino teachers do not frequently implement project-based learning and inquiry-based approaches due to insufficient resources and time constraints (Idul et al., 2025). Apparently, the problem of integrating climate change concepts into mathematics education is magnified further by the limitations of technology-enhanced project-based learning resources in the country.

The research gap lies in the unavailability of adequate technology-enhanced or digital project-based learning materials that seamlessly integrate environmental awareness into senior high school statistics instruction. Moreover, there also lies a significant gap in integrating Sustainable Development Goals (SDGs) within Philippine mathematics

curriculum, posing a threat to developing fundamental knowledge and skills for sustainability topics (Padilla et al., 2024). Thus, this study was conducted to develop and validate digital resources that incorporate project-based learning models into teaching statistics using climate contexts. This advances SDG 4 or Quality Education by developing the statistical literacy of students, and supports SDG 13 or Climate Action by injecting climate awareness into statistics education.

Specifically, this study aimed to achieve the following objectives: (1) identify the most appropriate learning objectives, content, instructional approaches, assessment strategies, and project design to effectively integrate climate change concepts into project-based statistics education for senior high school students; (2) determine appropriate digital features for the development of digitized project-based learning material; and (3) validate the developed digitized project-based learning material.

Literature Review

The theoretical architecture of this study rests on Vygotsky's and Piaget's *constructivism*, which holds that learners actively construct knowledge through experience, reflection, and social interaction rather than passive reception (Candra & Retnawati, 2020; Yating et al., 2025). This paradigm is not only a philosophical backdrop of this study but rather a generative principle that shaped how content, instruction, and technology were organized in this investigation. Constructivist instructional design, as elaborated by Kumaravadivelu (2006 as cited in Pourfarhad et al., 2018), prioritizes the presentation of situations with authentic problem contexts, encouraging collaborative inquiry and reflective practices as conditions which deep and transferable learning occurs. Project-based learning (PjBL) is among the most operationally coherent expressions of this paradigm because of its insistence on culminating in a tangible product or presentation (Nollmeyer & Torres, 2022), a feature that demands sustained contextualized engagement. This defining characteristic carries pedagogical weight in mathematics education. Accurate content, realistic connections, practical inquiry, meaningful assessment, and reflective growth as hallmarks of PjBL in mathematics education (McHugh, 2023), while PjBL's structured progression in inquiry is not incidental but fundamental to how students grasp and internalize mathematical concepts (Palatnik, 2022). These insights collectively position PjBL not merely as an instructional preference, but as a conceptually coherent response to the persistent problem of uncontextualized mathematics instruction.

However, PjBL within constructivism alone is insufficient especially when technology has long been proven to play a crucial role in the learning environment. Koehler et al.'s (2013) Technological Pedagogical Content Knowledge (TPACK) framework offers a more precise account of what effective technology-integrated instruction requires. That is, teachers must simultaneously navigate content knowledge, pedagogical knowledge, and technological knowledge since the intersection of all three produces meaningful learning (Alrwaished, 2024; Kumala et al., 2022). Technology-enhanced project-based learning is an effective strategy for developing digital literacies alongside critical and higher-order thinking (Fikria et al., 2025), which also directly implicates TPACK's central argument that technology cannot be layered onto pedagogy as an afterthought

(Fahadi & Khan, 2022). Moreover, although digitized project-based environments can sustain meaningful learning, teacher facilitation remains indispensable (Beneroso & Robinson, 2022), which aligns with TPACK's insistence that technological competence must be pedagogically purposeful (Alrwaished, 2024). Without this framing, studies on technology-enhanced PjBL tend to overemphasize the role of digital tools while undervaluing teachers' instructional decisions that make these tools effective.

While technology-enhanced PjBL provides meaningful experiences, its utilization and implementation in the senior high school level poses a different challenge especially in terms of cognitive load. Sweller's (2020) Cognitive Load Theory posits that learning is impaired when the cognitive demand imposed on an individual's working memory exceeds its capacity. This has direct implications for the design of digitized PjBL since students already perceived statistics as cognitively exhausting and irrelevant (Ritzhaupt et al., 2020; Kaufmann et al., 2022). Instructional activities utilizing worked-out examples in statistics that include web-based applets and simulations reduce the cognitive load (Hadfield, 2021), which directly implicates cognitive load theory's core idea that learning works best when information is presented in a way that reduces mental strain and actively engages how the mind processes and retains new knowledge (Aldalalah, 2021). Moreover, instructional designs should reduce extraneous cognitive load by segmenting content into meaningful parts, thereby easing cognitive load and freeing up the brain's working memory for information processing (Suryani et al., 2024; Altinpulluk et al., 2020). This in turn allows learners to engage more in the learning processes, get more out of the learning materials, and report higher satisfaction with their learning experience (Kok et al., 2024). Although students possess more sophisticated technological and cognitive abilities at this stage, an instructional design that attends to their cognitive load reduces unnecessary mental strain.

Building on this premise, digitized PjBL is an ideal approach for senior high school statistics instruction. Gal's (2002) model of statistical literacy distinguished between the ability to interpret and evaluate statistical information and the capacity to communicate statistical reasoning in context (L'Boy & Nazim Khan, 2023), framing literacy not as procedural competence but as a means by which individuals think critically and participate meaningfully in society. This distinction is important because it reframes the goal of statistics instruction at the senior high school level, wherein the target is not simply computational fluency but to develop dispositions and abilities to use data in ways that matter outside the classroom. Students' statistical literacy, engagement, motivation, confidence in working with data, and ability to apply statistical concepts to real-world contexts improved using PjBL approaches (Sabat, 2024). These gains are contingent on the use of authentic and contextually grounded data rather than isolating PjBL methodology. This suggests that the pedagogical approach and the learning content it carries must work together, a claim that echoes Gal's (2002) argument that literacy is always situated within a specific field of knowledge and purpose of communicating within it.

Considering this, statistics, along with other branches of mathematics education, is better delivered using contexts that are environmentally relevant to the students. Rousell and Cutter-Mackenzie-Knowles (2020) argue that climate literacy involves not only

knowledge of climate systems but also the capacity to connect scientific understanding to ethical responsibility and community action. Integrating climate contexts into mathematics instruction enables students to apply the fundamentals of mathematics in addressing critical societal climate issues, which, in turn, allow them to contribute to sustainable efforts in the community (Romero Ariza et al., 2024). Furthermore, environmentally relevant contexts strengthen students' problem-posing skills, mathematical competencies, and curricular knowledge beyond its contents (Steffensen, 2020). The convergence of statistical literacy and climate literacy in this study is therefore not arbitrary. It reflects a principled claim that authentic statistical learning in the senior high school context is most meaningful when it is directed toward problems that are environmentally and socially relevant to students.

METHOD

Methodologically, this study employed developmental research design outlined by Richey and Klein (2005, as referenced in Hamdani et al., 2022), which is comprised of three sequential and interdependent stages: analysis, design and development, and validation and evaluation. This design was appropriate for educational research that aims to develop and validate teaching and learning materials following a systematic process. This research design model was systematically integrated with three other frameworks at every stage of the study. Figure 1 shows the integrative framework of the study.

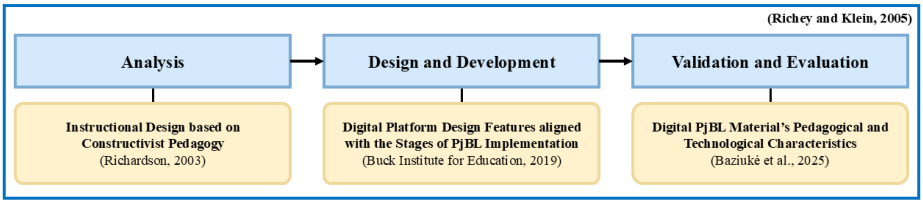

Figure 1
Framework of the study

The analysis stage was anchored on Richardson's (2003) constructivist pedagogy, which positions constructivist pedagogy in a light where learning environments, classroom activities, and instructional approaches are grounded in constructivist learning theory. Constructivist learning theory posits that students actively construct ideas based on their own experiences and the knowledge they get through creative and reflective engagement (Wibowo et al., 2025). Thus, the instructional design features of the material were rooted in students' active engagement with local climate contexts and collaborative projects.

The design and development stage was anchored on Buck Institute for Education's (2019) stages of project-based learning. The four stages of project-based learning include project launching (initiation and planning), knowledge building (research and investigation), developing and critiquing (execution, reflection, and iteration), and product presentation (presentation and evaluation). Looking further into the lens of the Technological Pedagogical Content Knowledge (TPACK) framework, teachers must

simultaneously navigate content knowledge, pedagogical knowledge, and technological knowledge since the intersection of all three produces meaningful learning (Alrwaished, 2024). Thus, the interactive design features of the materials were integrated seamlessly at every stage of project development while simultaneously addressing the instructional design features.

Finally, the validation and evaluation stage was anchored on Baziukė et al.'s (2025) assessment of pedagogical-technological characteristics of project-based learning materials. The assessment principle is composed of four overarching evaluation dimensions: pedagogical design, technical-functional aspects, assessment-analytical aspects, and support and usability. These dimensions were aligned with the instructional and interactive design features of a digital project-based learning material.

Data Gathering Instruments

To effectively identify the most appropriate instructional and interactive design features for the project-based learning material, the study employed semi-structured interview protocols developed within the context of this study. The first interview protocol aimed at identifying the most appropriate learning objectives, learning content, instructional approaches, assessment strategies and project design components. Meanwhile, the second interview protocol aimed at determining the interactive design features appropriate to the stages of project-based learning model. Both interview protocols were subjected to expert validation and revisions to effectively and appropriately capture the essential information needed to develop the digitized project-based learning material. Completing the study's framework, the developed material was subjected to expert validation using Baziukė et al.'s (2025) Assessment of Pedagogical-Technological Characteristics of PjBL Materials.

The validation tool was modified within the context of the present study. The original tool has four main indicators or criteria: Pedagogical Design, Technical-Functional Aspects, Assessment-Analytical Aspects, and Support and Usability. These dimensions were further divided into 11 sub-criteria. Each sub-criterion contains criterion statements upon which the developed digital material was evaluated. In total, the validation tool contains 42 criterion statements. In this study, the number of main criteria and sub-criteria were retained. The modification was only on the sentence structure of the statements, that is, interrogative sentences were transformed into declarative sentences. For example, the interrogative sentence "*Does the platform provide the capability to create or integrate evaluation rubrics?"* was transformed to a declarative sentence "*The platform provides the capability to create or integrate evaluation rubrics.*"

To establish the content validity of the validation tool, a panel of five experts evaluated each item based on its clarity, relevance, and representativeness to the constructs under investigation. All items yielded I-CVI scores ranging from 0.80 to 1.00, which met and exceeded the minimum acceptable threshold of 0.78 (Lynn, 1986). Then, the scale-level Content Validity Index (S-CVI), computed as the average of all item-level CVIs (S-CVI/Ave), was 0.91, surpassing the recommended cutoff of 0.90 (Polit & Beck, 2006).

This indicates a high degree of consensus among the panel of experts regarding the overall relevance and appropriateness of the tool's content.

Sample and Sampling Technique

Various participants from different fields of expertise agreed to be part of the study. The participants were selected and invited to participate at every stage of the study. For the analysis stage, there were a total of six participants (i.e., 2 Science teachers, 2 Statistics teachers, 2 Climate Change experts). For the design and development stage, there were a total of six participants (i.e., 2 Science teachers, 2 Statistics teachers, 1 Educational Technology, 1 Project-based Learning Approach Practitioner-Expert). For the validation and evaluation stage, there were a total of five participants (3 Educational Technology Experts and 2 Project-based Learning Approach Practitioners). Across stages, the participants were selected using purposive sampling design, a non-probability sampling strategy where sample selection is undertaken using thoughtful and structured non-random criteria (Ahmad & Wilkins, 2025). The teachers and experts performed their duties and responsibilities in their respective fields and positions for at least five years as this study's inclusion criterion.

Six participants were purposively selected for the semi-structured interviews. This sample size is considered appropriate given the scope and focus of the study, as the number of participants in qualitative interviews is not fixed but is instead shaped by factors such as the complexity of the topic, the accessibility of participants, the quality of data expected, and the overall study design (Morse, 2000). Moreover, five subject-matter experts were engaged to validate and evaluate the research instrument. This falls within the acceptable range recommended in the literature (Armstrong et al., 2005).

Data Collection and Analysis

The researchers carried out the study by carefully designing a data collection procedure that promotes exhaustive and objective documentation while protecting the rights of every participant. The data collection procedure for the analysis and design and development stages involved in-depth interviews with the selected participants. The in-depth interview (i.e., IDI1) for the analysis stage involved six participants (i.e., P1, P2, P3, P4, P5, and P6). Meanwhile, the in-depth interview (i.e., IDI2) for the design and development stage involved another six participants (i.e., P1, P2, P3, P4, P7, and P8). The interviews, which were scheduled for an hour, were conducted either online or face-to-face depending on the convenience and choice of the participants. Before the interview, the researchers secured signed consent from the participants, along with thorough briefing of the interview's purpose. While the interview was ongoing, the researchers conducted welfare checks every twenty minutes before proceeding.

After each interview, the researchers checked the file, saved a copy from the original file, and renamed it with the code assigned to the participant. The researchers then started with the verbatim transcriptions of the audio recordings. After all the recordings were completely transcribed, the researchers ensured that no identifying information about the participants remained in the data, and that all the files were in order. The researchers analyzed the transcriptions for each part of the data gathering procedures

using Braun and Clarke's six-phase thematic analysis framework. This framework aims to identify, familiarize, analyze, and report patterns that build up the themes in a dataset (Braun & Clarke, 2023).

Finally, the validation and evaluation stage involved five participants (i.e., P7, P8, P9, P10, P11). These participants were requested to validate the developed project-based learning material using the validated digitized PjBL material assessment tool. The expert validators provided their rating using 5-point Likert scale and gave their recommendations for improvement as qualitative insights. The quantitative results of the validation were analyzed using mean and standard deviation, while the qualitative insights were extracted and used to inform the data analysis.

The interpretive measure for the 5-point Likert scale was determined by calculating an interval of 0.80 (Range = 5 – 1; Interval 4/5 = 0.80). This created five equal ranges to interpret the mean score, ranging from Very Low (1.00-1.80) to Very High (4.21-5.00). Meanwhile, the standard deviation complemented the mean by providing insight into response consistency. A low SD (<1.0) suggested that the validators answered similarly, indicating consensus, while a high SD (>1.0) pointed to greater disagreement or diversity in perspectives among the validators (Creswell & Plano Clark, 2018).

FINDINGS

Analysis Stage

The analysis stage of this study aimed to identify the appropriate instructional design features of the digital learning material anchored essentially on constructivist pedagogy (Richardson, 2003). Table 1 shows the emerging themes in this stage, which informed the overall content and structure of the project-based learning material.

Table 1
Emerging themes for the analysis stage of the study

Themes	Sub-Themes	Core Ideas
Integrated Statistics and Climate Competence for Informed Action	Foundational Statistical Literacy	• Core skills: data sourcing, trend analysis, variability, visualization • Essential tools: time series, correlation, sampling • Full spectrum of statistical concepts for climate projects • Statistics to analyze, interpret, and communicate climate data
	Critical Evaluation of Data Sources	• Evaluate data quality, identify patterns, question assumptions • Push students past surface reading, investigate why and how • Statistics must be evidence-based and authentic
	Communication of Statistical Findings	• Create and interpret visualizations • Apply regression and correlation • Use correct reasoning via calculations, graphics, and models • Communicate climate data to diverse audiences
	Contextualization and Personal Relevance	• Use data to explain what is happening around them • Learn statistics through real climate issues • Focus on helping students analyze real, local climate data
	Responsible Application and Climate Action	• Balance technical skills with environmental awareness • Relate statistical findings to real-world climate impacts • Name statistical practice alongside interpretive responsibility • Long-term, multivariable, and relevant climate datasets
Active, Collaborative, and Technology-Enhanced Learning Approaches	Active and Investigative Learning	• Real-world environmental data as primary teaching tool • Statistics as a language for the story of the changing planet • Analyze real climate data through project-based tasks • Data collection guides students to reliable climate information
	Collaborative Learning Structures	• Evidence-based statistics anchors collaborative inquiry • Students solve problems together using statistical tools • Learning statistics while studying real climate issues together
	Differentiated Scaffolding and Inclusive Design	• Tiered tasks: basic charts to regression models • Positive and negative correlation as entry-level concept • Scaffold complex, multivariable datasets for varied learners • Correct reasoning through scaffolded calculations
Comprehensive, Authentic, and Reflective Project-Based Assessment	Process-Oriented and Varied Assessment	• Value process equally: rubrics, peer reviews, data audits • Assess both statistical competence and climate understanding • Assess analysis, interpretation, and societal implications
	Formative Progress Monitoring	• Ongoing focus on real climate data throughout the project • Track reliable data collection from the start • Continuous checking: think carefully, solve, understand
	Dual-Dimension Rubrics and Criteria	• Dual criteria: statistical competence and climate context • Rubrics capture data quality, patterns, and evidence-based conclusions
	Authentic Assessment Tasks	• Statistics informs sustainable, responsible decision-making • Interpret real events: temperature, emissions, extreme weather • Each task names a statistical practice and interpretive responsibility
	Reflective and Collaborative Self-Assessment	• Reflection paper: explain what was learned from the data • Peer reviews as part of collaborative assessment • Reflect on what data reveals about their own environment
Purposeful and Scaffolded Project-Based Learning	Real-World and Community-Rooted Datasets	• Authentic data replaces abstract textbook problems • Focus on community-level events: temperature, emissions • Statistics learned within the context of real climate issues
	Accessible, Credible, and Appropriately Complex Data	• Data spans collection, visualization, variability, and inference • Climate datasets are long-term, multivariable, and uncertain • Data use must remain central, evidence-based, and authentic • Students know how and where to gather reliable climate data
	Phased, Scaffolded Project Structure	• Multi-stage structure • Phased tasks: from visualization to modeling • Reflection marks the culminating phase of the project

Theme 1.1. Integrated Statistics and Climate Competence for Informed Action

This theme, endorsed universally by all six participants across all three professional groups, reveals a deeply held interpretive conviction that statistical literacy and climate understanding are not parallel competencies to be addressed sequentially. Rather, they are constitutively intertwined dimensions of a single educational purpose. Statistical methods derive their pedagogical significance from the climate contexts in which they are applied, and climate understanding is rendered analytically rigorous through the statistical tools that interrogate it.

The foundational dimension of this theme centers on the specific constellation of statistical concepts identified as essential for climate-data work. Most participants independently converged on an overlapping set of core competencies. P3 identified "*data sourcing; trend analysis; variability and uncertainty; data visualization and critical evaluation*", while P4 enumerated time series analysis, variability, correlation, and data sampling. The recurrence of these constructs, rather than a generic appeal to *'statistics'*, signals that participants were drawing on practical pedagogical experience to identify which statistical operations are activated by real climate datasets.

A more analytically significant pattern emerges when participants move beyond enumeration to articulate the epistemological implications of integration. P2 challenged superficial data literacy by asserting that learning objectives must push students to "*investigate the why and how behind the numbers*". This is not simply an appeal for pedagogical depth; it expresses a particular view of statistical reasoning, one in which correct procedure is insufficient without critical interrogation of data provenance, representativeness, and assumptions. P1 reinforced this orientation by framing statistical methods as "*a language for telling the story of our changing planet*". The implication is that learning objectives must cultivate a dual capacity, technical proficiency and discursive competence, understood as mutually constitutive rather than additive.

A further sub-pattern concerns contextualization and personal relevance. Several participants emphasized that climate data must be locally anchored for statistical analysis to become educationally meaningful. P1 observed that students should be guided to use data to explain what is happening around them, and P3 specified a focus on helping students analyze real, local climate data. This convergence suggests that abstractness, whether statistical or environmental, is perceived as a barrier to both technical understanding and motivated engagement. Notably, this pattern was not confined to any single professional group; both disciplinary specialists and domain experts expressed the same interpretive concern.

Theme 1.2: Active, Collaborative, and Technology-Enhanced Learning Approaches

Theme 1.2 was endorsed universally across all six participants and reveals a convergent interpretive framework regarding instructional approach, that is, effective statistics education in a climate-integrated project-based context requires that students function as active agents of data inquiry rather than passive recipients of statistical instruction. Where Theme 1.1 articulates what students should know and be able to do, Theme 1.2 concerns the pedagogical conditions under which such knowing and doing becomes possible.

The most analytically robust sub-pattern is the participants' shared rejection of decontextualized and transmission-based instruction. P5 articulated the implied critique most directly:

> "*The curriculum should move away from abstract numbers and use real-world environmental data as the primary teaching tool*" (P5).

P1 extended this through a reframing of what statistical activity is fundamentally for:

> "*The most effective way to connect these fields is to frame the statistical method as the tool and the climate challenge as the evidence*" (P1).

The analytical significance of this formulation lies in the inversion it performs. Rather than climate change serving as an applied example within a statistics curriculum, the climate challenge becomes the epistemic driver and statistical methods become instrumental to climate understanding. This relational reconfiguration has structural implications for how content is organized and sequenced within a project-based learning framework.

A related but distinct sub-pattern involves collaboration. Several participants cited collaborative structures not as a general pedagogical preference but as functionally necessary for the type of inquiry they envisioned. P2 observed that the learning environment should enable students to solve problems together using statistical tools, and P5 affirmed that students should learn statistics while studying real climate issues, implying shared inquiry rather than individual task completion.

A third sub-pattern, *differentiated scaffolding*, introduces a productive tension within this theme. P3 specified tiered tasks moving from basic chart creation to regression modeling, while P4 identified positive and negative correlation as an accessible entry-level concept. This manifests that participants understood active learning not as a uniform experience but as a structured continuum requiring intentional design for varied learners.

Theme 1.3: Comprehensive, Authentic, and Reflective Project-Based Assessment

Theme 1.3, endorsed by five of six participants across all professional groups, surfaces a coherent interpretive position on assessment that evaluation in a climate statistics project must be multi-modal, longitudinal, and anchored in both statistical accuracy and climate-contextual understanding. The pattern across responses indicates that participants understood assessment not as a terminal event but as an ongoing, embedded dimension of the learning process, one that generates formative data as much as it produces summative judgments.

The most analytically salient finding within this theme is P6's articulation of dual-evaluation logic:

> *"Effective assessment strategies should evaluate both students' statistical competence and their understanding of climate change contexts"* (P6)

This formulation encodes a significant epistemological claim that statistical competence assessed in isolation is insufficient as an indicator of meaningful learning in this context. A student who executes a regression analysis correctly but cannot situate that

analysis within a climate narrative has not achieved the integrated learning goals articulated in Theme 1.1. Consequently, assessment must be structurally aligned with the integrated competence the curriculum seeks to develop.

Most participants further specified that process must receive evaluative weight equivalent to product. P6 described the need for *"strategies that value the process just as much as the final calculation. Such as, authentic data recollection, multi-stage rubrics, peer reviews, and visual communication audits"*. The enumeration of specific assessment modalities, rather than a general commitment to process, indicates that participants were reasoning from practical instructional experience. The inclusion of visual communication audits as a named strategy reflects the expectation that students must communicate statistical findings to diverse audiences.

A further pattern concerns reflective assessment. P6 identified the reflection paper as a preferred culminating task because it allows students to explain what they learned from the data, and P1 corroborated this by emphasizing that students should use data to explain what is happening around them. These responses suggest that reflective assessment is valued not merely as a metacognitive exercise but as a vehicle for integrating the analytical and contextual dimensions of learning.

Theme 1.4: Purposeful and Scaffolded Project-Based Learning

Theme 1.4, endorsed by four of six participants and concentrated most strongly among Science and Mathematics teachers, addresses the structural and design principles governing the project-based learning experience. Theme 1.4 concerns the underlying architecture of the project itself, how it is sequenced, what data it is built upon, and what scaffolding sustains student progress throughout.

The foundational sub-pattern is participants' convergence on the primacy of authentic, community-relevant datasets. P5 explicitly contrasted authentic environmental data with the abstraction of conventional curriculum materials, asserting that learning should move away from textbook exercises toward real climate phenomena. P1 specified that this authenticity should extend to community-level events, temperature trends, emissions data, extreme weather events.

A second sub-pattern concerns the dual demands of accessibility and complexity. P4 specified that appropriate datasets should span the full range of statistical concepts from data collection through inference, while P2 noted that climate datasets are analytically powerful precisely because they are "*long-term, multivariable, uncertain, and socially relevant*" (P2). These assertions are in productive tension: datasets must be accessible enough for students to engage meaningfully at varying competency levels, yet complex enough to sustain genuine statistical inquiry. This tension suggests that data selection is understood as a pedagogical decision, not merely a logistical one.

The most structurally explicit sub-pattern concerns the phasing of the project itself. P6 specified a multi-stage progression from authentic data recollection through rubric-mediated analysis to visual and verbal communication. P1 articulated the theoretical framing of this progression that the statistical method serves as the tool and the climate challenge as the evidence, positioning each project phase as an application of that fundamental methodological relationship.

Cross-Theme Interpretation: Analysis Stage

Collectively, a structural thread connecting all four themes is the shared rejection of decontextualization. Across learning objectives, instructional approaches, assessment strategies, and project design, participants were consistently oriented toward authenticity, local relevance, and the importance of real data as pedagogical anchors. This cross-theme pattern suggests that despite their varied disciplinary vantage points, participants reflect a shared underlying theory of learning, one in which meaning is constructed through sustained and scaffolded engagement with genuine phenomena rather than through mastery of isolated procedures.

A productive tension also emerges across themes. Themes 1.1 and 1.2 highlight integration and active inquiry, implying learner autonomy. However, Theme 1.4 emphasizes structured scaffolding, phased sequencing, and curated datasets, suggesting that the freedom implied by active learning must be counterbalanced by deliberate architectural constraint. This tension appears to reflect a shared recognition that the complexity of climate data and the sophistication of the statistical methods required to analyze it necessitate a design that is simultaneously enabling and structuring.

Design and Development Stage

The design and development stage of this study aimed to identify the appropriate digital platform design features of the learning material to be integrated in the stages of project-based learning model (Buck Institute for Education, 2019). Table 2 shows the emerging themes in this stage.

Table 2
Emerging themes for the design and development stage of the study

Themes	Sub-Themes	Core Ideas
Interactive and Visual Interface Design	Use of Interactive Dashboards and Simulation Tools	• Interactive dashboards as preferred format • Simulation and modeling tools for data engagement • Short explanatory videos to introduce concepts
	Variable Manipulation and Dynamic Visualization	• Students manipulate variables and observe outcomes • Transition from passive viewer to active investigator • Dynamic visualizations updating with student interactions • Use of line charts, bar graphs, and thematic maps
Usability and Accessibility Features	Clear Layout and Intuitive Navigation	• Simple and uncluttered interface layout • Intuitive navigation to reduce cognitive load • Single-page integration of data, graph, and questions • Step-by-step guidance embedded in design • Layered complexity from simplified to raw data
	Language Clarity, Device Compatibility, and Multimedia Integration	• Clear and comprehensible language for all learners • Device compatibility (computers, tablets, and mobile) • High color contrast and screen-reader compatibility • Inclusive design removing digital learning barriers • Multimedia making concepts concrete and memorable
Real-Time Feedback and Support Systems	Instant and Actionable Feedback Mechanisms	• Instant checks upon student responses • Stepwise validation at each analysis phase • Hints provided immediately upon errors • Toggle between student and expert visualizations
	Motivational Features and Scaffolded Support	• Gamification to sustain engagement and energy • Real-time data updates for urgency and relevance • Layered support building statistical skills progressively • Digital material as a designed learning environment

Theme 2.1: Interactive and Visual Interface Design

Theme 2.1 was endorsed universally by all six participants across all professional groups. The convergent interpretive pattern across responses is that digital materials for climate-integrated statistics education must position students as active data investigators, rather than passive consumers of pre-processed statistical information. The most prevalent sub-pattern involves the identification of interactive dashboards and simulation tools as the definitively preferred format for digital climate-statistics materials. P3 identified interactive dashboards and simulations as most effective, P4 extended this to include real datasets with built-in visualization tools, P1 emphasized dashboards because they allow students to manipulate variables and observe outcomes, and P2 articulated the design principle underlying these preferences:

> *"The most effective digital material formats are those that combine interactivity, visualization, and real-world relevance, allowing students to explore, analyze, and interpret data meaningfully"* (P2)

The analytical significance of this formulation lies in its internal structure. Interactivity, visualization, and real-world relevance are presented not as additive features but as an integrated design logic. A material that provides real data without interactivity produces passive reading; interactivity without real-world relevance produces procedural exercise without meaning; and visualization without data authenticity produces aesthetic engagement without analytic substance.

A closely related sub-pattern concerns variable manipulation and dynamic visualization as the operational mechanism through which the above design logic is enacted. Most participants specified that students must be able to actively adjust parameters, selecting geographic regions, modifying time scales, filtering by local or personal criteria, and observe visualizations update in response. P3 articulated this most concretely, *"Materials should use sandbox features where students can filter data by their own city or birth year, making the analysis personal"*. The inclusion of personalization as a design principle is analytically notable. The mechanism by which climate data becomes personally relevant is not merely the choice of dataset but the architecture of the interactive environment that allows students to locate themselves within it.

P1 captured the broader epistemological significance of this sub-pattern when observing that turning raw numbers into visual patterns enables students to *"spot trends, compare data, identify correlations, and interpret results, which makes abstract statistical concepts more concrete and understandable"*. This formulation positions dynamic visualization not as a motivational supplement to statistical instruction but as a cognitive scaffold that makes the inferential logic of statistics visible and navigable. The implication is that the design of the visual layer is not a secondary consideration, it is a primary instructional decision.

Theme 2.2: Usability and Accessibility Features

Theme 2.2, endorsed universally by all six participants, surfaces a critical interpretive tension within the findings that the same digital complexity that makes climate-statistics materials analytically powerful also carries the risk of making them pedagogically

inaccessible. The convergent pattern across participant responses is that interface design must actively counteract this tension through deliberate usability and accessibility features that determine whether the interactive affordances identified in Theme 2.1 are genuinely available to all learners.

The most analytically salient sub-pattern within this theme is the shared insistence of participants on cognitive load management through interface simplicity. P3 specified that data, graph, and questions should be kept on one page to minimize cognitive load and tab-switching fatigue, a formulation that identifies a specific navigational failure mode: the fragmentation of learning across multiple screens interrupts the inferential flow that interactive data analysis requires. P2 articulated the underlying principle:

> *"Digital materials are user-friendly for students when they are intuitive, structured, and engaging, allowing learners to focus on understanding content rather than struggling with navigation or instructions"* (P2)

The phrasing here is interpretively significant. Struggling with navigation is positioned as a competing cognitive demand that actively displaces the struggle with statistical content that constitutes genuine learning. Interface friction, in this framing, is not merely inconvenient, it is educationally counterproductive.

P3 extended this logic through the concept of layered complexity, *"Use layered complexity. Start with a simplified clean version of a dataset before introducing the raw, messy data to avoid overwhelming students".* This formulation translates Theme 1.2's principle of differentiated scaffolding into a concrete interface design strategy. The progression from simplified to raw data mirrors the phased project structure articulated in Theme 1.4. This further suggests a structural equivalence between the learning sequence and the digital architecture that supports it.

A second sub-pattern pertains to equity-centered design. Several participants identified accessibility not as a technical add-on but as an integral dimension of effective instructional design. P2 asserted that accessibility features are essential to ensure all students, regardless of ability or background, can engage with climate-statistics materials effectively. P4 and P8 corroborated this by specifying mobile compatibility, clear language, and inclusive design as necessary conditions for ensuring diverse learners can access and use the materials.

The multimedia integration sub-pattern introduces a productive elaboration of the accessibility principle. Several participants specified that multimedia elements, animations, simulations, time-lapse satellite imagery, and interactive graphs, serve a dual function: they increase engagement and enhance comprehension by rendering abstract statistical concepts dynamic and tangible. P2 captured this duality:

> *"Multimedia elements can dramatically enhance both engagement and comprehension because they make abstract concepts dynamic, tangible, and visually intuitive"* (P2)

The analytical significance of this formulation is that it frames multimedia not as a motivational supplement nor an entertainment layer appended to instructional content, but as a cognitive tool that addresses the abstractness of statistical concepts when presented in purely symbolic or numerical form.

Theme 2.3: Real-Time Feedback and Support Systems

Theme 2.3, endorsed by five of six participants, addresses the dynamic support architecture that must accompany the interactive and accessible interface design. The convergent pattern across participant responses reveals a shared interpretive conviction that interactivity without embedded feedback is insufficient, that is, students who are empowered to manipulate data and generate visualizations require responsive mechanisms that identify errors, provide guidance, and sustain motivation.

The foundational sub-pattern within this theme focuses on immediate stepwise feedback as a pedagogical mechanism for error detection and self-correction. Most participants specified feedback that is instant, actionable, and sequenced to prevent error accumulation. P3 provided the most technically precise formulation, *"If a student calculates a mean incorrectly, provide a hint immediately so they don't carry the error into the next analysis phase".* Thus, stepwise validation becomes a structural safeguard for the integrity of the student's statistical reasoning process.

P7 introduced a particularly distinctive feedback mechanism absent from other responses, the expert visualization toggle. This feature allows students to *"toggle between their visualization and the expert-generated visualization. If a student generates a graph that is statistically misleading or incorrectly formatted, the material should provide an instant visual critique"*. This mechanism operationalizes the critical evaluation at the interface level wherein students must not merely generate visualizations but evaluate them against a standard of statistical accuracy.

The motivational features sub-pattern introduces a dimension that is both structurally consistent with the preceding sub-patterns. Participants identified gamification, real-time data updates, and layered support as mechanisms for sustaining engagement. P4 observed that interactivity, gamification, and real-time data updates increase motivation by making learning dynamic; and P8 articulated the integrated logic:

> *"Interactivity helps students explore and visualize data, gamification boosts engagement through challenges and rewards, and real-time updates make climate statistics relevant and current"* (P8)

The analytical pattern here is one of nested motivational logic that interactivity provides the mechanism for engagement, gamification provides the affective incentive structure, and real-time data makes the entire system meaningful. Importantly, P1 offered the most condensed formulation of this logic, *"By making learning more active, relevant and fun"*, which, while deceptively simple, encodes the same three-dimensional motivational architecture that more elaborate responses describe.

Cross-Theme Interpretation: Design and Development Stage

A further cross-theme pattern is the structural isomorphism between the findings in Analysis Stage and Design and Development Stage. The active learning approach specified in Theme 1.2 finds its digital operationalization in the interactive dashboards and manipulation tools of Theme 2.1. The differentiated scaffolding principle of Theme 1.2 is translated into the layered complexity and cognitive load management of Theme 2.2. The formative progress monitoring specified in Theme 1.3 is enacted through the

feedback mechanisms of Theme 2.3. This structural correspondence suggests that the digital design features identified in Design and Development Stage are not independent design decisions but represent the technological implementation layer of the pedagogical framework established in Analysis Stage.

Validation and Evaluation Stage

At this point of the study, the project-based material was fully developed with the themes from both the analysis and design and development stages informing its overall instructional and digital design features. The last stage subjected the developed material to expert validation using the assessment framework as articulated by Baziukė et al. (2025). Table 3 shows the quantitative and qualitative results of the expert validation.

Table 3
Summary of expert validation results

Criteria	Mean	SD	Sample Qualitative Insights
Pedagogical Design	4.13	0.18	"There is clear connection between statistical concepts and climate-related datasets." [P8] "Clarify how each activity builds from prior lessons." [P9]
Problem Formulation	4.60	0.55	
Activity Design and Planning	3.80	0.45	
Adaptability and Differentiation	4.00	0.71	
Technical-Functional Aspects	4.10	0.58	"The interface is stable and responsive even during extended activities." [P9] "Visualizations are smooth…tools support handling of datasets." [P8]
Content Creation and Presentation	4.20	0.45	
Integration and Data Management	4.00	0.71	
Collaboration and Group Work	4.20	0.84	
Communication Tools	4.00	0.71	
Assessment-Analytical Aspects	4.10	0.55	"The assessment methods are varied and authentic." [P8] "The hints are very effective." [P9]
Monitoring and Analytics	4.00	0.71	
Assessment and Feedback	4.20	0.84	
Support and Usability	4.30	0.45	"Instructions are straightforward and understandable" [P9] "Structure allows students to work with minimal guidance." [P8]
PBL Community and Ecosystem	4.40	0.55	
Usability, Accessibility, Compliance	4.20	0.45	
Overall	4.16	0.30	High

As shown in Table 3, the pedagogical-technological characteristics of the developed digitized project-based learning material following the insights of the participants during the analysis and development stages gained a mean score of 4.16 (SD=0.30), suggesting a high pedagogical alignment, technical consistency, and platform functionality based on strong validators' consensus. Among the four validation criteria, Support and Usability gained the highest mean of 4.30 (SD=0.45), suggesting a very strong performance in terms of teacher and student support features, user-friendly design, and system reliability. The very low variability standard deviation also shows strong consensus among the expert validators.

Meanwhile, Pedagogical Design gained the second highest mean score of 4.13 (SD=0.18), which is interpreted as high, suggesting that the material's problem formulation, activity structuring, and instructional differentiation are systematically planned and effectively aligned to support learner-centered engagement. The very low variability standard deviation also shows strong consensus among the expert validators. On the other hand, Technical-Functional Aspects and Assessment-Analytical Aspects both gained the lowest mean score of 4.10 (SD=0.58, 0.55), which is interpreted as

high, suggesting that the material robustly supports content delivery, collaboration, data integration, performance monitoring, and feedback protocols. The low variability standard deviations of both dimensions also show generally consistent perceptions among the expert validators.

With the foregoing research findings, the study's framework was modified to effectively represent the intertwining relationships among constructivist instructional design and digital and interactive features. Figure 2 shows the Integrative Framework of the study.

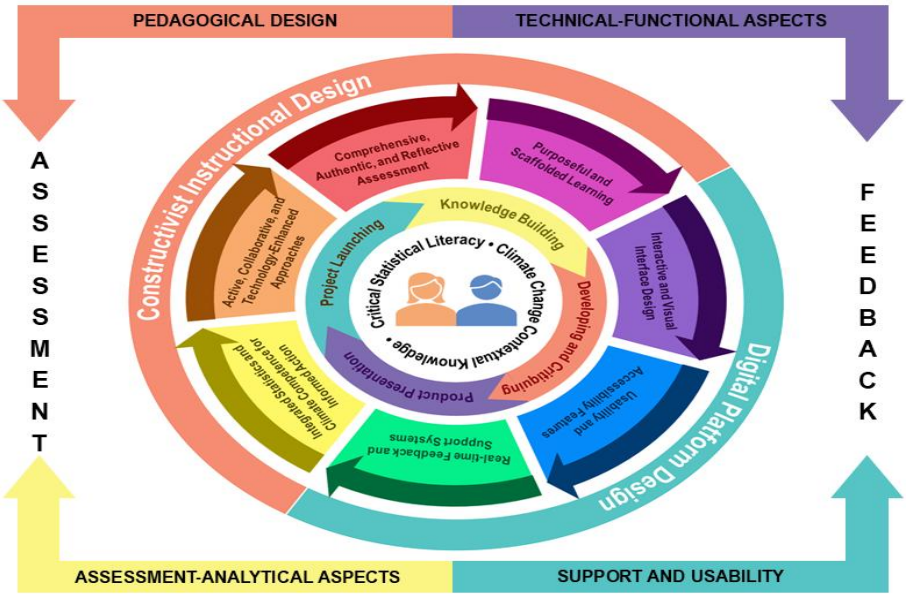

Figure 2
Integrative framework in developing digitized project-based learning material for senior high school statistics with climate change contexts

The validation results demonstrate that the instructional design anchored on constructivist pedagogy and interactive design aligned with the key stages of project-based learning (Zhang & Ma, 2023) are pedagogically comprehensive and technically solid when informed by the emerging themes highlighted in the present study.

DISCUSSION

Theoretical Implications

The findings substantiate several foundational frameworks. Vygotsky's and Piaget's Constructivist Theory is most prominently affirmed. The four emerging themes in the Analysis Stage confirm that understanding deepens when students investigate authentic climate datasets, collaborate with peers, receive scaffolded support, and reflect on their learning (Yating et al., 2025). Moreover, Koehler et al.'s (2013) TPACK framework is reinforced by the design findings, particularly in Themes 2.1 and 2.2, which establish

that effective digital materials must harmonize technological interactivity, pedagogical scaffolding, and disciplinary content. Furthermore, Sweller's (2020) Cognitive Load Theory is likewise validated through Theme 2.2's emphasis on neat interfaces, intuitive navigation, and single-page data integration, all of which reduce extraneous cognitive load and free students to pursue deeper statistical understanding within climate contexts. Finally, Gal's (2002) Statistical Literacy Model and Rousell and Cutter-Mackenzie-Knowles' (2020) Climate Literacy Model are jointly affirmed through Theme 1.1, treating them as complementary rather than isolated competencies.

Practical Implications

The four-theme instructional design framework serves as a comprehensive blueprint, ensuring materials address foundational statistical competencies, critical data evaluation, effective communication, personal relevance, and responsible environmental action. This responds to longstanding critiques that statistics education remains too abstract and disconnected from students' lived experiences (Bailey & McCulloch, 2023). The study also underscores the need to shift from transmitters of formulas to facilitators of collaborative climate investigations. Gamification, real-time data updates, peer reviews, and metacognitive tools such as reflection papers and self-assessments, highlighted in Themes 1.2 and 1.3, equip teachers with strategies that improve engagement, performance, and collaboration (Romero-Rodriguez et al., 2024; Mesghina et al., 2024). Expert validation results confirm the feasibility of these specifications, providing a model for developing digitized PBL materials that are both technologically sophisticated and pedagogically grounded (Nefianthi et al., 2023).

Methodological Limitations

The study employed a qualitative-dominant design relying on in-depth interviews and expert validation. This was appropriate for the study's exploratory and design-oriented goals, but it limits generalizability. Moreover, the expert validation stage relied on a limited panel of validators. Mean scores were consistently interpreted as High, but the small panel may not represent the full diversity of relevant stakeholder perspectives. Crucially, no student try-out data was collected. The validation results only reflect expert-perceived quality rather than empirically demonstrated effectiveness in actual classrooms. Finally, the constructivist and design-based orientation may have influenced both qualitative interpretation and the translation of themes into design decisions. The iterative analysis and validation process partially mitigated this, as did triangulation through document analysis and existing literature, including Rosado et al. (2024), and Dewi et al. (2024). Still, alternative analytical frameworks or different participant pools may have yielded different conclusions.

Scaling Limitations

The developed material is resource-intensive, requiring reliable internet connectivity, compatible devices, and institutional support for technology integration. These prerequisites may be unavailable in many public senior high schools in the Philippines, particularly in rural or underserved communities (Maspul, 2024). Teacher preparedness is an equally significant barrier. The TPACK framework requires teachers to possess

sufficient technological, pedagogical, and content knowledge to facilitate meaningful student engagement. Without sustained professional development, the material's sophisticated features risk being underutilized or misapplied. Finally, the use of authentic, community-level datasets covering temperature trends, rainfall patterns, and extreme weather events, affirmed by Rijken and Fraser (2024) and Martawijaya et al. (2023), enhances contextual relevance but complicates direct transferability.

CONCLUSION

Developing statistical literacy among senior high school students demands learning experiences that are contextually grounded, pedagogically coherent, and technologically intentional. This study addressed that demand by designing and validating a digitized project-based learning material that situates statistical inquiry within locally relevant climate change contexts. Anchored in constructivist principles, TPACK, and cognitive load theory, the material integrates carefully sequenced content, authentic datasets, collaborative tasks, scaffolded project phases, and adaptive digital features into a unified learning environment.

The study carries inherent limitations worth acknowledging. Validation depended exclusively on expert judgment, meaning the material's quality reflects perceived rather than demonstrated effectiveness. No student try-out was conducted, leaving its actual impact on statistical literacy and climate awareness empirically unestablished. In addition, the material presupposes digital infrastructure and teacher readiness that may be inconsistently available across diverse school settings, bounding the findings strictly within development and validation parameters.

This study being the first step, future studies may conduct classroom trials measuring the material's actual influence on student learning outcomes and climate literacy. Researchers may further explore how contextualizing statistics within environmental themes affects student engagement and mathematical disposition across different regional curricula. Curriculum developers, school administrators, and policymakers are therefore encouraged to invest in designing, validating, and sustainably implementing contextualized digital materials that develop both mathematical competence and environmental responsibility in equal measures.

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APPENDIX

A. Landing Page of the Digitize PjBL Material

B. Link to the Digitized PjBL Material

Link: https://goldengraphixstudios.github.io/pjbl-climate-statistics/
Sample Student Login Credential:

User: serjes_cafe
Password: cafe816

Note: The login credential is read-only access and for navigation purposes only. The material is available for full access and utilization upon formal request to the researcher using the contact details in the research article.

C. Software Used in Developing the Material and Information Thereof

The digitized instructional material *"PjBL Climate Statistics"* available at the Goldengraphix Studios GitHub site was developed by the researchers using standard front-end web development technologies, specifically HTML5, CSS3, and JavaScript, which collectively enabled the structuring, styling, and interactivity of the learning platform. The material is deployed through GitHub Pages, a platform that supports static website hosting, version control, and continuous updates, making it suitable for educational web applications.