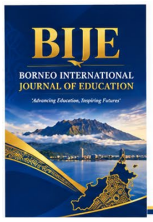
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DEVELOPMENT OF EDP.AI: AN AI-INTEGRATED ENGINEERING DESIGN MODULE TO ENHANCE STUDENT ENGAGEMENT IN STEM LEARNING

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Abstract

STEM education is a national priority in Malaysia; however, clear gaps in learning outcomes and student participation remain, particularly in rural areas. In Sabah, very low Indeks STEM Murid (ISM) scores, coupled with declining enrolment in the STEM Package A stream, indicate persistent challenges in the quality and continuity of STEM learning at the lower secondary level. These trends suggest that many students do not experience STEM learning as sufficiently meaningful or structured to build confidence and sustain their interest in STEM pathways. This paper reports Phase 1A of a Design and Development Research (DDR) study, focusing on the needs analysis and conceptualisation of EDP.AI, an AI-assisted module designed to scaffold the Engineering Design Process (EDP) for lower secondary students in rural Sabah. Document analysis was conducted to examine challenges related to STEM learning, EDP implementation, artificial intelligence in education, and Cognitive Load Theory (CLT) in low-resource contexts. The evidence was synthesised using design rationale mapping to translate theoretical and contextual insights into actionable design decisions. The outcomes of Phase 1A include the identification of key needs and challenges, the formulation of preliminary design requirements and design principles, and the development of a conceptual model to guide the design of EDP.AI. The proposed module emphasises step-by-step scaffolding aligned with EDP stages, reduced cognitive load, low-bandwidth accessibility, and support for both student reasoning and teacher workload. Overall, this study provides a theoretical and contextual foundation for the subsequent development and expert validation of EDP.AI to support more meaningful and sustainable STEM learning experiences in rural schools.

Kata kunci:
Proses reka bentuk kejuruteraan, kecerdasan buatan, teori beban kognitif, pembelajaran

Pendidikan STEM merupakan keutamaan nasional di Malaysia; namun, jurang yang ketara dalam hasil pembelajaran dan penyertaan murid masih wujud, khususnya di kawasan luar bandar. Di Sabah, skor Indeks STEM Murid (ISM) yang sangat rendah, berserta penurunan enrolmen dalam aliran Pakej STEM A, menunjukkan cabaran berterusan terhadap kualiti dan kesinambungan pembelajaran STEM pada peringkat menengah rendah. Trend ini menunjukkan

berasaskan reka bentuk, pendidikan STEM luar bandar

bahawa pembelajaran STEM yang dilalui oleh ramai murid masih belum cukup bermakna atau berstruktur untuk membina keyakinan dan mengekalkan minat mereka terhadap laluan STEM. Kertas kerja ini melaporkan Fasa 1A bagi kajian Penyelidikan Reka Bentuk dan Pembangunan (DDR), yang memfokuskan analisis keperluan dan pengkonsepan EDP.AI, iaitu modul berbantukan kecerdasan buatan (AI) yang direka bentuk untuk menyediakan sokongan perancah bagi Proses Reka Bentuk Kejuruteraan (EDP) kepada murid sekolah menengah rendah di luar bandar Sabah. Analisis dokumen telah dijalankan untuk meneliti cabaran berkaitan pembelajaran STEM, pelaksanaan EDP, kecerdasan buatan dalam pendidikan, dan Teori Beban Kognitif (CLT) dalam konteks sumber terhad. Bukti tersebut disintesis menggunakan pemetaan rasional reka bentuk bagi menterjemahkan dapatan teoretis dan kontekstual kepada keputusan reka bentuk yang dapat dilaksanakan. Hasil Fasa 1A merangkumi pengenalpastian keperluan dan cabaran utama, penggubalan keperluan reka bentuk awal dan prinsip reka bentuk, serta pembangunan model konseptual untuk memandu reka bentuk EDP.AI. Modul yang dicadangkan menekankan sokongan perancah langkah demi langkah yang sejajar dengan peringkat EDP, pengurangan beban kognitif, kebolehcapaian dalam persekitaran dengan jalur lebar terhad, serta sokongan terhadap penaakulan murid dan pengurusan beban tugas guru. Secara keseluruhannya, kajian ini menyediakan asas teoretis dan kontekstual bagi pembangunan dan pengesahan EDP.AI oleh pakar pada peringkat seterusnya untuk menyokong pengalaman pembelajaran STEM yang lebih bermakna dan mampan di sekolah luar bandar.

1.0 Introduction

STEM education remains a national priority in Malaysia as the country seeks to strengthen workforce readiness and technological resilience (Ministry of Education Malaysia, 2025). However, access to meaningful STEM learning experiences continues to vary across regions, particularly between urban and rural schools (Idris et al., 2023). These disparities highlight ongoing challenges in ensuring that all students benefit equally from national STEM initiatives (United Nations Educational, Scientific and Cultural Organization, 2023). The *Indeks STEM Murid* (ISM) 2023 reported a national mean score of 46.77, while students in Sabah recorded a score of only 7.92, the lowest nationwide (Ministry of Education Malaysia, 2023). This gap suggests that many students in rural and remote areas experience STEM learning that is limited in depth, structure, and meaningful engagement (Yaakob et al., 2023). Such learning conditions reduce opportunities for students to develop reasoning, problem-solving, and higher-order thinking skills through inquiry-based and practical activities (Bybee, 2011; Roehrig et al., 2021). These challenges are further intensified by limited digital access, unstable internet connectivity, and heavy instructional workloads among teachers in rural schools (Suherman et al., 2025; Surianshah, 2021).

Beyond ISM performance indicators, enrolment trends also highlight concerns regarding the continuity of STEM education (Idris & Bacotang, 2023). In 2024, Sabah recorded the lowest enrolment rate of Form 4 students in STEM Package A, at 11.98%, which declined further to 10.42% in 2025, remaining the lowest in Malaysia. When considered together, the low ISM scores and declining STEM enrolment point to a related issue: weak and fragmented STEM learning experiences at the lower secondary level may limit both students' understanding and their motivation to continue along STEM pathways at the upper secondary level (Fayzullina et al., 2024; Yaakob et al.,

2023).

Despite these challenges, students in rural Sabah show strong interest in hands-on and project-based learning activities (Han et al., 2022). Participation is often enthusiastic; however, many STEM activities remain highly teacher-directed and focus primarily on producing final products rather than engaging students in reasoning, iteration, and reflection (Cunningham & Carlsen, 2014). Without clear and consistent scaffolding, students tend to bypass key stages of structured design processes, such as problem definition, idea comparison, testing, and refinement (Samad et al., 2023; Nordlöf et al., 2024). As a result, hands-on activities may not translate into meaningful learning experiences that build students' understanding and confidence in STEM (Sneider & Ravel, 2021). Students may remain actively engaged in producing prototypes but often have limited opportunities to articulate, justify, or improve their design decisions (Elsen et al., 2025).

The Engineering Design Process (EDP) provides a structured approach that supports systematic thinking, iteration, and reflection through guided design activities (Bybee, 2011; Cunningham et al., 2020). By helping students understand problems, make decisions, and improve solutions, the EDP can strengthen learning outcomes and sustain students' interest in STEM (Sen et al., 2021; Roehrig et al., 2021). However, implementing the EDP consistently in rural classrooms remains challenging due to limited instructional time, high teacher workloads, and differences in students' prior knowledge (Yüksel, 2025; Ioannou & Gravel, 2024).

Recent studies highlight the potential of artificial intelligence (AI) to support learners during complex tasks by helping them organise ideas, clarify explanations, and engage in iterative thinking (Liu et al., 2025). When carefully designed, AI can function as a cognitive scaffold that reduces learning difficulties and supports student autonomy (Garg et al., 2025; Sreenivasan & Suresh, 2024). However, most available AI tools are not designed for low-resource contexts and may increase cognitive load when used without appropriate pedagogical structure (Sweller, 2011; Mogavi et al., 2024). This highlights the need for a guided and context-sensitive approach to integrating AI into STEM learning (Crompton & Burke, 2023).

In response to these challenges, this study introduces EDP.AI, an AI-assisted module designed for lower secondary students in rural Sabah. Grounded in Cognitive Load Theory (CLT), the module provides structured, step-by-step scaffolding aligned with the stages of the EDP to support student reasoning while managing cognitive load. Employing a Design and Development Research (DDR) approach in the needs analysis phase, this paper aims to identify the key challenges, preliminary design requirements, and design principles that will guide the development of the EDP.AI module.

2.0 Literature Review

The literature review is organised into four sections: STEM Education, the Engineering Design Process (EDP), Artificial Intelligence in Education (AIEd), and Cognitive Load Theory (CLT). Each section synthesises existing findings, identifies tensions and contradictions in previous studies, and considers their implications for rural learning contexts.

2.1 STEM Education: Consistent Benefits but Uneven Implementation

STEM education has long been recognised for its ability to develop higher-order thinking, creativity, and motivation when implemented through structured and meaningful activities. Studies such as Rahman et al. (2025) and Suherman et al. (2025) show that students benefit substantially from hands-on tasks, inquiry-based learning, and opportunities to solve real-world problems. These approaches allow learners to actively construct knowledge and apply concepts in authentic contexts. Consistent with these findings, Hiğde and Aktamis (2022) reported that well-designed STEM activities significantly enhance students' engagement and understanding across STEM disciplines.

However, the effectiveness of STEM education varies across school environments (Fayzullina et al., 2024). Research in rural Malaysia highlights challenges such as limited access to hands-on learning, negative attitudes toward science, and weaker conceptual foundations among students (Yaakob et al., 2023; Ismail et al., 2019; Vieira et al., 2025; Sharif et al., n.d.). While well-resourced schools tend to perform strongly due to adequate materials and support, rural schools often face constraints such as limited facilities, restricted digital access, and high teacher workloads. These factors contribute to disparities in the benefits of STEM education across regions (Idris & Bacotang, 2023). The contrast between promising outcomes in structured environments and weaker results in low-resource settings suggests that effective STEM learning depends heavily on appropriate scaffolding and sustained support. This tension highlights the need for tools such as EDP.AI that can provide consistent guidance across different school resource contexts.

2.2 Engineering Design Process: Strong Potential but Difficult to Implement

The Engineering Design Process (EDP) is widely used to support authentic problem-solving, creativity, and iterative thinking among students (Bybee, 2011; Cunningham et al., 2020). Studies show consistent gains in students' reasoning and computational thinking when the EDP is implemented systematically (Samad et al., 2023; Sen et al., 2021). The structured nature of the EDP helps students organise their thinking and manage complex tasks, making it suitable for developing innovation skills within authentic learning contexts (Bybee, 2011; Roehrig et al., 2021). Despite these benefits, EDP implementation in schools is often inconsistent. Many teachers report challenges related to time constraints, limited materials, and unfamiliarity with design-based teaching approaches (Yüksel, 2025; Ioannou & Gravel, 2024; Arnab et al., 2025). These challenges are especially prominent in rural settings, where teachers frequently rely on improvised strategies and have fewer opportunities for professional training (Radloff & Capobianco, 2020). Innovation competitions may also contribute to a product-over-process culture, in which students focus on producing a final prototype rather than exploring ideas or refining solutions. This mismatch between the theoretical strengths of the EDP and its inconsistent implementation in classrooms reveals a clear tension between theory and practice (Cunningham et al., 2020). It highlights the need for structured and accessible scaffolds that can guide both teachers and students through the iterative stages of the EDP.

2.3 Artificial Intelligence in Education (AIEd): High Potential, High Cognitive Risk

AI has emerged as a promising tool for supporting teaching and learning (Zhang, 2022; Chiu, 2024). Studies show that AI can assist students by helping them generate ideas, clarify their understanding, access explanations, and receive timely feedback during complex tasks (El Fathi et al., 2025). AI also has the potential to enhance engagement and promote learner autonomy by offering personalised support (Liu et al., 2020; Sreenivasan & Suresh, 2024). This is especially important in environments where teachers manage heavy workloads and have limited time for individualised guidance (Mogavi et al., 2024).

However, the use of AI in education also presents challenges. The open-ended nature of AI-generated information may create difficulties for learners who require more structured guidance. Mogavi et al. (2024) reported that students sometimes misinterpret AI-generated content or become overly dependent on it, highlighting the importance of appropriate guidance when AI is used for learning. In addition, the effective use of AI tools may depend on reliable internet connectivity and adequate access to digital devices, which can present challenges in rural school contexts. Batan and Jamaludin (2022) found that poor connectivity, limited access to devices, and uneven digital literacy continue to limit the adoption of AI-based learning tools in rural contexts, a challenge also reported by Luo et al. (2023). These realities highlight a tension between the potential of AI and the practical constraints associated with its implementation in low-resource environments. Therefore, AI tools for rural schools need to be carefully structured, purposefully limited, and designed to function effectively under low-bandwidth conditions. This underscores the relevance of developing EDP.AI as a structured and context-sensitive approach to supporting STEM learning in rural settings.

2.4 Cognitive Load Theory: A Framework for Understanding Student Challenges

Cognitive Load Theory (CLT) provides a clear framework for understanding why students may experience difficulties with multi-step and iterative tasks such as the Engineering Design Process (EDP). EDP activities place considerable cognitive demands on learners because students must understand the problem, think creatively, plan their design, test solutions, and evaluate their results. For novice learners, especially those in rural areas with limited prior exposure, these demands may exceed working memory capacity (Kotovsky et al., 1985; Sweller, 1988). When instructions are unclear or when tasks require students to manage too many elements simultaneously, extraneous cognitive load increases, making it more difficult for students to reason effectively (Paas et al., 2010; Sweller, 2011).

The differences across previous studies can also be interpreted through a CLT lens. Positive outcomes reported in structured STEM studies (Rahman et al., 2025; Suherman et al., 2025) may be associated with learning conditions that provide greater structure and reduce unnecessary cognitive demands. In contrast, the challenges reported in rural settings (Yaakob et al., 2023) may be understood in relation to learning conditions that place greater demands on students' working

memory. Similarly, open-ended AI systems may introduce additional cognitive burden due to the volume of unfiltered information (Mogavi et al., 2024). Collectively, these findings suggest that effective learning may benefit from structured, step-by-step scaffolding that reduces extraneous cognitive load. In response to this need for clear guidance, EDP.AI is designed to provide step-by-step support as students progress through each stage of the EDP.

2.5 Synthesis: Identifying the Gaps

i. STEM activities are most effective when appropriate structure and support are provided.
ii. EDP offers substantial learning benefits but remains challenging to implement consistently in classroom settings.
iii. AI offers educational potential, but many AI tools provide limited pedagogical structure and may not adequately address the needs of rural learning contexts.
iv. Cognitive load presents particular challenges for novice learners and those with limited prior exposure to complex learning tasks.
v. There remains a need for an approach that integrates EDP, AI-assisted scaffolding, and CLT while addressing the low-bandwidth and resource constraints of rural learning contexts.

These unresolved tensions provide a rationale for the development of EDP.AI as an integrated approach that provides structured, stage-aligned AI scaffolding to support students' participation in the EDP while managing cognitive load within the constraints of rural educational contexts.

3.0 Method

This study adopted a Design and Development Research (DDR) approach (Richey & Klein, 2014), focusing on Phase 1A: Needs Analysis. Document analysis was conducted to examine challenges related to STEM-EDP implementation in rural schools. Documents, including journal articles and reports on the use of EDP and AI in STEM education, were reviewed. Relevant literature and theoretical perspectives related to the Engineering Design Process (EDP), AI-assisted learning, and Cognitive Load Theory (CLT) were also synthesised. All documents were imported into Mendeley Desktop, and thematic analysis was conducted to identify relevant themes across the reviewed materials. Subsequently, design rationale mapping was used to translate insights derived from the document analysis into design decisions. This process informed the formulation of preliminary design requirements, design principles, and a conceptual model for EDP.AI. Figure 1 illustrates the methodological flow of the study. It integrates two complementary components of Phase 1A: (i) document analysis and (ii) design rationale mapping.

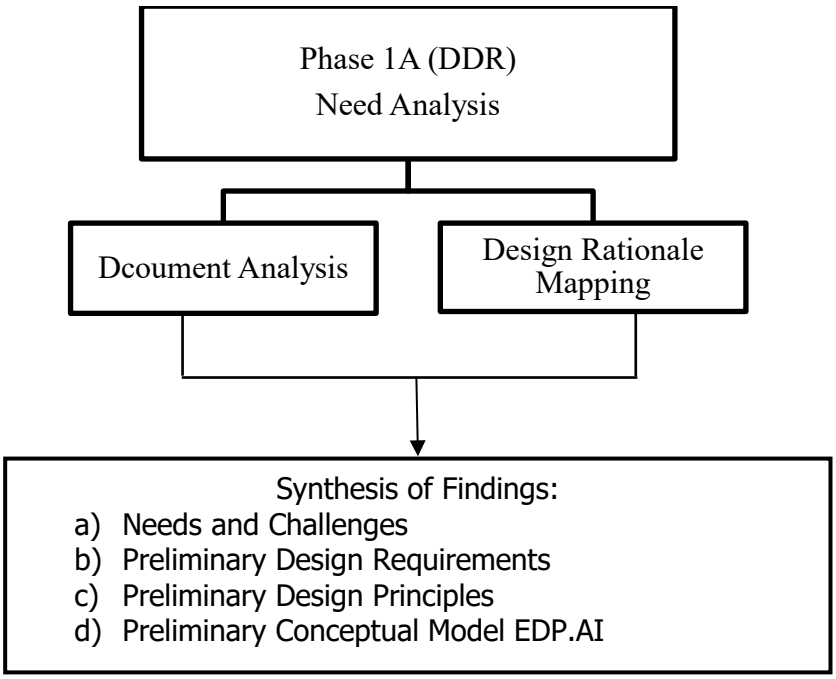


Figure 1. Methodological Flow for phase 1A (DDR)

3.1 Dcoument Analysis

For the document analysis, key theoretical foundations relevant to the development of EDP.AI were integrated. The analysis examined influential and contemporary literature on: (a) the Engineering Design Process (EDP), (b) STEM and project-based learning, (c) AI-assisted learning and generative AI scaffolding, (d) Cognitive Load Theory (CLT), and (e) low-resource or rural learning environments. Sources were selected based on their relevance, citation impact, and alignment with the intended outcomes of the module.

3.2 Design Rationale Mapping

A design rationale mapping approach (McKenney & Reeves, 2025) was used to ensure that design decisions were grounded in evidence rather than assumptions. The process began with problem analysis, through which key challenges related to rural learning conditions, cognitive load, and limitations in STEM-EDP implementation were identified. This step helped clarify the specific learning and teaching issues that needed to be addressed.

Next, evidence mapping was conducted by linking each identified problem to relevant theoretical constructs and findings from the literature. This ensured that the design decisions were informed by established theoretical perspectives, including the Engineering Design Process (EDP), AI-assisted learning (AIEd), and Cognitive Load Theory (CLT).

Finally, design translation was conducted to translate the mapped evidence into actionable design decisions. This involved formulating preliminary Design Requirements (DRs) and Design Principles (DPs) to guide the development of the EDP.AI module. Through this structured process, the proposed design was grounded

in theory, made transparent through explicit links between evidence and design decisions, and aligned with the learning context. The outcomes of this phase provide the design foundation for Phase 1B, which will focus on expert validation and early prototype development.

3.3 Ethical Considerations and Limitations

Phase 1A used only secondary data from published literature and official reports. No human participants were involved; therefore, formal ethical approval was not required. Issues related to responsible AI use, data privacy, and equitable digital access will be considered in subsequent phases of the study.

As Phase 1A focused on needs analysis and conceptualisation, it did not involve empirical testing or user feedback. Consequently, the findings are based on theoretical synthesis and contextual analysis. This study contributes to the emerging research on AI-assisted EDP implementation in low-bandwidth and rural contexts. These aspects will be further examined in Phase 1B through expert review and early prototype refinement.

4.0 Finding

Phase 1A generated four main findings through a synthesis of the literature and contextual documents: (a) the identification of needs and challenges related to design-based learning in rural settings; (b) the formulation of preliminary Design Requirements (DRs); (c) the formulation of preliminary Design Principles (DPs); and (d) the development of a preliminary conceptual model for EDP.AI. These findings provide the foundation for the structure and direction of the EDP.AI module.

4.1 Needs and Challenges Identified from Literature

Through document analysis, four interrelated areas of challenge influencing the implementation of EDP in rural schools in Sabah were identified: (a) student-related challenges, (b) teacher-related challenges, (c) cognitive load demands, and (d) digital and contextual limitations, as shown in Table 1.

Table 1. Needs and Challenges Identified from Literature

Areas	Needs and Challenges
Student-related Challenges	Students show low interest and negative attitude toward science; hard to understand abstract topics (Yaakob et al., 2023) Students struggle to apply experiment results to real-life situations (Yaakob et al., 2023) Students have low creative confidence, especially girls in STEM tasks (Vieira et al., 2025) Limited hands-on exposure; practical activities only happen rarely (Han et al., 2022) Students' HOTS (*KBAT*) are often weak without strong guidance (Ahmad et al., 2021)
Teacher-related Challenges	Teachers have low confidence and skills in STEM–EDP teaching (Idris et al., 2023)

	Teachers lack training in design thinking and EDP pedagogy (Nordlöf et al., 2024)
	Heavy workload, limited preparation time for EDP projects (Yüksel, 2025)
	Teachers struggle to support creativity, prototyping, and design cycles (Sneider & Ravel, 2021)
Cognitive Load Demands	Complex EDP tasks increase cognitive load for students with low prior knowledge (Paas et al., 2010)
	Lack of scaffolding causes confusion during design stages (Nordlöf et al., 2024)
	Open-ended problem-solving increases mental demand, especially for rural learners (Paas et al., 2010)
Digital, Contextual Limitations	Limited internet, device access; strong digital divide in rural Sabah (Surianshah, 2021)
	Lack of facilities, tools, and makerspace for prototyping (Han et al., 2022)
	Rural schools face material constraints for long EDP projects (Sharif et al., n.d)
	Teachers rely on low-cost or frugal resources; difficult to balance curriculum needs (Arnab et al., 2025)

Table 2 illustrates how each area of challenge is linked to established theoretical perspectives to guide the formulation of the Design Requirements (DRs) and Design Principles (DPs) for the EDP.AI module.

Table 2. Evidence Mapping

Area	Needs and Challenges	Linked Theory
Student-Related Challenges	Low interest, weak higher-order thinking skills (HOTS), and difficulty understanding abstract concepts	Extraneous Load Reduction: Step-by-step scaffolding (Student) autonomy development.
	Limited hands-on learning experience	Cognitive Load Theory (CLT): Simple and guided tasks support students' understanding of concepts.
Teacher-Related Challenge	Low confidence in implementing EDP and limited training	EDP Structure: Clearly defined stages provide a structured framework for teachers to guide students through the design process.
	Heavy workload	AI-Assisted Scaffolding: CLT-informed AI scaffolding can provide structured support and reduce demands on teacher guidance.
Cognitive Load	Cognitive overload during multi-step tasks	Cognitive Load Theory (CLT): Managing intrinsic and extraneous cognitive load requires structured, step-by-step scaffolding.
Digital and Contextual Limitations	Poor internet connectivity and limited access to digital devices	Cognitive Load Theory (CLT): Complex digital tools may increase extraneous cognitive load, particularly in resource-constrained learning environments.
	Limited tools and resources for prototyping	Cognitive Load Theory (CLT): The use of simple and accessible materials can reduce unnecessary cognitive demands during prototyping activities.

4.2 Preliminary Design Requirements and Design Principles for EDP.AI

Based on the needs and challenges identified through the literature review and evidence mapping, a set of preliminary Design Requirements (DRs) was formulated to guide the development of the EDP.AI module. Table 3 presents ten Design Requirements (DR1–DR10), organised according to four areas: student-related challenges, teacher-related challenges, cognitive load demands, and digital and contextual limitations. These Design Requirements specify the key aspects that the EDP.AI module should address to respond effectively to the learning context of rural schools.

Table 3. Preliminary Design Requirements for EDP.AI

Needs and Challenges Identified	Code	Preliminary Design Requirements	Rationale
Student-Related Challenges	DR1	Step-by-Step Scaffolding for Students	Reduces extraneous cognitive load and provides structured guidance.
	DR2	Guided Hands-On Tasks	Supports students' understanding of abstract concepts through structured practical activities.
	DR3	Support for Student Autonomy	Encourages active engagement while providing appropriate levels of guidance.
Teacher-Related Challenges	DR4	Support for Teacher Workload Management	Reduces demands on direct teacher guidance during learning activities.
	DR5	Clear EDP Guidance for Teachers	Supports consistent implementation and scaffolding across EDP stages.
Cognitive Load Demands	DR6	Chunked Information Delivery	Manages cognitive demands by presenting information in manageable segments.
	DR7	CLT-Informed Simple Interface	Minimises unnecessary cognitive demands during interaction with the module.
	DR8	Student-Driven Reasoning	Supports students in developing and articulating their reasoning through structured guidance.
Digital and Contextual Limitations	DR9	Low-Bandwidth Accessibility	Supports access and use under limited internet connectivity.
	DR10	Low-Resource Adaptation	Enables implementation in resource-constrained learning environments.

To operationalise the Design Requirements, a set of preliminary Design Principles (DPs) was developed. As shown in Table 4, these principles translate key insights from the literature into clear guidance for the design and implementation of the EDP.AI module. Collectively, the Design Principles address the instructional, cognitive, and contextual considerations that guide the module's development. They ensure alignment with Cognitive Load Theory (CLT), EDP pedagogy, and the constraints of rural learning environments.

Table 4. Preliminary Design Principles for EDP.AI

DPs	Preliminary Design Principles
DP1	AI prompts must minimise extraneous load: Prompts must be short, simple and structured.
DP2	Student scaffolds must follow EDP stages.
DP3	Scaffolding must fade gradually to build student autonomy.
DP4	Standardised scaffolds must support teachers consistently.
DP5	Teacher scaffolds must follow EDP stages.
DP6	Information must be broken into small, manageable units.
DP7	Interface must follow CLT visual design principles. (Clean layout, low distraction, no excessive graphics)
DP8	AI must stimulate reasoning, not provide answers. (Prompts must encourage analysis, comparing, reflecting & justifying ideas without giving ready-made solutions)
DP9	Scaffolds must streamline EDP to fit curriculum time limits. (30-60 mins)
DP10	Prompts must support iteration using low-cost materials.

5.0 Discussion

The findings from Phase 1A indicate that students and teachers in rural schools face several interconnected challenges when engaging in design-based STEM activities. Students are often actively engaged in hands-on tasks; however, these activities do not necessarily reflect the full stages of the Engineering Design Process (EDP), particularly reasoning, comparing ideas, and refining designs. This does not suggest that students fail to follow the EDP, but rather that the process is rarely made explicit or systematically scaffolded in classroom practice. As a result, students may focus primarily on completing a final product rather than engaging in iterative design thinking.

These findings are consistent with previous studies indicating that students require clear and consistent scaffolding to engage meaningfully in multi-step and iterative processes such as the EDP. Cognitive Load Theory (CLT) provides a useful framework for understanding these challenges. EDP-related tasks require learners to manage multiple cognitive demands simultaneously, including understanding the problem, generating ideas, evaluating options, and reflecting on outcomes. For students with limited prior knowledge, these demands may exceed working memory capacity. The challenge may be further intensified when instructions are unclear or when AI tools provide excessive or unstructured information, thereby increasing extraneous cognitive load.

The preliminary Design Requirements (DRs) and Design Principles (DPs) developed in this study respond to these challenges by positioning the EDP as a guided learning process rather than an assumed skill. Through simple prompts, step-by-step scaffolding, and structured support aligned with the stages of the EDP, the proposed EDP.AI module aims to make the design process more explicit, manageable, and cognitively accessible to students. In this way, EDP.AI is intended to support students in engaging with the full design cycle, including in contexts where the EDP has not been formally introduced.

Teacher-related challenges also play an important role in shaping EDP

implementation. Teachers in rural schools may face heavy workloads and limited training in EDP pedagogy, making it challenging to provide individualised guidance throughout the design cycle. EDP.AI is therefore designed to support teachers by providing stage-specific scaffolding that promotes greater consistency in learning activities when instructional time is limited. This approach is consistent with previous findings highlighting the need for practical tools that support teachers in managing project-based and design-based learning more effectively.

Digital and contextual limitations further shape the learning environment. Rural schools may experience unstable internet connectivity, limited access to digital devices, and restricted availability of materials for prototyping. These conditions may limit the suitability of AI tools that depend heavily on continuous connectivity or extensive digital resources. In response, low-bandwidth accessibility and low-resource adaptation were incorporated into the preliminary DRs and DPs. These considerations are intended to enhance the practicality, accessibility, and usability of EDP.AI within rural learning environments.

Overall, the findings indicate that challenges related to student reasoning, teacher workload, cognitive load, and digital and contextual limitations are interconnected. The preliminary conceptual model of EDP.AI addresses these challenges through structured, cognitively manageable, and context-sensitive scaffolding. Phase 1B will focus on expert review to refine the DRs, DPs, and conceptual model before proceeding to prototype development.

6.0 Recommendations for Phase 1B

Phase 1B should:

a. Conduct an expert review to validate the conceptual model and design principles.
b. Develop initial prototype, including basic structure and user flow.
c. Plan iterative improvements based on expert feedback.

7.0 Conclusion

Phase 1A of this study provided the foundation for the development of EDP.AI, an AI-assisted module designed to support the Engineering Design Process (EDP) in rural schools in Sabah. Through document analysis and design rationale mapping, this phase identified key challenges related to student understanding of the EDP, inconsistent scaffolding, cognitive load demands, teacher workload, and digital and contextual limitations. These findings indicate that existing learning conditions may not consistently support structured design-based learning, particularly in rural contexts.

Based on these findings, a preliminary conceptual model, Design Requirements (DRs), and Design Principles (DPs) were developed to guide the development of EDP.AI. These outputs emphasise the importance of simple, stage-specific scaffolding that supports student reasoning while managing cognitive demands. Overall, this study establishes a clear rationale for the development of EDP.AI and provides a theoretical and contextual foundation for the next phase of the study. Phase 1B will involve expert validation of the conceptual model, DRs, and DPs, followed by prototype development and iterative refinement. In the longer term, EDP.AI has the potential to

support meaningful STEM learning, strengthen instructional support for teachers, and expand opportunities for students in rural Sabah to engage in structured design and innovation activities.

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9.0 Conflict of Interest Statement:

The author(s) declare that there is no conflict of interest regarding the publication of this article.

10.0 Research and Publication Ethics Statement:

This article is conceptual in nature and does not involve human participants or the collection of primary data. Therefore, ethical approval and informed consent were not required. The authors confirm that the manuscript is original and complies with established principles of academic integrity and publication ethics.

11.0 Author Contributions:

All authors contributed to the conceptualisation, literature review, critical analysis and synthesis of existing literature, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript and take full responsibility for its content.

12.0 Data Availability Statement:

Data availability is not applicable to this article as no new empirical data were generated or analysed.

13.0 AI Disclosure Statement:

The authors used ChatGPT to assist with language refinement and structuring the manuscript. Consensus was used to support literature searches and assess the relevance and credibility of scholarly sources and citations. All AI-assisted content was reviewed and verified by the authors, who take full responsibility for the final content of the manuscript.

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15.0 References

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