

Design and validation of a technology-enhanced inquiry-based learning package for junior secondary natural science in resource-constrained contexts

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Abstract: This study designed and validated a Technology-Enhanced Inquiry-Based Learning Package (TIBLEP) for junior secondary natural science in a resource-constrained context, addressing the offline connectivity barriers common in under-resourced schools. A Design and Development Research (DDR) approach guided needs analysis, design, development, expert validation, revision, and field implementation. TIBLEP was built as an offline environment combining curriculum-aligned content, guided inquiry, multimedia demonstrations, self-paced navigation, and formative feedback. Five experts assessed the package across six dimensions. Sixty Grade 8 students from two intact classes then completed a five-week field trial (30 in the TIBLEP group and 30 in the conventional group), with interviews capturing participant experiences. Expert ratings were consistently positive (grand mean = 3.69, SD = 0.29), with the highest ratings for overall suitability (M = 3.78) and the lowest for technology integration (M = 3.60). Posttest achievement was higher for TIBLEP (M = 68.30, SD = 6.20) than for the control group (M = 54.70, SD = 5.80). Interviews indicated perceived gains in conceptual clarity, autonomy, engagement, collaboration, and teachers' technological competence. TIBLEP is a feasible, expert-validated offline model for inquiry-oriented science learning where connectivity is unreliable and access remains uneven. The package offers teachers and policymakers a validated, curriculum-aligned tool for delivering inquiry-based science instruction without depending on internet access.

Keywords: Educational design research, Formative assessment, Inquiry-based learning, Natural Science education, Offline digital learning, Technology-enhanced learning.

1. Introduction

Science education increasingly expects learners to interpret evidence, explain phenomena, solve unfamiliar problems, communicate their reasoning, and apply scientific knowledge to everyday decisions [1]. These expectations make the quality of classroom activities central to science education, which emphasizes inquiry-based learning. Inquiry-based learning (IBL) is particularly relevant because it positions learners as active participants in questioning, investigating, interpreting evidence, and constructing explanations. Recent work continues to show that inquiry can support conceptual understanding, inquiry skills, motivation, and attitudes when learners receive adequate structure and pedagogical support [2-4].

The evidence, however, does not support the simplistic conclusion that technology or inquiry automatically produces better learning. Inquiry ranges from highly open discovery to carefully guided investigation, and the level of guidance matters [5]. The contemporary literature increasingly emphasizes the design of inquiry environments rather than the label attached to an intervention. For example, Bónus, et al. [2] demonstrated the potential of a digital game-based inquiry program for eighth-grade biology, showing that digital environments can support the development of inquiry skills when activities are embedded in a coherent curricular sequence. Similarly, Kapici [6] quasi-experimental study comparing

regular and computer-based inquiry environments found that computer-supported inquiry can influence conceptual understanding, inquiry skills, and motivation, but the effect depends on how the learning environment is structured. These findings contrast with technology-first approaches that treat digital delivery as the principal innovation. In other words, the educational value of technology appears to stem more from what it enables learners to do than from the technology itself [2, 7, 8].

Systematic evidence strengthens this distinction. Chen and Chen [3] reviewed technology-enhanced collaborative inquiry in K–12 classrooms and highlighted the diversity of technological tools, inquiry designs, learning processes, and outcomes represented in the field. Their review suggests that technology can extend opportunities for collaboration, investigation, representation, and reflection, but it does not remove the need for intentional instructional design. The UNESCO [9] Global Education Monitoring Report makes a related argument at the system level: digital technology should be judged by relevance, equity, scalability, sustainability, and its contribution to educational goals rather than by novelty alone. This position is especially important in contexts where the infrastructure required by many technology-supported learning environments cannot be taken for granted [10].

The infrastructure question is especially consequential for science education in Africa. South African science curricula emphasize active learning and practical engagement, yet the implementation of inquiry remains uneven. Recent South African research continues to document the importance of teacher preparation, classroom conditions, and the availability of practical resources in shaping the enactment of inquiry Lotter and Ramnarain [11] and Photo [12]. Dunn and Ramnarain [13], for instance, showed how mobile technology can support abductive inquiry in South African physical science classrooms. Their study illustrates the pedagogical possibilities of technology, but it also reinforces a broader point: technology becomes educationally meaningful when it is embedded within a particular form of inquiry and a clear learning purpose. Similarly, research on flipped classrooms in South African Natural Sciences indicates that technology-mediated approaches can create opportunities for inquiry while still requiring teachers to carefully orchestrate classroom activities [11].

A second challenge concerns access. Much of the contemporary literature on technology-enhanced learning assumes reliable connectivity, online resources, or continuous access to digital platforms. These assumptions can obscure the needs of schools where connectivity, data affordability, device availability, electricity, or technical support are inconsistent. The UNESCO [9] GEM Report cautions that digital technologies can either reduce or reproduce educational inequality, depending on how they are designed and deployed. Therefore, an equitable technology-enhanced learning intervention should not simply replicate an online course in digital form. It should be designed around the actual conditions of the learners and schools it aims to serve.

This study addresses that challenge by developing the Technology-Enhanced Inquiry-Based Learning Package (TIBLEP). TIBLEP is an offline digital learning package designed for junior secondary Natural Science. It combines curriculum-aligned scientific content with guided inquiry activities, multimedia demonstrations, self-paced navigation, formative assessment, immediate feedback, and remediation. The intervention was designed to function without Wi-Fi or mobile data. Its central design proposition is not that technology should replace the teacher or practical science, but that an offline digital environment can provide structured opportunities for learners to investigate scientific ideas, revisit difficult concepts, receive immediate information about their performance, and proceed at a manageable pace.

The design is also informed by the specific learning needs identified during the needs-analysis phase. The original study identified persistent difficulties with topics such as forms and transformations of energy, electricity, and chemical substances. These topics involve concepts that junior secondary learners may find abstract when presented primarily through verbal explanation or textbook representations. TIBLEP consequently uses multimedia and inquiry sequences to make scientific processes more visible while maintaining learner activity. This distinction matters. Multimedia can illustrate a process, but illustration alone is not inquiry. In TIBLEP, multimedia demonstrations are connected to questions, activities, self-assessment, and opportunities to revisit concepts.

The package also incorporates formative assessment as part of the learning process rather than as a final measurement event. Learners encounter assessment tasks as they progress through the material. When an answer is incorrect, the navigation structure allows them to return to relevant learning content and attempt the concept again. This design aligns with broader evidence that feedback is most educationally useful when it is timely and connected to the learner's next action. The intervention therefore treats assessment as a corrective learning mechanism rather than merely a score-generating procedure.

The literature, however, reveals a gap. Studies of technology-enhanced inquiry often focus on specific digital environments, whereas design research frequently emphasizes the development and validation process [14]. Fewer studies connect these strands in resource-constrained junior secondary Natural Science contexts by documenting needs analysis, curriculum alignment, expert validation, offline design, inquiry pedagogy, formative assessment, and classroom implementation. This study addresses that gap by treating TIBLEP as both an instructional artifact and a context-responsive design solution.

The study also differs from research that treats expert validation as sufficient evidence of effectiveness. Expert judgment can establish design suitability, but it cannot demonstrate classroom effectiveness. The present study therefore combines expert validation with field implementation, consistent with the educational design research principle of methodological fit [15].

The study was guided by three research questions:

1. How valid is TIBLEP in terms of its content, pedagogical and inquiry design, technology integration, usability and design, assessment and feedback, and overall suitability?
2. What difference is observed in Natural Science achievement between students who receive TIBLEP-supported instruction and those who receive conventional instruction?
3. How do students and teachers describe their experiences of using TIBLEP?

The study's contribution is threefold. First, it documents and validates a design process for an offline technology-enhanced inquiry package. Second, it offers preliminary classroom evidence on achievement differences between TIBLEP-supported and conventional instruction. Third, it identifies practical design features that teachers and learners perceived as useful, including simplification of abstract concepts, self-paced learning, active engagement, collaboration, and increased teachers' technological competence. Rather than presenting TIBLEP as a universal solution, the study positions it as a context-sensitive design response whose value depends on curriculum alignment, structured inquiry, appropriate scaffolding, formative feedback, and feasible technological conditions.

2. Theoretical Framework

2.1. Constructivist Learning Theory

The primary theoretical foundation for TIBLEP is constructivist learning theory. Constructivism views learning as an active process in which learners build and reorganize knowledge through interaction with ideas, experiences, evidence, and prior understanding [16, 17]. In science education, this position is especially relevant because scientific knowledge is not learned effectively when learners are limited to memorizing definitions. Learners need opportunities to connect observations with explanations and to test emerging ideas against evidence.

TIBLEP operationalizes this principle through inquiry sequences in which learners encounter a scientific problem or phenomenon, access an explanation or demonstration, engage in a task, answer formative questions, and revisit material when misconceptions or gaps are identified. The digital environment therefore serves as a learning space where learners interact with content rather than simply reading it. This aligns with contemporary research on technology-enhanced inquiry, which emphasizes the relationship between digital affordances and learner activity rather than treating technology as an independent cause of learning [3].

Constructivism also underscores the importance of prior knowledge. Learners entering Natural Science lessons do not arrive as blank slates; they bring everyday explanations, experiences, and partial understandings. TIBLEP's navigation and remediation functions offer opportunities to reconnect new

concepts with earlier content. The design therefore supports learning as a process of conceptual development rather than a one-time exposure to information.

2.2. Guided Inquiry and Scaffolding

The second theoretical strand is guided inquiry. Inquiry-based learning is not synonymous with unstructured discovery. Recent evidence shows that productive inquiry depends on the quality of the questions, representations, tasks, feedback, and scaffolds available to learners. The intervention therefore uses structured inquiry rather than minimal guidance. Learners are encouraged to investigate, interpret, and make decisions, while the sequence provides clear instructions, demonstrations, task prompts, and opportunities for correction.

This distinction is theoretically important. Critiques of minimally guided inquiry have long argued that novice learners can experience excessive cognitive demands when expected to discover complex scientific principles without adequate support. TIBLEP responds to this concern by combining learner activity with guidance. The package does not ask learners to discover the curriculum independently; instead, it organizes inquiry experiences around defined curriculum outcomes and progressively supports learners toward those outcomes.

Recent digital inquiry research supports this position. Bónus, et al. [2] showed how digital inquiry activities can be embedded in a structured curriculum to develop inquiry skills, while Dunn and Ramnarain [13] demonstrated how mobile technology can support a particular form of guided scientific reasoning. The theoretical implication is that technology should amplify the inquiry process while preserving the instructional structure that makes inquiry manageable.

2.3. Formative Assessment and Feedback

A third theoretical strand is formative assessment. Within TIBLEP, assessment is integrated into instruction rather than positioned only at the end of a lesson. Learners receive immediate feedback after formative tasks and can return to relevant learning material before progressing. This creates a feedback loop: engage—respond—receive feedback—revisit—attempt again—progress.

The feedback loop serves as an important bridge between pedagogy and technology. Effective feedback is most useful when it guides the learner's next action rather than merely reporting performance [18]. Digital technology can deliver feedback quickly, but speed alone does not make feedback formative. Its educational value depends on whether the feedback helps learners understand the gap between their current performance and the intended learning goal and whether the system provides a feasible next step. TIBLEP's remediation mechanism attempts to operationalize that principle by routing learners back to the relevant learning material rather than simply displaying a right-or-wrong result.

2.4. Culturally Responsive Pedagogy

Culturally responsive pedagogy provides a contextual layer to the framework. Science learning does not occur in a cultural vacuum. Learners interpret phenomena through experiences shaped by family, community, language, environment, and prior schooling. A technology-enhanced package intended for African classrooms should therefore avoid assuming that examples, contexts, and representations developed elsewhere are automatically meaningful to local learners [19].

In the present study, cultural responsiveness is treated as a design principle rather than as a separate outcome variable. Where appropriate, examples and inquiry contexts are connected to learners' everyday environments and familiar phenomena. This approach complements the broader argument that educational technology should be locally relevant and should strengthen, rather than displace, human interaction and contextual knowledge [9].

2.5. The Integrated Theoretical Position

The theoretical framework can therefore be summarized as follows. Constructivism explains 'why learners should actively construct understanding'; guided inquiry explains 'how they can investigate

scientific ideas with appropriate structure'; formative assessment explains 'how feedback and remediation can regulate learning during the process'; and culturally responsive pedagogy explains 'why the content and learning experience must be situated in learners' contexts' [20]. Technology provides the delivery and interaction infrastructure that brings these principles together.

The framework avoids technological determinism. TIBLEP is not expected to improve learning simply because it is digital. Its anticipated contribution stems from the interaction among pedagogy, content, assessment, learner activity, and feasible access to technology. This theoretical position aligns with contemporary evidence that technology-enhanced inquiry is most productive when technological affordances are deliberately aligned with inquiry goals and classroom needs [3, 15].

3. Conceptual Framework

The conceptual framework translates the theoretical assumptions into a testable instructional pathway. It is organized around four linked components: instructional input, learning process, proximal mechanisms, and outcomes. The framework is adapted conceptually from technology-enabled active learning work [21] and the design logic of educational design research, but the specific relationships shown here are developed for TIBLEP and the present study.

3.1. Instructional Input: TIBLEP

The input is the Technology-Enhanced Inquiry-Based Learning Package. TIBLEP includes five design features that are central to the intervention: (1) curriculum-aligned natural science content; (2) guided inquiry and practical activities supported by multimedia demonstrations; (3) self-paced navigation; (4) embedded formative assessment with immediate feedback; and (5) remediation through opportunities to revisit relevant concepts [22]. The offline architecture is not treated as an incidental technical feature. It is part of the intervention's equity-oriented design because it reduces dependence on continuous internet access.

3.2. Learning Process: Active Inquiry

The input is expected to influence learning through active inquiry. Learners encounter scientific ideas, investigate or interpret phenomena, engage with demonstrations and tasks, answer questions, receive feedback, and revisit concepts as needed [21]. This process differs from a simple digital presentation because learners must repeatedly interact with the content and make decisions about their responses.

3.3. Proximal Mechanisms: Engagement and Regulation

The framework proposes engagement as a proximal mechanism linking TIBLEP with learning outcomes. Engagement is reflected in learners' active participation, persistence, interaction with tasks, and willingness to revisit difficult material. The remediation cycle also supports self-regulation by making errors actionable. An incorrect response becomes information about what to revisit rather than an endpoint [23].

3.4. Outcomes: Achievement and Attitudes

The framework's output reflects the expected learning outcomes of implementing TIBLEP. Sustained engagement in hands-on activities, participation in problem-based learning, and exposure to simple inquiry experiments collectively lead to an improved understanding of Natural Science concepts, better knowledge retention, enhanced practical skills, and overall improved academic performance. Alongside achievement, learners are expected to develop more positive attitudes and a favorable perception of science, as engagement through inquiry and culturally responsive instruction fosters intrinsic motivation, curiosity, and confidence in scientific learning [24].

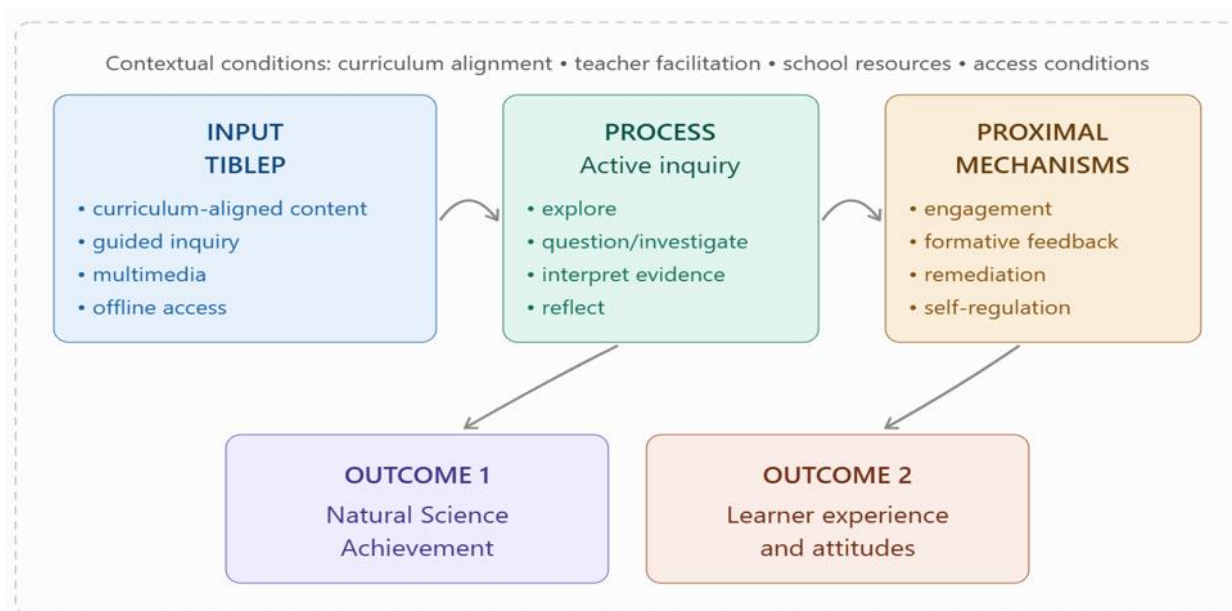


Figure 1.
Conceptual framework linking TIBLEP features, guided inquiry, proximal learning mechanisms, and outcomes.

Figure 1 shows the conceptual framework linking TIBLEP features, guided inquiry, proximal learning mechanisms, and outcomes. The conceptual logic is therefore explained as follows:

TIBLEP features → guided inquiry and a formative learning process → engagement, feedback, and remediation → achievement, attitude, and learner experience.

The framework also treats contextual conditions, curriculum alignment, teacher facilitation, school resources, and connectivity as boundary conditions. This prevents the model from implying that TIBLEP operates identically across all settings.

3.5. Expected Relationships

The framework predicts that the instructional value of TIBLEP will be greatest when its components function as a coherent system. Curriculum alignment establishes relevance; inquiry tasks activate learner participation; multimedia representations support visualization of difficult phenomena; formative assessment reveals learning gaps; immediate feedback identifies the next step; and remediation allows learners to correct misunderstandings. The expected outcome is therefore attributable not to a single feature but to the interaction among the package's components [25].

This conceptualization also helps distinguish the present study from technology-comparison research. The central question is not whether “technology” is better than “no technology.” Instead, it asks whether a deliberately designed, validated, offline, technology-supported inquiry environment can yield a more productive learning process than conventional instruction under the study's conditions [26].

4. Methodology

4.1. Research Design

The study employed Design and Development Research (DDR) as the overarching methodological approach, with quantitative and qualitative evidence collected during validation and field implementation. DDR was appropriate because the study was concerned not only with determining whether an intervention worked, but also with designing, refining, validating, and documenting an instructional artefact. Contemporary educational design research emphasizes methodological fit: research methods should align with the questions the design study is intended to answer and generate evidence about both

the intervention and the design process [15]. Figure 2 illustrates the process of using DDR during the development, validation, and field testing of the learning package (TIBLEP).

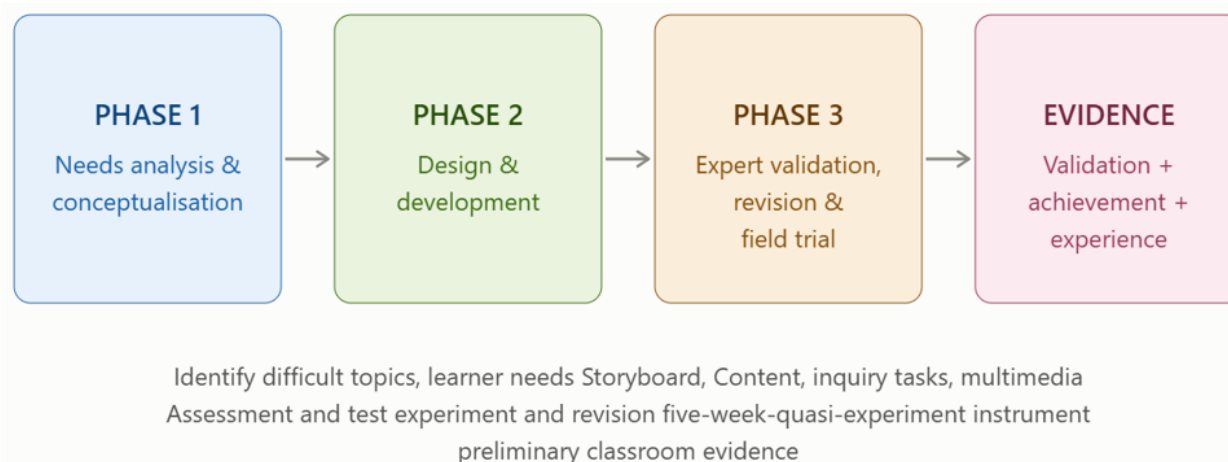


Figure 2.
DDR process used to develop, validate, revise, and field-test TIBLEP.

Figure 2 outlines the Design and Development Research (DDR) process used to develop, validate, revise, and field-test the Technology-Enhanced Inquiry-Based Learning Package (TIBLEP).

The study proceeded through three connected phases: needs analysis and conceptualization; design and development; and validation, revision, and field implementation. The field component used a pretest–posttest comparison involving two intact classes. One class received TIBLEP-supported instruction, and the other received conventional instruction. Because intact classes, rather than randomly assigned individual learners, were used, the study is appropriately described as quasi-experimental rather than randomized experimental research. The study also incorporated qualitative interviews with teachers and students to illuminate experiences and design affordances not captured by achievement scores.

4.2. Context and Needs Analysis

The needs-analysis phase examined learning difficulties in junior secondary Natural Science. The source manuscript identifies recurring difficulties in Energy and forms of energy, Energy conversion and transfer, Electricity, and Chemical substances, including acids, bases, neutrals, and substance testing. These areas were used to define the scope of TIBLEP's content.

The needs analysis drew on diagnostic information from students and teachers, as well as on existing assessment data. The purpose was not only to identify low-performing topics but also to determine where a technology-enhanced inquiry package could add instructional value. The design problem was therefore framed as a combination of conceptual difficulty, the need for practical representation, learner engagement, formative assessment, and constraints on access to technology.

4.3. Design and Development of TIBLEP

TIBLEP was developed using Articulate Storyline 360 and was organized around the instructional principles identified during the needs analysis. The development process followed an ADDIE-informed sequence of analysis, design, development, implementation, and evaluation. The package included a user guide, learner instructions, learner biodata entry, navigation controls, multimedia resources, inquiry activities, practical demonstrations, formative assessment, immediate feedback, and remediation.

The package was deliberately designed to operate offline. This means that students did not require Wi-Fi or mobile data to access the instructional material during implementation. The intervention therefore differs from web-dependent inquiry environments in which access to external resources is an essential part of the learning design.

The multimedia components were designed to support inquiry rather than replace it. Videos and visual demonstrations were linked to questions and tasks, allowing learners to observe scientific processes and then use the information to respond to learning prompts. Navigation allowed learners to move backward to revisit a concept and forward to continue the relevant learning sequence. Formative assessment was embedded within the learning modules rather than postponed until the end of the intervention. Figure 3 shows the flowchart of Articulate Storyline interactive media based on the case method. Figure 4 shows the interface for the design output of the learning package (TIBLEP).

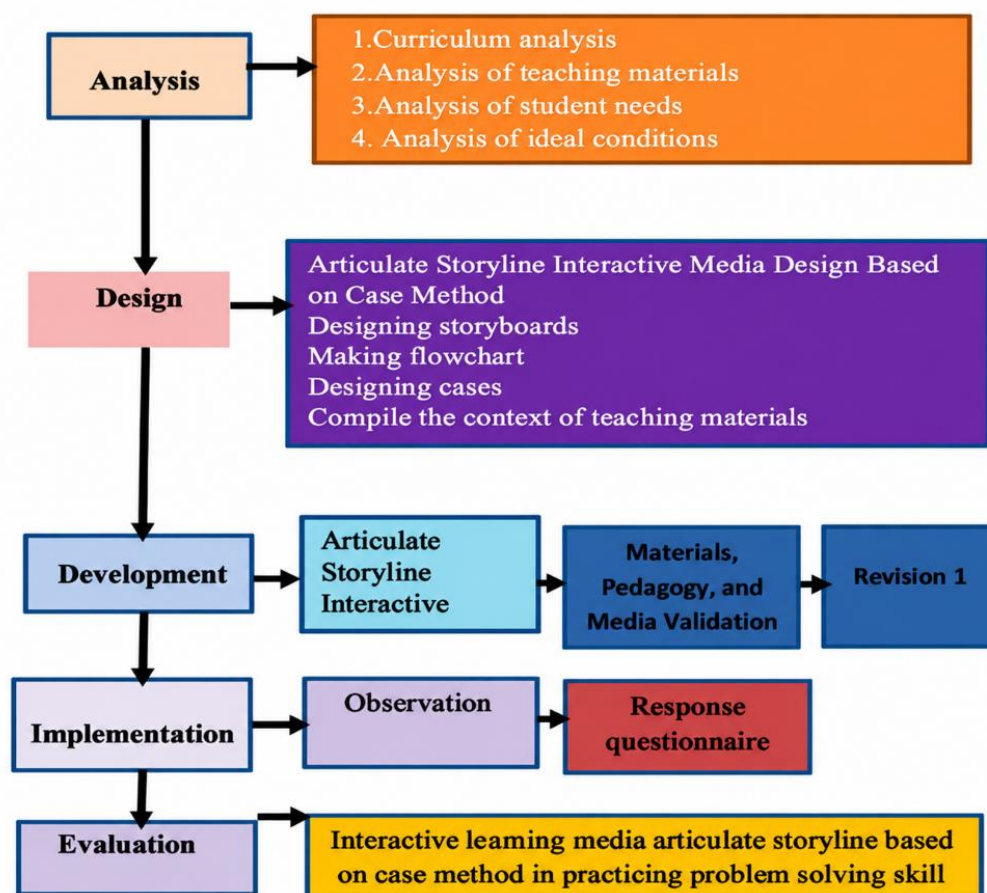


Figure 3.

Flow Chart of Articulate Storyline Interactive Media Design Based on Case Method.

Source: Daryanes, et al. [27] and Syam, et al. [28].

The framework's output, shown in Figure 3, outlines the expected learning outcomes of implementing TIBLEP. Sustained engagement in hands-on activities, participation in problem-based learning, and exposure to simple inquiry experiments collectively lead to improved understanding of Natural Science concepts, better knowledge retention, enhanced practical skills, and overall academic performance. Alongside achievement, learners are expected to develop more positive attitudes toward science, as engagement through inquiry and culturally responsive instruction fosters intrinsic motivation, curiosity, and confidence in scientific learning. Figure 4 explains the interface.

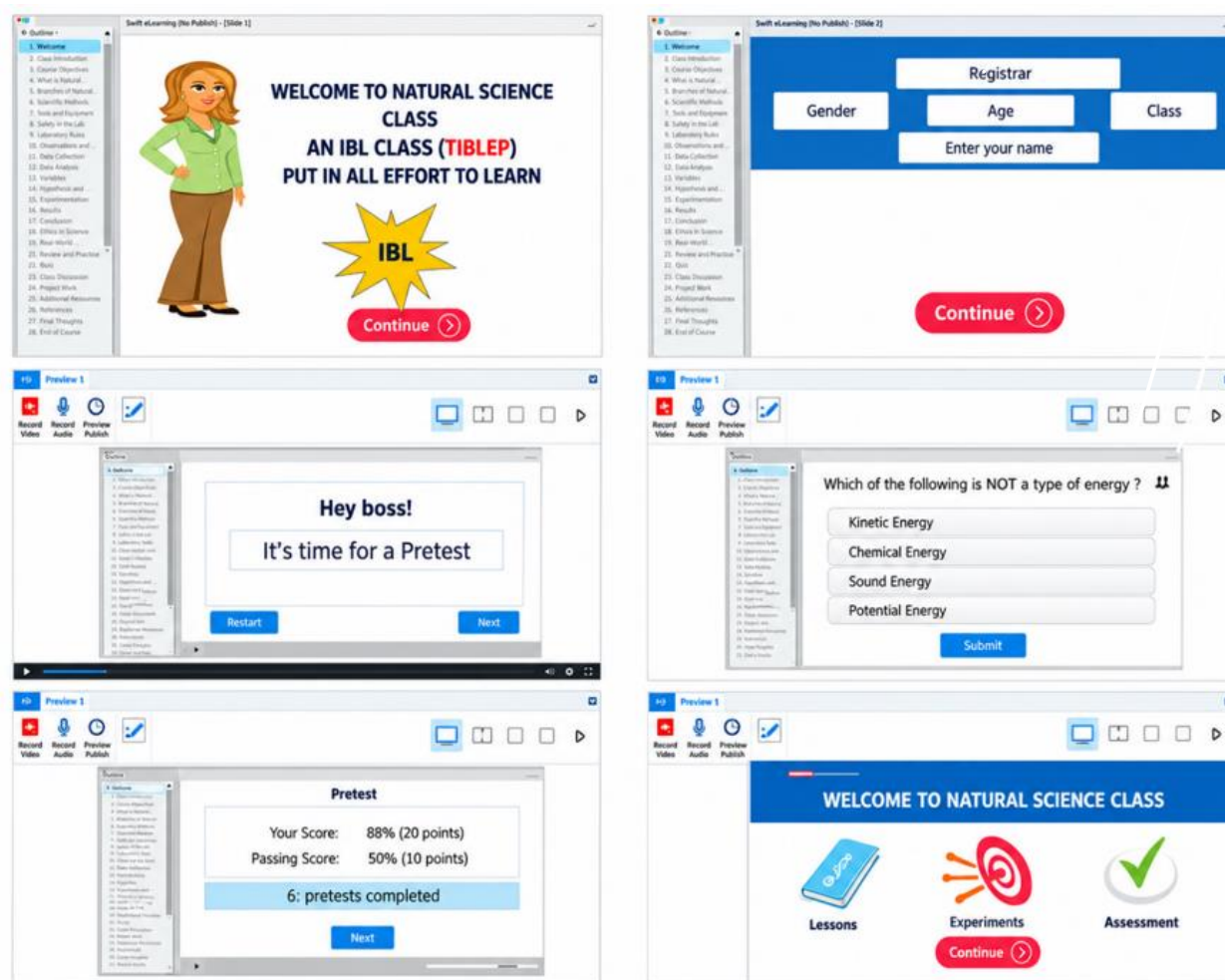


Figure 4.
The interface of the output of the design of the learning package.

Figure 4 shows the interface for the learning package's design output. It explains the welcome page, the learners' demographics page, and the pretest page, including the item format. It also shows the pretest results page, which displays percentages.

4.4. Expert Validation

Validation involved five experts with expertise in natural science education, educational technology, and measurement and evaluation. The experts reviewed the package using a four-point Technology-Enhanced Inquiry-Based Learning Package Validation Rating Scale (TIBLEPVRS). The scale ranged from 1 = Not Appropriate to 4 = Very Appropriate and covered six dimensions: content validity; pedagogy and inquiry design; technology integration; usability and design; assessment and feedback; and overall suitability.

The validation process consisted of expert ratings and qualitative review. Experts were invited to comment on curriculum alignment, instructional sequence, inquiry structure, technology use, navigation, readability, assessment quality, feedback, and the package's suitability for classroom use. Recommendations were considered during revision before field implementation.

Recent science-module development work also illustrates the value of combining expert review, pilot evidence, and intervention evidence rather than relying on a single validation source [29]. This validation

approach deliberately differs from a graduate-student-pilot sequence, in which one-to-one testing is followed by small-group testing and then a field trial. The present study used two complementary strands, expert validation and classroom field implementation. This distinction is important for methodological transparency: expert review provided evidence of the designed artifact's quality and suitability, whereas the field trial provided preliminary evidence of classroom implementation and learning outcomes.

4.5. *Participants and Sampling*

Sixty Grade 8 students from two intact classes participated in the field implementation, with 30 students in the TIBLEP group and 30 in the conventional-instruction group. The classes included both male and female learners. The two schools were described in the source manuscript as geographically separated, reducing the likelihood of direct interaction between learners in the two conditions during the intervention.

The expert validation panel consisted of five experts, three of whom were male and two of whom were female. Six participants subsequently contributed qualitative interview data: three teachers and three students from the experimental group. The teachers differed in teaching experience and familiarity with technology, while the student participants were of both sexes.

Sampling was purposive at the intervention level because the study targeted the grade level and curriculum for which TIBLEP was developed. The use of intact classes was practical for school-based implementation but limits causal generalization.

4.6. *Instruments*

Three main instruments were used.

Expert validation scale: The TIBLEPVRS assessed the six dimensions described above. The manuscript reports an internal consistency coefficient of $\alpha = 0.76$ for the scale. The item-level results were summarized using means and standard deviations.

Natural Science Achievement Test: Achievement was assessed through pretest and posttest measures aligned with the content addressed in the intervention. The test's reliability was $\alpha = 0.81$.

Teacher and Student Inquiry-Based Learning Interview Guide: Semi-structured interviews were used to elicit participants' experiences of the intervention. The questions focused on conceptual understanding, learner autonomy, engagement, collaboration, instructional workload, and technology experience.

4.7. *Validation and Pilot Procedures*

The field implementation lasted five weeks. In Week 1, the learning package was introduced to teachers and students, and guidance was provided on its use. Pretests were administered to the two groups before the intervention.

During Weeks 2–4, the experimental group used TIBLEP-supported instruction, while the control group received conventional instruction. Students in the experimental condition worked individually on computers. The package was designed to support self-paced progression, with teachers providing assistance as needed, particularly for technical or instructional difficulties.

In Week 5, posttests were administered. Interviews were then conducted with selected teachers and students to capture their experiences with the package. This sequence allowed the study to combine evidence from expert review, baseline achievement, post-intervention achievement, and participant experience.

4.8. *Data Analysis*

Expert validation data were analyzed descriptively using item means, dimension means, standard deviations, and an overall grand mean. A four-point response scale was used, with higher values indicating stronger expert endorsement.

For achievement, the results included independent-groups pretest and posttest statistics. However, the posttest table contains an internally inconsistent t value and degrees of freedom. Based on $n = 30$ per

group, the pretest difference was very small ($M\text{-TIBLEP} = 32.40$, $SD = 4.50$; $M\text{-control} = 31.80$, $SD = 4.70$), corresponding to an estimated Cohen's d of approximately 0.13. For the posttest, the reported means were $M\text{-TIBLEP} = 68.30$ ($SD = 6.20$) and $M\text{-control} = 54.70$ ($SD = 5.80$), yielding a mean difference of 13.60 points and an estimated standardized mean difference of approximately $d = 2.27$.

Qualitative interview data were analyzed thematically. Initial coding focused on recurring descriptions of learning difficulty, learner autonomy, engagement, collaboration, performance, and teacher experience. Related codes were grouped into themes and compared across teacher and student accounts. The qualitative findings were used to complement, rather than statistically validate, the quantitative results.

4.9. Research Ethics

Participation was voluntary, and participants provided informed consent. Participants were informed of their right to withdraw, and confidentiality was maintained by anonymizing responses. The control group continued to receive conventional instruction, while the experimental group received the intervention under study. Cultural relevance and equity were considered during the development of the package. Ethical approval was obtained from the Faculty of Education Research Ethics Committee at the University of Johannesburg (Ethical Clearance Number: SEM 2-2025-108), and permission to conduct the research was granted by the relevant education authorities and the participating school principals.

5. Results

5.1. Expert Validation of TIBLEP

The five experts provided consistently positive evaluations across the six validation dimensions. The grand mean was 3.69 ($SD = 0.29$) on the four-point scale, indicating high overall endorsement. The results are summarized in Table 1.

Table 1.

Expert validation of TIBLEP.

Validation dimension	Items	Mean	SD	Decision
Content validity	5	3.72	0.28	Highly valid
Pedagogy and inquiry design	5	3.68	0.31	Highly valid
Technology integration	5	3.60	0.34	Highly valid
Usability and design	5	3.65	0.29	Highly valid
Assessment and feedback	5	3.70	0.26	Highly valid
Overall suitability	5	3.78	0.24	Highly valid
Grand mean	30	3.69	0.29	Highly valid

Source: Supplied manuscript, expert-validation summary. The grand mean and dimension values are retained from the source.

Table 1 presents the results of expert validation of the learning package (TIBLEP). The strongest dimension was overall suitability ($M = 3.78$, $SD = 0.24$), followed by content validity ($M = 3.72$, $SD = 0.28$) and assessment and feedback ($M = 3.70$, $SD = 0.26$). Technology integration had the lowest mean ($M = 3.60$, $SD = 0.34$) but remained within the study's high-validity range. This pattern indicates that experts considered more than technological novelty; they also assessed curriculum fit, pedagogy, usability, and assessment.

At the item level, curriculum alignment, navigation, and assessment alignment each received a mean score of 3.80. Inquiry structure clarity and meaningful technology use each received a mean score of 3.60. These results suggest that the package was perceived as strongest in curriculum fit, navigation, and assessment coherence, while technology integration and inquiry structure were areas for further refinement.

5.2. Baseline Achievement

The two groups were similar at pretest. The TIBLEP group recorded a mean of 32.40 (SD = 4.50), while the control group recorded a mean of 31.80 (SD = 4.70), a mean difference of 0.60 points. The standardized difference calculated from the reported descriptive statistics was approximately $d = 0.13$, indicating a negligible baseline difference.

Table 2.

Achievement comparison at baseline.

Group	n	Mean	SD	Estimated Cohen's d
TIBLEP	30	32.40	4.50	0.13
Control	30	31.80	4.70	—

Table 2 presents the achievement comparison at baseline. The source manuscript reports $t = 0.56$ and $p = 0.58$; however, these inferential values are not fully consistent with the reported means, standard deviations, and equal group sizes. Recalculation using the supplied descriptive statistics yields $t(58) \approx 0.51$, $p \approx 0.62$. The revised manuscript therefore treats the groups as descriptively comparable at baseline and does not retain the inconsistent original inferential value.

5.3. Post-Intervention Achievement

The posttest results showed a substantial descriptive advantage for the TIBLEP group. Students who received TIBLEP-supported instruction obtained a mean of 68.30 (SD = 6.20), whereas the control group obtained a mean of 54.70 (SD = 5.80). The mean difference was 13.60 points in favor of the intervention.

Table 3.

Achievement comparison after the intervention.

Group	n	Mean	SD	Mean difference	Estimated d	t (58)
TIBLEP	30	68.30	6.20	13.60	2.27	8.77
Control	30	54.70	5.80	—	—	—

Table 3 presents the posttest results for the intervention, TIBLEP, and indicates that the intervention had a significant effect in favor of the experimental group. Using the reported means and standard deviations, the pooled-standard-deviation effect estimate is approximately $d = 2.27$, indicating a large standardized difference. An independent-samples comparison yields $t(58) = 8.77$, $p < 0.001$. The achievement pattern is therefore clear at the descriptive level: the groups were closely matched before instruction, but the TIBLEP group performed substantially better after the five-week intervention.

5.4. Baseline Attitude

Table 4.

ANCOVA of Post-Attitude by Treatment, Controlling for Pre-Attitude.

Source	Type III Sum of Squares	df	Mean Square	F	p	Partial η^2
Pre-attitude	954.352	1	954.352	9.338	0.003	0.145
Treatment	1,490.785	1	1,490.785	14.586	< 0.001	0.210
Error	5,621.253	55	102.205	—	—	—

Note: Dependent variable: post-attitude. Covariate: pre-attitude. Treatment is TIBLEP versus conventional instruction. $p < 0.05$.

Table 4 presents the baseline attitude results, which concern pre-attitude. After controlling for students' pre-attitude, pre-attitude had a statistically significant effect on post-attitude, $F(1, 55) = 9.338$, $p = 0.003$, partial $\eta^2 = 0.145$. This indicates that students' initial attitudes accounted for a meaningful proportion of the variance in their post-intervention attitudes.

More importantly, treatment had a statistically significant effect on students' post-attitude: $F(1, 55) = 14.586$, $p < 0.001$, partial $\eta^2 = 0.210$. Thus, after controlling for pre-attitude, students exposed to

TIBLEP had significantly different post-attitude scores from those receiving conventional instruction. The partial eta squared of 0.210 indicates a substantial treatment effect, with approximately 21.0% of the variance in post-attitude attributable to treatment after accounting for the covariate and error variance.

Table 5.

Post-Attitude Means by Treatment Group, Controlling for Pre-Attitude.

Treatment Group	Adjusted Mean	Standard Error (SE)	95% CI Lower Bound	95% CI Upper Bound
Technology-Enhanced Learning (TIBLEP)	34.646	2.176	30.285	39.007
Control	24.621	1.466	21.683	27.559
Adjusted Mean Difference	10.025	—	—	—

Table 5 shows that, after controlling for pre-attitude, students in the Technology-Enhanced Learning (TIBLEP) group had an adjusted post-attitude mean of 34.646 (SE = 2.176, 95% CI [30.285, 39.007]), whereas those in the control group had an adjusted mean of 24.621 (SE = 1.466, 95% CI [21.683, 27.559]). The adjusted mean difference was therefore 10.025 points in favor of TIBLEP.

5.5. Participant Experiences

5.5.1. Theme 1: Simplification of Abstract Concepts.

Participants described TIBLEP as making difficult scientific ideas easier to understand. Teachers emphasized the package's ability to represent abstract concepts through digital demonstrations and structured learning sequences. Students similarly described Natural Science as easier to follow when concepts were presented through the package.

5.5.2. Theme 2: Student-Centered and Self-Paced Learning.

Participants repeatedly described the ability to move through the content at an individual pace. Students valued the opportunity to revisit material, while teachers viewed the structure as supporting learner independence.

5.5.3. Theme 3: Perceived Improvement in Performance and Cognitive Engagement.

Teachers reported improvements in learners' understanding, retention, and recall. Students described the package as helping them understand concepts and improve their performance. These accounts are consistent with the achievement pattern but should be interpreted as participant perceptions rather than independent measures of cognitive gain.

5.5.4. Theme 4: Engagement and Collaboration.

Students reported greater participation in activities with peers. Although TIBLEP was used individually on computers, participants reported that inquiry tasks also created opportunities for discussion and peer interaction.

5.5.5. Theme 5: Teacher Technological Development.

Teachers reported greater familiarity with digital tools and perceived reductions in certain routine instructional demands. This theme suggests that the intervention's potential influence extends beyond students, although teacher professional development was not measured quantitatively.

Taken together, the qualitative evidence portrays TIBLEP as a structured learning environment that participants perceived to be more accessible, self-paced, interactive, and supportive of conceptual understanding than conventional classroom routines.

6. Discussion

The findings provide important evidence of the design quality, effectiveness, and contextual relevance of the Technology-Enhanced Inquiry-Based Learning Package (TIBLEP). Expert validation across six

dimensions yielded a grand mean of 3.69, confirming that TIBLEP is not merely a technological product but an integrated instructional system encompassing content, pedagogy, inquiry, technology, usability, assessment, and overall suitability. This multidimensional approach aligns with contemporary design research that emphasizes coherence among objectives, design, implementation, and evidence of quality [15].

Content validity scored highest ($M = 3.72$), indicating strong alignment with the Natural Science curriculum. This reinforces the principle that curriculum and pedagogy should guide technology selection rather than allowing technology to dictate instructional practice. The score for pedagogy and inquiry design ($M = 3.68$) indicated that experts considered the activities sufficiently inquiry-oriented and learner-centered, consistent with findings that technology-enhanced inquiry is most effective when embedded within structured pedagogy [2, 3]. TIBLEP extends this by integrating inquiry in an offline environment with formative assessment and remediation, thereby highlighting coherence between technological and pedagogical components.

Technology integration had the lowest mean ($M = 3.60$) but remained positive, underscoring the principle that technology should serve an instructional purpose. UNESCO [9] likewise emphasizes evaluating technology for relevance, equity, scalability, and sustainability. TIBLEP's offline feasibility is its key contribution, reducing reliance on continuous internet access. Usability ($M = 3.65$) was rated positively, indicating accessible navigation and reduced cognitive load. Assessment and feedback ($M = 3.70$) supported the embedding of formative assessment directly into the learning sequence, creating a cycle in which errors become learning opportunities.

Achievement results were substantial: the TIBLEP group scored 13.60 points higher on the posttest than the comparison group, yielding an effect size of $d \approx 2.27$. This aligns with research showing that technology-supported inquiry can enhance conceptual understanding, inquiry skills, and motivation when carefully structured [2, 30]. Importantly, the achievement difference reflects the package's instructional affordances: multimedia, guided inquiry, formative assessment, feedback, and remediation, rather than digital delivery alone. Thus, TIBLEP should be understood as a pedagogical package, not a technology treatment.

South African studies support this interpretation. Dunn and Ramnarain [13] found that mobile technology supported abductive inquiry when integrated with reasoning processes, while Lotter and Ramnarain [11] showed that classroom enactment shaped inquiry opportunities. TIBLEP contributes by focusing on offline packages for junior secondary Natural Science. Although inquiry research has reported motivational gains [4, 31], this study cannot claim quantitative improvement in attitude due to incomplete statistical data.

The offline architecture is a context-sensitive innovation. Many settings lack reliable internet, and UNESCO [9] warns that digital technologies can widen inequalities when access and sustainability are overlooked. While devices and electricity remain necessary, TIBLEP reduces reliance on Wi-Fi and mobile data. Pedagogically, offline delivery enables curated instructional pathways aligned with curriculum objectives, benefiting novice learners who need structured guidance. Rather than exposing students to unrestricted information, TIBLEP offers bounded opportunities for inquiry through multimedia, questions, and feedback.

Qualitative findings further explain achievement gains. Students reported that TIBLEP made abstract concepts easier to understand, consistent with multimedia demonstrations linked to inquiry tasks. Self-paced learning was valued, enabling learners to revisit content and progress at their own pace, which was particularly useful in heterogeneous classrooms. This supports adaptive instruction, in which remediation transforms errors into learning opportunities. Collaboration also emerged: although learners engaged individually with the package, they reported peer interaction during inquiry tasks, showing that individualized digital learning can coexist with social collaboration [32].

Teachers reported greater technological familiarity and a reduced workload, though only three participated in the qualitative component. These insights are promising but not conclusive evidence of the intervention's effects. Theoretically, TIBLEP integrates active knowledge construction, guided

inquiry, formative feedback, remediation, and contextual responsiveness into a coherent instructional logic. It reconciles learner agency with concerns about cognitive overload in minimally guided inquiry by operationalizing guided inquiry through scaffolding, multimedia, explicit navigation, and feedback.

Comparisons with conventional instruction must be interpreted carefully. The study does not claim that conventional teaching is ineffective; rather, under field-trial conditions, TIBLEP students achieved higher posttest scores. This avoids a simplistic technology-versus-teacher narrative. Teachers remain central, while TIBLEP provides structured support. UNESCO [9] similarly advocates a human-centered approach to technology, in which digital tools complement teachers.

The principal contribution of TIBLEP is the coherence of its instructional architecture: curriculum-aligned content, guided inquiry, multimedia support, formative assessment, remediation, and offline feasibility. Strong expert validation and substantial achievement gains provide credible evidence of promise. However, limitations include small, non-randomized samples, incomplete outcome data, and limited teacher participation. Larger multi-school studies, stronger statistical controls, documented fidelity, and longer follow-up are needed to confirm durability and identify which components most strongly support learning.

7. Implications for Research, Practice, and Policy

The study shows that technology is most valuable when integrated with sound pedagogy rather than added as a standalone feature. For classroom practice, TIBLEP offers a structured approach to guided inquiry, formative assessment, feedback, and remediation, while allowing learners to progress at an appropriate pace. For instructional designers, the findings emphasize curriculum alignment, structured inquiry, usability, meaningful multimedia, embedded assessment, and remediation, with technology selected for its instructional value. Teacher development should prepare teachers to facilitate inquiry, interpret feedback, address misconceptions, and manage technical challenges, rather than function as passive users. At the policy level, offline and low-bandwidth solutions may improve equitable access, but scaling requires investment in devices, electricity, maintenance, teacher training, content updates, and data protection. Future research should use larger multi-school designs, examine implementation fidelity and contextual differences, and assess whether learning gains are sustained.

8. Limitations of the Study

The study involved only 60 learners from two intact classes, limiting statistical precision and generalizability. Unmeasured class-level differences may also have influenced outcomes. The qualitative component included only six participants. Although their accounts provide useful design insights, they cannot represent the experiences of all students and teachers who might use TIBLEP. Future research should use a larger, more deliberately varied qualitative sample and report the coding procedure, researcher reflexivity, and evidence of analytic credibility in greater detail.

These limitations do not invalidate the study. Rather, they define its evidential status: TIBLEP has strong preliminary design-validation evidence and encouraging field-trial evidence, but it requires larger and more rigorous effectiveness studies before broad causal or generalizable claims are warranted.

9. Conclusion

This study developed and validated TIBLEP, an offline, technology-enhanced, inquiry-based learning package for junior secondary Natural Science. The design was grounded in practical needs identified during the needs-analysis phase, which were translated into a structured learning environment that combines curriculum-aligned content, guided inquiry, multimedia demonstrations, self-paced learning, formative assessment, immediate feedback, and remediation.

Expert evaluation provided strong evidence of design suitability. Across six dimensions, the package achieved a grand mean of 3.69 on a four-point scale. The strongest rating was for overall suitability, while technology integration received the lowest rating but remained positive. These findings suggest that the

package's principal strength lies in the coherence among content, pedagogy, assessment, usability, and technology rather than in technological novelty alone.

The field trial also showed a substantial difference in achievement. Students in the TIBLEP condition obtained a posttest mean 13.60 points higher than students in the conventional condition, with a large standardized difference based on the reported descriptive statistics. Qualitative accounts complemented this result by describing improved conceptual clarity, self-paced learning, engagement, collaboration, and teachers' technological experience.

The study does not claim that digital technology is inherently superior to conventional teaching. Rather, it demonstrates a feasible way to design technology around inquiry, feedback, remediation, and contextual access, where continuous internet access cannot be assumed.

Future versions should also systematically examine attitudes, inquiry skills, retention, scientific reasoning, and learner differences. With these additional validations, TIBLEP has the potential to contribute to more equitable and pedagogically coherent technology-supported Natural Science education in resource-constrained settings.

10. Recommendations

Educational stakeholders should adopt technology-enhanced learning as a complement to effective pedagogy rather than as a replacement for teachers. Teachers should receive practical training in guided inquiry, formative assessment, feedback, remediation, and classroom management in digital environments. Curriculum developers should ensure that technology-based packages are curriculum-aligned, user-friendly, interactive, and capable of functioning offline or with limited connectivity. School leaders and policymakers should provide adequate devices, electricity, technical support, maintenance, and teacher professional development before large-scale implementation. Future studies should use larger, more diverse samples, cluster-randomized or matched designs, stronger documentation of control conditions, and verified datasets. Researchers should also examine gender, socioeconomic context, implementation fidelity, and the durability of learning gains through longer-term follow-up studies.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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