Design and Development of Numflex Application for Number System Learning: A DDR Approach with Fuzzy Delphi Method

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ABSTRACT

This study presents the design and development of the NumFlex App, an interactive educational tool aimed at improving students' understanding of number system conversions (binary, octal, decimal, hexadecimal) in secondary schools. The objective was to obtain expert agreement and views on the app's content, interaction, and interface design. Using the Fuzzy Delphi Method (FDM) and a 7-point Likert scale, responses were collected from seven experts in various fields of education. The data were analyzed using triangular fuzzy numbers, and the ranking of each variable was determined through the defuzzification process. The study followed a Design and Development Research (DDR) methodology, starting with a Nominal Group Technique (NGT) to identify learning challenges. The findings demonstrated 100% expert consensus, with key elements such as content clarity (defuzzification value 0.95714) and interface design (defuzzification value 0.97143) ranked highest. The results confirm that NumFlex successfully integrates clear, pedagogically sound content with intuitive interactive features, making it an effective learning tool. Future research should focus on expanding the app to additional platforms and exploring its integration into the Malaysian national curriculum through collaboration with the Ministry of Education Malaysia (KPM) to broaden its educational impact.

Keywords: NumFlex App, Fuzzy Delphi Method, Number System Conversions, Educational Technology, Expert Consensus

INTRODUCTION

In today's digital age, digital literacy and computational thinking have become essential competencies for students, particularly within the realm of computer science education. One of the foundational concepts in computer science is the understanding of number systems, such as binary, decimal, octal, and hexadecimal, which serve as the building blocks for many higher-level concepts in programming and computing. However, research has consistently shown that students, particularly at the secondary school level, face significant challenges in grasping these abstract and often complex ideas [1].

In Malaysia, the introduction of Asas Sains Komputer (ASK) under the Kurikulum Standard Sekolah Menengah (KSSM) aims to equip students with basic computer science knowledge, including number system conversion [1]. Despite the curriculum's efforts, many students still struggle to understand the concepts of binary, octal, decimal, and hexadecimal conversions due to the abstract nature of the subject and the traditional teaching methods employed [1].

The understanding of number systems, particularly binary, octal, decimal, and hexadecimal, remains a significant challenge for many students despite curricular efforts aimed at enhancing numeracy skills. This struggle can be attributed to the abstract nature of these concepts and the traditional pedagogical methods employed in teaching them. Research indicates that students often find it difficult to grasp the fundamental principles underlying these number systems, which are essential for various applications in mathematics and computer science [2][3].

One of the primary reasons for students' difficulties is the lack of effective instructional strategies that cater to diverse learning styles. Traditional teaching methods often rely heavily on rote memorization and procedural tasks, which do not foster deep understanding or conceptual connections among different number systems. For instance, a study highlighted that students frequently struggle with switching between symbolic representations of rational numbers, which parallels the challenges faced in converting between binary, octal, and hexadecimal systems [4]. Furthermore, the abstract nature of these conversions can lead to increased anxiety and disengagement among learners, particularly when they do not see the relevance of these concepts to real-world applications [5].

Moreover, the cognitive load associated with learning these conversions can be overwhelming. The complexity of the conversion processes, such as moving from octal to hexadecimal through binary, requires a solid understanding of each system's structure and rules [6]. This complexity is compounded by the fact that many students lack foundational numeracy skills, which are critical for performing conversions accurately [7]. The Numeracy Scale, for example, has been utilized to assess individuals' numeric abilities, revealing that many students struggle with basic conversions and computations, which are prerequisites for mastering more advanced concepts [7].

Additionally, the role of student positioning and self-efficacy in learning these concepts cannot be overlooked. Research has shown that students who actively engage with their learning process and articulate their challenges are more likely to develop a better understanding of complex topics like number system conversions [8]. This suggests that fostering a classroom environment that encourages dialogue, and self-reflection could enhance students' mastery of these abstract concepts.

In conclusion, the persistent difficulties students face in understanding binary, octal, decimal, and hexadecimal conversions can be attributed to traditional teaching methods, the abstract nature of the subject, and a lack of foundational numeracy skills. To address these challenges, educators must adopt more innovative and student-centred teaching strategies that promote engagement, conceptual understanding, and the application of these number systems in practical contexts. This gap highlights the need for more innovative and interactive approaches to learning these core topics.

NumFlex is an educational application designed to address this learning gap by providing students with an interactive platform to practice and master number system conversions. The application employs various gamification strategies and real-time feedback to engage students and enhance their learning experience. By offering a hands-on approach, NumFlex aims to reduce the cognitive load associated with traditional teaching methods, allowing students to visualize and interact with number conversions in a more intuitive manner [1].

In line with Design and Development Research (DDR) methodology, the development of NumFlex began with a comprehensive need analysis, which identified key challenges faced by students in understanding number systems [1]. This was followed by the design and development phases, which are the focus of this article. The DDR framework is a widely recognized approach in educational technology research, providing a structured pathway to the systematic design, development, and evaluation of educational interventions [9].

To ensure that the design of NumFlex is aligned with both pedagogical goals and practical usability, the Fuzzy Delphi method was employed to gather input and consensus from experts in the field of computer science education [10]. This method allows for a more robust and systematic collection of expert opinions, reducing uncertainty and increasing the reliability of the data [11]. The input from these experts played a critical role in shaping the features and functionalities of the application, ensuring that it not only meets the needs of students but also aligns with the educational goals outlined in Malaysia’s secondary school curriculum [1].

Research Aims and Objectives

The aim of this research is to design, develop, and evaluate the NumFlex application to enhance students' understanding of number system conversions (binary, octal, decimal, and hexadecimal) within the Basic Computer Science curriculum. Utilizing the Design and Development Research (DDR) framework, along with the Fuzzy Delphi method, the study seeks to ensure the application's pedagogical effectiveness, usability, and alignment with curriculum standards.

To achieve this aim, the research focuses on the following objectives:

i. To design an interactive application that assists Basic Computer Science students in comprehending number system conversions, including binary, octal, decimal, and hexadecimal, through engaging and effective learning tools.

ii. To develop the application following the ADDIE Model (Analysis, Design, Development, Implementation, and Evaluation) to ensure a structured and systematic learning experience that enhances students' understanding of number system conversions.

iii. To evaluate the effectiveness of the application in terms of content design, user interaction, and interface usability, with a focus on improving students' comprehension through educational technology.

METHODOLOGY

The NumFlex educational application was developed using the ADDIE model [12], a well-established framework for systematic instructional design. The five phases of the ADDIE model—Analysis, Design, Development, Implementation, and Evaluation—provided a structured approach that facilitated the organized development of the NumFlex app, ensuring that each phase of the process was well-planned and systematically executed. Learning and accomplishment analysis, application design, development, implementation, and assessment are all part of the design model, which is a systematic process in the creation of technological resources [13]. The five primary steps that developers follow while creating mobile apps are derived from the ADDIE Model.

The learning application was developed using the ADDIE approach, which stresses repetition for each step in its design. All these steps are dependent on one another. The ADDIE model served as a foundation for subsequent models and was the first of its kind. Several subsequent design models might trace their roots back to the original ADDIE paradigm. See references [13], [14], [15], [16], [17], [18], and [19]. Analysis, Design, Development, Implementation, and Evaluation is the acronym for the ADDIE process.

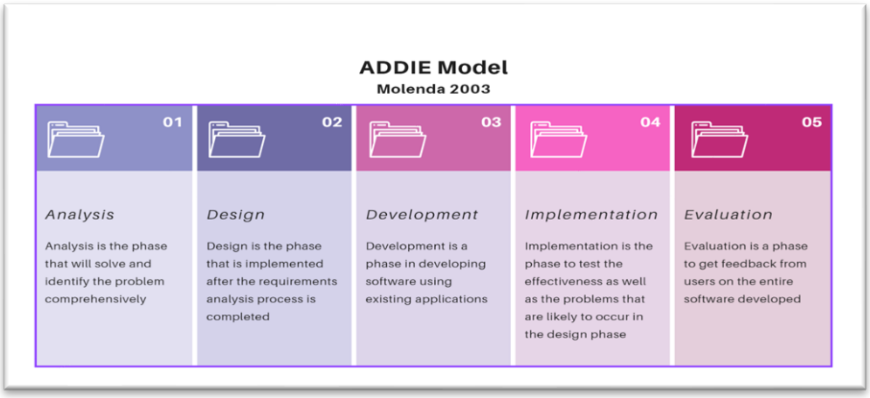

Figure 1: ADDIE Model

In addition, this study followed the Multi Research Method strategy introduced by [20], integrating Design and Development Research (DDR) and expert input to further refine the development process. The combination of DDR and expert feedback allowed for the creation of adaptable prototypes, models, and frameworks suitable for educational technology. Despite the time constraints, modifications were made to the methodology to ensure the effective development of the NumFlex app.

The research was conducted in two key stages:

Stage One: Need Analysis using the Nominal Group Technique (NGT)

The need analysis for the NumFlex application was conducted using the Nominal Group Technique (NGT) to identify the core challenges that students face when learning number system conversions (binary, octal, decimal, hexadecimal). NGT is a structured method for gathering expert opinions and achieving consensus. In this stage, experts engaged in brainstorming sessions and discussions, which provided a comprehensive understanding of the difficulties students encounter, such as conceptual complexity and application of the number system in exercises. This process led to the identification of the essential elements needed for the application, laying a strong foundation for the NumFlex framework.

Stage Two: Expert Consensus through the Fuzzy Delphi Method (FDM)

Following the identification of key components in Stage One, the second stage involved refining the framework by gathering additional expert input through the Fuzzy Delphi Method (FDM). The objective was to reach a consensus on the specific design elements and functionalities of the application, with a focus on three key areas: content design, interaction design, and interface design.

1. Content Design: Experts assessed the educational content to ensure it aligned with the learning objectives for teaching number system conversions, including binary, octal, decimal, and hexadecimal systems. The content was designed to be interactive, engaging, and structured in a way that fosters deeper understanding of these complex concepts. the development of educational curricula often follows a structured approach that includes performing needs assessments, determining content priorities, and writing clear goals and objectives. Greenwald et al. outline a six-step process for curriculum development that underscores the importance of aligning educational content with specific learning objectives [21]. This structured approach is essential for ensuring that the educational materials used in teaching number system conversions are not only relevant but also effectively address the learning needs of students. In addition, the validation of educational content through expert assessment is crucial for maintaining the quality and relevance of educational materials. Wilson et al. emphasize the role of content expert feedback in the development of assessment tools, which can provide valuable insights into the adequacy and effectiveness of educational content [22].

2. Interaction Design: The FDM process also focused on how users would interact with the NumFlex app. The consensus highlighted the importance of intuitive user flow, real-time feedback, and sufficient scaffolding to guide students through the learning process. This ensured that the interaction design supported an engaging and meaningful learning experience. Real-time feedback plays a pivotal role in the learning process by providing immediate responses to learners' actions. Johnson et al. illustrate this concept in the context of learning musical instruments, where real-time feedback is essential for maintaining motivation and improving performance [23]. The authors emphasize that timely feedback can significantly enhance the learning experience by allowing students to adjust and corrections as they practice. Additionally, Faisal emphasizes the importance of effective user interface design in educational applications, noting that real-time feedback mechanisms can greatly enhance user satisfaction and learning outcomes [24]. This is supported by Zhao, who discusses how intuitive interfaces that provide real-time feedback can improve user understanding and engagement in complex systems [25].

3. Interface Design: Experts evaluated the user interface (UI) to ensure it was accessible, user-friendly, and appropriate for secondary school students. The consensus emphasized the need for a clean, minimalistic design that avoids cognitive overload while facilitating ease of use and navigation, thus promoting a smoother learning experience. Accessibility in user interface design is paramount, particularly for secondary school students who may have varying levels of digital literacy. Gajos et al. discuss the potential of automatically generating personalized user interfaces that cater to novice users, allowing them to navigate complex systems more easily [26]. This approach enhances user satisfaction and ensures that the interface remains accessible to all users, regardless of their prior experience. Similarly, Peißner and Edlin-White emphasize the role of user control in adaptive user interfaces, suggesting that providing users with the ability to customize their experience can significantly improve accessibility and user satisfaction [27].

The expert feedback gathered through the Fuzzy Delphi Method was analyzed using Fudelo 1.0 (Fuzzy Delphi Logic) software. The results of the analysis, based on consensus across content, interaction, and interface design, directly informed the final structure and features of the NumFlex application. This iterative expert-driven process ensured that the final product was not only pedagogically sound but also user-friendly, with robust interactive

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learning tools to enhance students' mastery of number system conversions.

A. Sampling

In this research, purposive sampling is used. As the researcher aims to get a consensus viewpoint and agreement on a certain issue, this approach is quite suitable. According to [28], the best approach to FDM is purposeful sampling. All, seven experts were involved in this probe at the same time. The specialists are hand-picked for their deep expertise and years of relevant work experience. The required number of specialists is 5-10 if the experts involved in this study are uniform. Assuming a high degree of homogeneity among them, [29] state that ten to fifteen experts are the optimal number for the Delphi approach. According to [30], a sufficiently large and homogenous sample of 8 to 12 people is suitable for FDM. In a similar vein, [31] suggests a range of 7 to 12 experts for expert perspectives. Despite this, the researcher enlisted the help of seven experts for this inquiry because of the difficulties in collecting expert replies and the time limitations. However, to gain information and reach expert agreement, a total of seven samples are sufficient.

B. Experts Criteria

Expert selection is emphasized as a critical subject that demands careful thought in the Fuzzy Delphi investigation. When experts are chosen using flawed methods and criteria, the reliability and validity of the results might be questioned [32]. For the Delphi or Fuzzy Delphi method to evaluate the reliability, validity, and correctness of the results, the experts chosen and how precisely they were chosen are of utmost importance. Research challenges and survey questions should be in line with the competence and relevance of the experts involved to get relevant, accurate, and high-quality findings using the Delphi method [33], [34], [35].

Table 1: Experts list

Participant	Role	Year of experiences	Expertise Area
Expert 1	Teacher	20	Information Technology and Computer Science
Expert 2	Teacher	16	Information Technology and Computer Science
Expert 3	Teacher	15	Computer Science
Expert 4	Teacher	23	Mathematics
Expert 5	Teacher	25	Information Technology and Computer Science
Expert 6	Teacher	18	Mathematics
Expert 7	Teacher	23	Computer Science

C. Research Instrument

The researcher refined the NumFlex Apps framework using a research instrument built for the Fuzzy Delphi approach, which was based on expert interviews. Researchers may draw from literature, pilot studies, and first-hand experience to develop questionnaire features [36]. Questions for the Fuzzy Delphi approach is generated at the same time using research highlights, expert interviews, and focus group techniques [32].

In addition, to establish the items and content for the research, it is recommended to undertake a thorough literature review that is relevant to the study's scope [37]. That is why the researcher combed through essential literature to compile the NumFlex Apps' components. After that, a set of questions designed for experts were developed utilizing a 7-point Likert scale. According to [38], there is evidence that more scales lead to increased dependability, which is why a 7-point scale was chosen. To make the questionnaire more user-friendly for experts, the researcher substituted a numerical value ranging from 1 to 7 for the fuzzy value on the 7-point scale (as indicated in Table 2).

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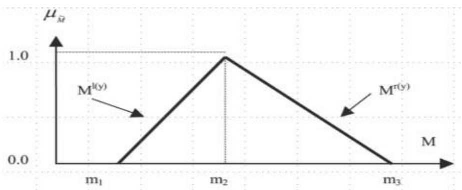
Table 2: Fuzzy number

Item	Fuzzy number
Strongly Disagree	(0.0. 0.0, 0.1)
Disagree	(0.0, 0.1, 0.3)
Somewhat Disagree	(0.0,0.3, 0.5)
Neither agree or disagree	(0.3, 0.5, 0.7)
Somewhat agree	(0.5, 0.7, 0.9)
Agree	(0.7, 0.9, 1.0)
Strongly agree	(0.9, 1.0, 1.0)

D. Steps in implementing Fuzzy Delphi Method

Table 3: Fuzzy Delphi Steps

Step	Formulation
1. Selecting experts	A total of 7 experts participated in this study. An expert panel was convened to evaluate the importance of the assessment criteria in relation to the factors being examined, utilizing linguistic variables. They also provided insights into potential issues with the evaluation, among other considerations.
2. Finding the language's magnitude	This process involves converting all linguistic variables into triangular fuzzy numbers. It also includes adding fuzzy numbers during the conversion of linguistic variables [39]. A Triangular Fuzzy Number is represented by three values, m1, m2, and m3, and is denoted as (m1, m2, m3). The value of m1 corresponds to the lowest possible value, m2 represents the most reasonable or likely value, and m3 signifies the highest possible value. The Triangular Fuzzy Number is used to create a Fuzzy Scale, which facilitates the transformation of linguistic variables into fuzzy numbers.  Figure 1: Triangular fuzzy number
3. The Establishment of Language Variables and Mean Answers	After consulting with the designated expert, researchers are required to transform all numerical data from measurements into Fuzzy scales. According to [40], this is often seen to acknowledge each response.
4. The determination of threshold value "d"	Expert consensus is best measured by the threshold value [41]. When m = (m1, m2, m3) and n = (m1, m2, m3) are fuzzy integers, the formula is used to compute the distances:

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	$$d(\tilde{m},\tilde{n}) = \sqrt{\frac{1}{3}\left[(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2\right]}.$$ Figure 2: Threshold value
5. Determine the absolute degree of fuzzy evaluation using the alpha cut.	A fuzzy number is given to every item if an expert agreement is established [32]. The method for determining and quantifying fuzzy values is as follows: $$A_{max} = ¼\ (m_1 + m_2 + m_3)$$ Figure 3: Aggregate consensus
6. Defuzzification process	The formula Amax = (1)/4 (a1 + a2 + a3) is used in this procedure. According to [42], researchers may utilize average responses or Average Fuzzy Numbers to get score numbers between zero and one. These steps include three formulas: I. A = 1/3 * (m1 + m2 + m3), or II. A = 1/4 * (m1 + 2m2 + m3), or III. A = 1/6 * (m1 + m2 + m3). The median value for '0' and '1' is equal to half of the A-cut value, which is calculated as (0 + 1) / 2. We will reject the item since it does not show expert agreement if the resultant A value is less than the α-cut value = 0.5. The alpha cut value needs to be more than 0.5, as stated by [43]. The statement that the α-cut value needs to be greater than 0.5 is backed by [44].
7. Ranking process	Experts believe that the most significant element is the most important spot for decision-making, hence the placement process involves defining components based on defuzzification values [45].

E. The Development of NumFlex Apps Framework Elements

At this stage, the researcher designed the elements of the NumFlex Apps framework focusing on three key areas: content design, interface design and interaction design. Using a comprehensive literature review approach, relevant elements were gathered and organized systematically. These elements were then arranged for evaluation by experts to ensure their effectiveness in supporting student learning. The identified elements for the study are as follows:

Table 4: NumFlex contruct elements

Construct	Elements / Items
Content Design	1. The content of the topics in this app meets the learning standards 2. The content of the topics in this application is in accordance with the learning topics 3. The information in this application coincides with the content of the learning topic 4. In-app information according to the latest DSKP KSSM 5. The presentation of information in this application is clear and easy to understand
Interaction Design	1. The use of text on each navigation button of the app helps the user to explore to another view. 2. The use of buttons in this app is consistent 3. The button size in this app is appropriate 4. The position of the icons in this app is consistent

	5. Every button in this app works well 6. The function of the navigation buttons used in this application can be easily identified
Interface Design	1. The background colour of the application interface design used is appropriate 2. The type of writing used for each statement of the content of the application is appropriate 3. The use of text in the app is appropriate 4. The use of button colours on the app is appropriate 5. The description of the content on the application is appropriate 6. The use of audio in the app is clear and easy to understand

This structure integrates content, interface, and interaction design in the development of the NumFlex application, ensuring a holistic approach to enhancing student learning.

FINDINGS

Based on expert consensus, the researcher presents the study data in this section, which aims to provide insights into the development of the NumFlex apps. The data was collected through seven rounds of Fuzzy Delphi surveys, administered to a panel of seven subject-matter experts. The results of the study are as follows:

Table 5: Finding of expert consensus of Content Design, Interaction Design and Interface Design

Construct	Item	Value of the Item	Value of the Construct	Item < 0.2	% of Item < 0.2	Average of % Consensus	Defuzzification	Ranking	Status
Content Design	Item 1	0.05656	0.05656	7	100%	0.78571	0.78571	5	Accept
	Item 2	0.05656	0.05656	7	100%	0.87143	0.87143	4	Accept
	Item 3	0.01414	0.01414	7	100%	0.91429	0.91429	3	Accept
	Item 4	0.06127	0.06127	7	100%	0.88571	0.88571	2	Accept
	Item 5	0.02828	0.04336	7	100%	0.95714	0.95714	1	Accept
Interaction Design	Item 1	0.02828	0.02828	7	100%	0.94286	0.94286	2	Accept
	Item 2	0.04242	0.04242	7	100%	0.91429	0.91429	3	Accept
	Item 3	0.03064	0.03064	7	100%	0.88571	0.88571	4	Accept
	Item 4	0.05184	0.05184	7	100%	0.85714	0.85714	5	Accept
	Item 5	0.02828	0.02828	7	100%	0.94286	0.94286	2	Accept
	Item 6	0.02828	0.02828	7	100%	0.94286	0.94286	2	Accept
	Item 7	0.02828	0.034	7	100%	0.95714	0.95714	1	Accept
Interface Design	Item 1	0.02828	0.02828	7	100%	0.94286	0.94286	3	Accept
	Item 2	0.02357	0.02357	7	100%	0.97143	0.97143	1	Accept

	Item 3	0.02828	0.02828	7	100%	0.95714	0.95714	2	Accept
	Item 4	0.02357	0.02357	7	100%	0.92857	0.92857	4	Accept
	Item 5	0.02828	0.02828	7	100%	0.94286	0.94286	3	Accept
	Item 6	0.02671	0.02671	7	100%	0.94286	0.94286	3	Accept

Based on the FDM analysis (refer to Table 5), all items in the constructs of Content Design, Interaction Design, and Interface Design successfully achieved consensus, with the threshold value for each item falling below the 0.2 threshold (Item < 0.2 = 100%). This indicates that there is no significant divergence in expert opinions across any of the evaluated items, which reflects a strong agreement among experts [46], [38].

The average threshold value (d) for all items in the constructs was well below 0.2, with the lowest value being 0.01414 and the highest being 0.06127, indicating strong agreement across the items. The overall percentage of consensus across all items was 100%, which exceeds the required threshold of 75% for expert agreement [44]. These findings demonstrate that the NumFlex App guidelines, encompassing content, interaction, and interface design, have received robust expert validation.

In terms of defuzzification values (the average of fuzzy responses), all items achieved α-cut values > 0.5, with the highest defuzzification value reaching 0.97143 (Item 2 of Interface Design), confirming that all items meet the criteria for expert consensus. According to [43] and [44], an α-cut value greater than 0.5 signifies a strong agreement among experts, while values lower than 0.5 would require revision or exclusion.

Furthermore, the ranking of items across constructs prioritizes areas for development based on expert feedback. For Content Design, Item 5 was ranked the highest with a defuzzification score of 0.95714, highlighting the clarity and relevance of the content. Similarly, in Interaction Design, Item 7 (also with a defuzzification score of 0.95714) was prioritized, demonstrating expert preference for intuitive navigation and consistent interface elements. Interface Design showed strong consensus, with Item 2 ranked highest, emphasizing the importance of appropriate text and design for user engagement.

Overall, the findings support the conclusion that the NumFlex App guidelines have garnered substantial expert agreement across all constructs. These results suggest that the app is well-designed to meet educational needs, with priorities established based on the ranking of items agreed upon by expert consensus.

Table 6: NumFlex Guidelines Based on Expert Consensus

Previous Rank	New Rank	Guideline of NumFlex Based on Expert Consensus	Guidelines Elements
5	5	Ensure content meets learning standards	The content of topics aligns with the curriculum.
4	4	Present information clearly and comprehensively	Information is presented clearly and is easy to understand.
3	3	Ensure content is up-to-date and relevant	Content aligns with the latest DSKP KSSM.
2	2	Use interactive features effectively	Interactive elements, such as buttons, work consistently.
1	1	Prioritize user experience by keeping navigation intuitive	Buttons are appropriately sized, positioned, and functional.
2	2	Maintain consistency in design	Icons and elements follow a consistent design approach.

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3	4	Simplify user interaction	Text and buttons assist navigation effectively.
5	5	Make use of colors and interface elements that enhance learning	Background colors and text are appropriate and appealing.
2	2	Ensure ease of use by maintaining a minimalistic design	Navigation buttons and color schemes are well-defined.
3	1	Use an intuitive interface design that supports learning objectives	Design elements are easy to identify and work smoothly.
1	1	Ensure the interface is accessible and user-friendly	Text and audio are clear and easy to understand.
4	4	Design elements must be aligned with curriculum requirements	Interface design supports ease of use and accessibility.
3	3	Provide a smooth user experience	Interface elements and buttons are appropriately sized.

User Interface and Interactive Features of the NumFlex App

The NumFlex App is designed with a vibrant and minimalistic interface that aligns with the expert feedback regarding clarity and user engagement. As shown in the application screenshots (Figure 4), the app uses bright, distinguishable colours to create an intuitive user experience. The primary menu presents options for various number system conversion exercises and interactive quizzes, each button clearly labelled and color-coded for ease of navigation.

One of the key interactive elements, as emphasized in the expert consensus, is the real-time conversion tool (Figure 7), which allows students to input values in different number systems (binary, decimal, octal, hexadecimal) and receive instant feedback with detailed conversion steps. This approach simplifies complex concepts, making it easier for students to understand the process.

Additionally, the mind challenge game (Figure 8) and quiz section (Figure 9) promote active engagement through time-limited tasks and real-time scoring, elements identified as critical in maintaining student interest. These interactive tools not only reinforce learning but also offer immediate feedback, which is essential for improving comprehension, as highlighted by expert consensus in the interaction and interface design constructs.

The use of consistent navigation buttons, clear typography, and appropriate color schemes, as seen in the interface design (Figure 5), further aligns with best practices for educational technology. The clean layout reduces cognitive overload, allowing students to focus on the learning tasks without unnecessary distractions.

In conclusion, the NumFlex App effectively incorporates expert-recommended guidelines in its design, offering an educational tool that is both visually appealing and pedagogically effective for teaching number system conversions.

Figure 4: NumFlex App Login Screen

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Figure 5: Main Menu of the NumFlex App

Figure 7: Number System Conversion Tool

Figure 8: Mind Challenge Game Interface

Figure 9: Number System Quiz Interface

DISCUSSION

The analysis of the NumFlex App through the Fuzzy Delphi Method (FDM) has provided valuable insights into the expert consensus on the design and functionality of the application, which is developed to support the teaching of number system conversions. The results indicate a high level of expert agreement across three main constructs: Content Design, Interaction Design, and Interface Design, suggesting that the app is robust in meeting the pedagogical and user experience needs of students and educators.

Content Design

The content design construct received a strong consensus, with Item 5 (clarity and relevance of information) ranked highest with a defuzzification value of 0.95714, reflecting its priority among experts. This suggests that the content of the NumFlex App is well-aligned with educational standards such as the DSKP KSSM [49], ensuring that the material is up-to-date and relevant to students' learning needs. Additionally, the average consensus for all content design items was 100%, and the threshold for all items was less than 0.2, meeting the criteria for expert agreement [46]. The inclusion of clear, comprehensible instructional content is a critical factor in improving student engagement and learning outcomes in complex topics like number system conversions.

The prioritization of Item 5 in the content design construct highlights the importance of content clarity, which plays a crucial role in supporting students' understanding of abstract mathematical concepts. This aligns with findings from similar educational tools where content clarity was identified as a significant predictor of student success [50]. Thus, the expert feedback underscores the necessity for NumFlex to maintain a focus on delivering clear, structured, and curriculum-aligned content.

Interaction Design

Interaction design was another area where the NumFlex App achieved high levels of expert agreement. Item 7 (navigation and consistency of interactive elements) was ranked highest in this construct, with a defuzzification value of 0.95714. The consensus for interaction design items was also 100%, with all items maintaining a threshold value under 0.2, indicating that the interactive elements of the app—such as buttons, icons, and navigation—are designed in a way that fosters ease of use and enhances the user experience.

The high ranking of Item 7 emphasizes the importance of intuitive navigation and consistent interactive elements, particularly for younger students or those new to computer-based learning environments. Research has consistently shown that usability is a key factor in the effectiveness of educational technology [51]. By ensuring that buttons, icons, and other interactive components are appropriately sized, positioned, and functional, the NumFlex App can significantly reduce cognitive load and improve students' ability to focus on learning content rather than interface mechanics. The results indicate that the app's interaction design aligns well with best practices for user-centred design in educational software.

Interface Design

The interface design of NumFlex also received substantial expert approval, with Item 2 (appropriate text and interface design) being ranked highest with a defuzzification score of 0.97143. This high level of consensus reflects the expert view that the visual and auditory elements of the app contribute significantly to a positive learning experience. The findings are consistent with the literature, which suggests that a clean, minimalistic design can improve usability and reduce distractions, particularly for educational tools aimed at younger audiences [52].

The overall agreement on interface design reinforces the importance of maintaining a user-friendly and accessible interface. According to the Alpha-Cut Defuzzification analysis, all items exceeded the α-cut value of 0.5, further confirming that the interface is not only acceptable but also optimized for effective learning experiences [47], [43]. The high ranking of text-based elements and appropriate use of colours and buttons indicates that experts prioritize interface features that directly contribute to improving the user's engagement with the educational content.

Guidelines for NumFlex Development

The expert consensus revealed clear guidelines for further development and refinement of the NumFlex App. Based on the expert rankings and defuzzification values, the following key guidelines emerge:

1. Maintain clarity and alignment with curriculum standards: Ensuring that the content is updated regularly and aligns with educational curricula is crucial, as evidenced by the high ranking of related content design items.
2. Prioritize user-friendly interaction: Features like navigation buttons, icons, and interactive elements should be consistent and intuitive to promote seamless use and engagement, especially for younger students.
3. Focus on clean, minimalistic design: A user-friendly interface that reduces cognitive load is vital for enhancing the educational experience. The use of appropriate colors, text, and audio should remain a focus to ensure that students can easily navigate the app without distractions.

Implications for Educational Technology

The findings from this expert consensus provide important implications for the broader field of educational technology. Firstly, the emphasis on content clarity and curriculum alignment reflects a growing recognition of the importance of educational technology tools that are deeply integrated into existing curricula, rather than being used as standalone applications [53]. Secondly, the focus on interaction and interface design highlights the role of usability in enhancing student engagement with digital learning environments. Given the increasing adoption of digital tools in education, particularly in STEM fields, the findings of this study suggest that developers should prioritize user-centred design principles to maximize the effectiveness of educational applications.

CONCLUSION

The NumFlex App presents a well-rounded solution for teaching number system conversions, leveraging expert-driven insights to create a tool that is both pedagogically effective and user-friendly. The expert consensus, derived through the Fuzzy Delphi Method (FDM), demonstrates that the app excels in aligning with modern educational requirements. The app's design adheres to key principles of content clarity, usability, and student engagement, all of which are critical in the context of educational technology.

The strength of NumFlex lies in its ability to integrate core content with interactive features, ensuring that students are not only receiving information but actively engaging with it. This is particularly important in the field of computer science and mathematics, where complex concepts such as number systems often require multiple layers of understanding. The application's interface is tailored to reduce cognitive load while enhancing ease of use, making it an ideal learning tool for secondary school students.

The significance of this study goes beyond the development of a single application; it offers valuable insights into the broader development of educational technology. The expert feedback reveals key considerations for the design of effective learning tools: adherence to curriculum standards, intuitive interaction, and visually accessible interfaces. Adherence to curriculum standards is crucial in the development of educational tools, as it ensures that the content aligns with educational objectives and learning outcomes. Dai et al. emphasize the importance of student-centered learning activities in the Chinese mathematics curriculum, which necessitates that online learning tools facilitate self-regulated learning and align with curriculum goals [54]. This alignment not only enhances the relevance of the learning materials but also promotes student engagement and motivation. Furthermore, Belland et al. argue that effective scaffolding in STEM education must be grounded in curriculum standards to ensure that learning tools are both pedagogically sound and aligned with educational frameworks [55]. This adherence helps educators integrate technology into their teaching practices while maintaining educational integrity. These principles should guide future developments in educational applications, particularly as the adoption of technology in classrooms continues to grow.

Intuitive interaction is essential for creating user-friendly educational tools that facilitate learning. Munshi et al.

discuss the role of adaptive scaffolding in helping students develop self-regulated learning behaviour's, emphasizing that tools must be designed to respond to students' needs in real-time [56]. This adaptability fosters an intuitive interaction that allows students to engage with the material more effectively. Similarly, Doo et al. highlight the importance of scaffolding in online learning environments, noting that tools that provide timely and relevant support can significantly enhance the learning experience [57]. By ensuring that interactions are intuitive, educational tools can reduce cognitive load and allow students to focus on content rather than navigation.

Visually accessible interfaces are critical for ensuring that all students can engage with learning tools effectively. Valencia-Vallejo and Vargas found that metacognitive scaffolding can improve students' self-efficacy and learning outcomes in e-learning environments, underscoring the need for interfaces that are not only functional but also visually appealing and easy to navigate [58]. This is particularly important for secondary school students, who may have varying levels of experience with technology. Lee's research supports this notion by demonstrating that well-designed interfaces in computer-based learning environments can significantly impact students' problem-solving performance [59]. Furthermore, the work of Park emphasizes the importance of visual scaffolding design principles in web-based learning environments, advocating for designs that enhance clarity and usability [60].

NumFlex's success provides a model for how educational tools can be developed through a structured, research-driven process. The use of expert consensus to refine the app's content and design elements ensures that it meets both educational and usability standards, creating a balance between functionality and learning outcomes. As digital learning becomes more prevalent, the lessons learned from this study can be applied to other subject areas and educational contexts, emphasizing the importance of evidence-based design in educational technologies.

Moving forward, the NumFlex App offers potential for expansion. Incorporating adaptive learning mechanisms, real-time feedback, and personalized learning paths could further enhance its utility, catering to the diverse learning needs of students. Additionally, the framework used to develop NumFlex could be adapted for other areas of STEM education, where interactive, user-friendly platforms are increasingly necessary for tackling complex topics.

In conclusion, the NumFlex App stands as a robust educational tool that meets the needs of today's learners. Its development, guided by expert consensus, highlights the value of integrating pedagogical principles with technology, ensuring that the app is both engaging and effective in promoting deeper understanding. As educational tools continue to evolve, the NumFlex App sets a high standard for how technology can support meaningful learning experiences.

FURTHER RESEARCH AND DEVELOPMENT

While the NumFlex App has proven to be a promising tool for teaching number system conversions, the next phase of its development must strategically focus on enhancing accessibility and maximizing educational impact across diverse platforms and learning contexts. Currently, the app's exclusive compatibility with Apple devices limits its use in educational settings where a variety of hardware, such as Android, Windows, and web-based platforms, is prevalent. To overcome this limitation, broadening its compatibility to support these platforms is crucial. This expansion would not only increase the app's reach to a wider spectrum of students and educators but also amplify its potential to serve as an essential digital learning tool on a national scale, particularly for schools with limited access to Apple devices.

Strategic Collaboration with Educational Authorities**:** To address accessibility challenges effectively, collaboration with the Ministry of Education Malaysia (KPM) is proposed. This partnership would enable NumFlex to be adapted and optimized for cross-platform compatibility while ensuring its alignment with national curriculum standards. Through such collaboration, the app can be integrated as a standardized tool for teaching number system conversions across Malaysian secondary schools. Furthermore, this partnership would facilitate its distribution to underserved regions, promoting equitable access to quality digital education and reinforcing NumFlex's role as a pioneering educational technology that directly supports Malaysia's educational objectives.

Integrating Adaptive Learning Technologies: Enhancing the personalization of learning experiences is another key objective for future versions of NumFlex. The integration of adaptive learning technologies is planned to address this need. By employing intelligent algorithms that adjust content difficulty based on each student's performance, the app can create tailored learning pathways. This dynamic approach will cater to various learning paces and styles, providing immediate feedback and targeted support to boost student engagement and comprehension, especially in more complex topics. These adaptive mechanisms will transform NumFlex into an interactive, student-centric learning tool, better supporting the diverse needs of learners.

Conducting Long-Term Empirical Studies**:** To validate NumFlex's effectiveness in real-world educational contexts, long-term empirical studies will be conducted across various schools. These studies will collect comprehensive data on student comprehension, engagement, and performance to measure the app's actual impact. Utilizing a mixed-methods research approach that combines quantitative and qualitative data collection, these studies will provide robust evidence of NumFlex's educational value. The findings from this research will also help identify areas for improvement, ensuring that future iterations of the application are grounded in empirical data and address the specific needs of learners and educators.

Implementation of Pilot Trials**:** Before undertaking large-scale empirical studies, pilot trials will be conducted in selected schools with different educational environments. These trials will serve as an initial phase to gather baseline data on the app's usability, functionality, and effectiveness in diverse learning contexts. The insights gained from these pilot trials will be crucial in fine-tuning the app, allowing for timely adjustments and optimizations before proceeding to full-scale research. This phased approach ensures that the app is rigorously tested, thereby enhancing its potential for broader adoption and success.

Systematic Collection of User Feedback: In addition to structured studies, a plan for the systematic collection of user feedback will be established. Engaging both students and educators in this process is vital, as their feedback will offer real-time insights into the app's strengths and areas needing further development. This continuous feedback loop will guide the integration of future adaptive learning features and ensure that the application remains responsive to users' evolving needs, thereby enhancing its long-term educational impact.

Development of Training Modules for Educators: Recognizing the pivotal role of educators in successfully implementing digital learning tools**,** training modules will be developed to support teachers in using NumFlex effectively. These modules will provide detailed guidance on utilizing the app's adaptive learning features to tailor instruction based on individual student needs. By empowering teachers with the necessary knowledge and skills, the app's educational potential can be maximized, fostering a more engaging and supportive learning environment for students.

Integrating Gamification and Expanding to Other STEM Subjects: Finally, future versions of NumFlex will integrate gamification elements and explore expanding its scope to include additional STEM subjects. Gamified learning modules not only make the learning process more interactive and enjoyable but also reinforce key concepts through practice and competition. Moreover, extending the app's content beyond number system conversions to other critical areas of mathematics and computer science will position NumFlex as a comprehensive educational platform capable of meeting a broad range of educational needs and fostering a deeper interest in STEM learning.

In conclusion, by prioritizing cross-platform expansion, leveraging adaptive learning technologies, conducting empirical research, implementing pilot trials, systematically collecting user feedback, providing educator training, and exploring gamification, NumFlex is poised to become a cornerstone in Malaysia's digital learning landscape. These strategies demonstrate a proactive commitment to addressing current limitations while embracing innovation to meet the dynamic needs of students and educators. By adopting this holistic and research-driven approach, NumFlex is set to evolve into a sustainable and impactful educational tool, solidifying its place at the forefront of educational technology.

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