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Fuzzy Delphi method for project approach module in early science for children

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ABSTRACT

This study focuses on designing a project-based learning module for early science education for home-based learning. The module comprises four dimensions: plants, planets, magnets and robotics, and weather. Using a quantitative approach and the design and development research (DDR) method, 15 early childhood education (ECE) experts were surveyed through a questionnaire with 20 items on a seven-point Likert scale. The fuzzy Delphi method (FDM) with triangular fuzzy numbers (TFN) was employed for data analysis, revealing a high level of expert consensus on the essential components of the module. The study achieved over 75% agreement, exceeding the threshold value (d) of 0.2 and α-cut of 0.5. Each dimension received favorable acceptance scores: plants (0.874), magnets and robotics (0.890), planets (0.918), and weather (0.903). The study emphasizes the acceptability of expert opinions on these dimensions, providing a valuable resource for early science education at home. The findings support addressing gaps in contributing to achieving sustainable development goal 4.2 by ensuring access to quality education for children.

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1. INTRODUCTION

This study focusses the fuzzy Delphi method (FDM) on designing a project-based learning module for early science education for home-based learning. While earlier studies have explored the need analysis of a project-based learning module for early science education for home-based learning. In the context of early childhood education (ECE), young children are innately curious about the world around them.

ECE is an important aspect in shaping a better and more balanced pattern of future learning [1]. This disposition should be taken as an opportunity by educators to arouse a lifelong interest, passion, and motivation in understanding the world around them from a young age. Teaching and learning of science in the early childhood years if delivered effectively, is expected to nurture new generations who are capable of devising solutions for a range of socio-scientific issues affecting the world [2].

In Malaysia, the main purpose of the establishment of a nursery was to provide a conducive space and environment for supporting children's growth from to zero to four years old by providing developmentally appropriate learning experiences [3]. In the context of curriculum and teaching reform, project-based learning is a new approach to teaching and learning that takes real-world issues as its starting point, breaks down disciplinary boundaries, integrates many disciplines into a single project, and helps students develop future-focused skills like critical thinking, problem-raising, creative thinking, and teamwork [4]. According to Meng *et al.* [5], in addition to supplying learning materials, teachers were frequently in charge of monitoring their students' development in both individual and group cooperation, monitoring their performance in class, giving prompt feedback, and facilitating enough interactions between students, teachers, and subject. The goal of nurturing learning through interest is ultimately trying to move away from the teacher centered spoon-feeding approach [6].

The current change in education enquires teachers to shift their traditional teaching to emergency remote teaching in which technology becomes fully utilised [7]. A matrix mapping by compiling journal articles that were gathered between December 2022 and January 2023 and included in this work [8]. The Turkish and English journal papers were scanned using various keyword combinations. "Science education," "project-based learning," "science teachers," "students," and "implementation" are these keywords.

The journal articles were numbered, and the study objectives were entered into the synthesis matrix beneath the primary concepts. Put another way, the key concepts of "project-based learning's effects on students," "project-based learning's effects on teachers," and "project-based learning's implementations with opportunities, and challenges" were developed in accordance with the study outcomes. Given the established effectiveness of project-based learning as evidenced by experts' studies, it can be implemented in early science education, starting as early as 3 to 6 years old. As such, researchers have produced one learning-based project module for early childhood science or known as ProHomeScience module, designed and developed by experts. This module has four dimensions, namely components of the i) world of life: plants; ii) material world: magnets and robotics; iii) universe: planets; and iv) physical world: weather. This module emphasizes hands-on activities for children because it can enhance their capabilities and address the insufficient physical activity provided for their skill development. Through this approach, it is particularly significant for children as it centers on the child, fosters critical thinking, encourages exploration and inquiry, supports holistic development, and cultivates a sense of responsibility toward their environment and community [9]. Moreover, this is important for teachers, students, and stakeholders in making informed educational decisions to improve classroom learning scenarios. The overarching goal of curriculum negotiation is in line with prevailing ideas on student voice, as both strive for student empowerment [10].

The project approach fulfils the characteristics of children who enjoy exploring and investigating their rich environment, offering opportunities to apply basic skills through meaningful project activities [11]. Learning is achieved through self-activity, initiative, experience, cooperation, creativity, and free expression. [12]. Spending quality time with children by being fully present in their preferred activities can enhance their learning experiences [13]. The activities in this module support such interactions by utilizing low-cost materials, making them accessible for all families. This is especially important in contexts where parents from lower socioeconomic backgrounds, ethnic minorities, and children with disabilities in rural areas often face challenges in affording educational expenses.

To conduct project approach learning, facilitator have to plan the process of teaching and learning carefully and precisely before implementation. The lack of parental involvement in their children's learning process at home is a critical issue in the implementation of home-based learning. Many parents are not fully aware of the importance of their role in supporting their children's learning process, especially in the context of home-based learning [14].

2. METHOD

According to Richey and Klein [15], the design and development research (DDR) unfolds in three distinct phases. The initial phase is dedicated to needs analysis, followed by design and development in the second phase, and concluding with the evaluation phase. This article delves into the discussion of phase two: design and development.

The FDM approach applied in this study has followed the guidelines introduced by Murray *et al*. [16], and reviewed by Guttorp *et al*. [17], FDM is a combination of a fuzzy set theory, which is applied in traditional Delphi techniques. This technique is an improved and rebranded measurement based on the conventional Delphi method [18]. Therefore, using consensus building methods, such as the Delphi technique, may serve as a way to understand teachers' viewpoints and priorities on a larger scale [19].

This research uses purposive sampling via 15 experts (i.e., lecturers) in ECE in five universities. Data collection is regularly question investigated, which contains 20 items, using a seven-point Likert scale. In the data analysis phase, FDM numbering with triangular fuzzy number (TFN) is employed. The ranking of each enabler change is determined through a defuzzification process. The steps taken for data collection and analysis are outlined as follows:

2.1. Choosing experts

This research involving 15 experts. This is mentioned by Adler and Ziglio [20], that a suitable number of experts involved in a study are between 10 and 15 people to obtain high uniformity among experts. Jamil and Noh [21] also stated that 15 experts are sufficient to ensure that this Delphi study is able to measure something that needs to be measured.

This study uses purposive sampling based on experts in the field of early science and ECE. According to Creswell and Creswell [22], individuals with a service tenure ranging from five to ten years are deemed as experts. The Delphi method emphasizes the critical importance of selecting experts, as this step profoundly influences the quality of research findings, with selection criteria requiring a background or experience in a relevant field of study [23]. Table 1 shows the demographic information of experts with expertise in science education and ECE. The respondent holds a PhD. Five are from science education, and ten are from ECE.

Table 1. Demographic information expert

Expertise	Level of education				Gender	
	Diploma	Bachelor	Master	PhD	Male	Female
Science education	-	-	-	5	3	2
ECE	-	-	-	10	2	8
Total	-	-	-	15	15	

2.2. Questionnaire

In this procedure, the questionnaire is crafted through a combination of interview methods and a comprehensive literature review. According to Powell [24], the Delphi method stands out as a highly adaptable approach to secure expert consensus. The initial round of the Delphi process involves identifying an issue through expert interviews. Additionally, alternative methods, such as question investigation derived from relevant literature, can be employed to explore pertinent issues [25]. In the design and development phase of the ProHomeSains module, the foundation for constructing the research is established through a synthesis of literature review mapping and insights gathered from expert interviews conducted during the needs analysis in phase one. A total of 59 items for each of the 4 main components are formulated for this questionnaire phase, representing a comprehensive approach to data collection and expert input.

2.3. Dissemination of the survey form

The dissemination of a survey form refers to the process of distributing the survey to the targeted respondents. This can be done through various methods depending on the study's objectives, target audience, and resources available. The researcher personally administered the questionnaire through face-to-face interactions with the designated experts. This method allows for more direct engagement, immediate clarification of questions, and a deeper understanding of responses. This personalized approach ensures that the data collected is rich in context and can help address complex or nuanced questions effectively.

2.4. Changing linguistic variables

This process involves the transformation of all scale enablers from linguistic terms to a three-sided numbering fuzzy system, specifically the TFN. The TFN is characterized by values m_1 , m_2 , and m_3 . In this context, m_1 represents the minimum value, m_2 corresponds to the most reasonable value, and m_3 denotes the maximum value. Subsequently, the TFN is utilized to generate a fuzzy scale, employing a Likert scale to convert linguistic variables into fuzzy numbers. The fuzzy scale is configured with an odd number of levels, with a higher fuzzy scale yielding more precise data. Figure 1 shows the illustrates that will be used to analyze the research data using the triangular graph depicting the mean against the Triangular value, encompassing the three values within the TFN.

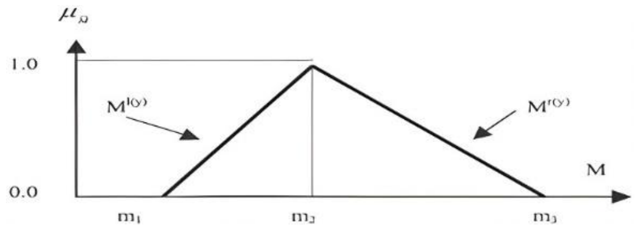

Figure 1. A facet graph three min triangular [20]

2.5. Analyse the data

TFN numbering is employed to determine the Threshold (d) value. As emphasized by Thomaidis *et al.* [26], identifying the Threshold (d) value is crucial for achieving a consensus among experts. In the quest for expert agreement on each item, the Threshold (d) value mustn't exceed or equal 0.2, as per the condition set forth by Cheng and Lin [27]. If this condition is met, it is considered that expert agreement has been successfully attained. The calculation for each fuzzy number, denoted as $m=(m_1, m_2, m_3)$ and $n=(n_1, n_2, n_3)$, is determined using the following formula that will be used to analyze the research data.

$$d(\bar{m}, \bar{n}) = \sqrt{(1/3) * [(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]}$$

Where m_1, m_2, and m_3 are these represent the average values derived from all expert opinions; n_1, n_2, and n_3 are these are the cryptic values for the three parameters associated with each user.

The threshold value is a critical factor in determining the level of consensus within an expert circle. Chu and Hwang [28], if the calculated threshold value is less than or equal to 0.2, it is considered that all experts have reached an agreement. Achieving a consensus of over 75% within the entire expert group is crucial; otherwise, a second round of fuzzy Delphi needs to be conducted. This approach ensures a rigorous assessment of expert opinions, aiming for a high level of agreement before finalizing conclusions or making decisions based on the gathered insights.

2.6. Determination of the percentage value of expert agreement

The second condition for establishing the percentage of expert agreement is that the overall agreement, or group consensus, must surpass 75.0% for each item. If the consensus falls below this threshold, a second round of the FDM needs to be implemented [29]. FDM effective for module improvement through consensus building and uncertainty management.

2.7. Data analysis using the average of fuzzy numbers (defuzzification process)

The final step, known as the defuzzification process, involves calculating the defuzzification value for each questionnaire item using the following formula:

$$\mathrm{A_max} = \frac{1}{4}(\mathrm{a_1} + 2\mathrm{a_m} + \mathrm{a_2})$$

at this stage, the researcher examines the value of the fuzzy score, aiming to produce a number within the range of 0 to 1. Chia-Wei and Cheng-Ta [30] emphasize that the α-cut value should exceed 0.5. This defuzzification process is instrumental in providing a clear and actionable output, facilitating the identification and prioritization of enabler variables based on the level of consensus among the experts.

2.8. Validity and realibility

The validity of an instrument is its ability to measure what should be measured and to allow the interpretation of the appropriate score. The purposes of instrument validity are defensibility, accuracy, appropriateness, meaningfulness, and usefulness. Cohen's Kappa index will be used to content validate and analyse the questionnaire. Two out of three experts showed a Kappa value of 1.0, which demonstrates a very good interpretation. Table 2 presents the Kappa values for expert evaluations of the questionnaire instruments. The results indicate that expert 1 and expert 3 achieved a perfect agreement with a Kappa value of 1, while expert 2 demonstrated a strong level of agreement with a Kappa value of 0.96.

Table 2. Expert Kappa values for questionnaire instruments

Expert	Kappa value
Expert 1	1
Expert 2	0.96
Expert 3	1

3. RESULTS

This article took 6 months for preliminary observation, 6 months for data collection, and 4 months for data analysis. In total, it took 16 months to complete the writing of this article. Table 3 shows the research findings for four elements of the main components in the development of ProHomeScience module for children, while the following findings are regularly detailed for each element. This data represents the threshold value calculated for each item (d items), expert group agreement percentage (%), m_1, m_2, m_3 values, and fuzzy score (A). Table 4 presents the research findings on the elements of the activity world of life in the module, including the threshold value (d items), expert agreement percentage (%), m_1 , m_2 , m_3 values, fuzzy score (A), and expert agreement acceptance. Likewise, Table 5 provides findings on the Material Activities elements, analyzed using the FDM, with the same data parameters as in Table 4. Table 6 shows the findings on planet activities, while Table 7 presents the findings on physical world activities, both analyzed using the FDM.

Table 3. Elements of main components in the development of the ProHomeScience module for children

No.	Components	Terms of TFN	Conditions of fuzzy evaluation process					Expert agreement	Elements are accepted
		Threshold value (d)	Percentage of expert group agreement (%)	m_1	m_2	m_3	Fuzzy score (A)		
1	Components of the life world: plants	0.133	100.0	0.746	0.900	0.977	0.874	Accepted	0.874
2	Components of the material world: magnets and robotics	0.142	100.0	0.777	0.915	0.977	0.890	Accepted	0.890
3	Components of the universe: planets	0.111	84.6	0.823	0.946	0.985	0.918	Accepted	0.918
4	Components of the physical world: weather	0.119	100.00	0.792	0.931	0.985	0.903	Accepted	0.903
Suggested elements from expert:									
1	None								

Table 4. Elements of life activities: plants

No.	Item/element	Terms of TFN		Conditions of fuzzy evaluation process				Expert agreement
		Threshold value (d)	Percentage of expert group agreement (%)	m_1	m_2	m_3	Fuzzy score (A)	
1	Parents need to apply about the existence of plants	0.091	92.3	0.823	0.954	0.992	0.923	Accepted
2	Parents have to explain the five types of plants	0.091	92.3	0.823	0.954	0.992	0.923	Accepted
3	Parents need to explain how plants live	0.091	92.3	0.823	0.954	0.992	0.923	Accepted
4	Parents need to explain the effects if the plants are cared for and not cared for	0.148	92.31	0.792	0.923	0.969	0.895	Accepted
5	Parents need to explain the importance of plants to humans	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
Recommended elements from experts:								
1	None							

Table 5. Elements of material activities: magnets and robots

No.	Item/element	Terms of TFN		Conditions of fuzzy evaluation process				Expert agreement
		Threshold value (d)	Percentage of expert group agreement (%)	m_1	m_2	m_3	Fuzzy score (A)	
1	Parents need to provide knowledge about what robotics is and its importance	0.148	92.31	0.792	0.923	0.969	0.895	Accepted
2	Parents need to explain how an object can move using an engine	0.139	76.92	0.808	0.931	0.977	0.905	Accepted
3	Parents need to explain the engine’s power source	0.139	76.92	0.808	0.931	0.977	0.905	Accepted
4	Parents need to give exposure to robotics around them	0.142	100.00	0.777	0.915	0.977	0.890	Accepted
5	Parents need to explain the importance of robotics to humans	0.095	92.31	0.808	0.946	0.992	0.915	Accepted
Recommended elements from experts:								
1	None							

Table 6. Elements of universe activity: planet

No.	Item/element	Terms of TFN		Conditions of fuzzy evaluation process				Expert agreement
		Threshold value (d)	Percentage of expert group agreement (%)	m_1	m_2	m_3	Fuzzy score (A)	
1	Parents should encourage children to find out about the planets found in the solar system	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
2	Parents need to explain the characteristics of the planets found in the solar system	0.195	84.62	0.715	0.869	0.946	0.844	Accepted
3	Parents need to explain the difference between planet earth and other planets in the solar system	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
4	Parents need to disclose the effects of not taking good care of the planet (global warming)	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
5	Parents should encourage children to find out about the planets found in the solar system	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
Recommended elements from experts:								
1	None							

Table 7. Elements of the physical world: weather

No.	Item/element	Terms of TFN		Conditions of fuzzy evaluation process				Expert agreement
		Threshold value (d)	Percentage of expert group agreement (%)	m_1	m_2	m_3	Fuzzy score (A)	
1	Parents need to give exposure about the diversity of seasons found in the world	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
2	Parents need to stress about why some countries have four seasons and some don’t	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
3	Parents need to explain the changes that occur when they occur each season	0.095	92.31	0.808	0.946	0.992	0.915	Accepted
4	Parents provide knowledge on how to cope with the four seasons	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
5	Parents need to emphasise the reason for the change in the current situation when there is a change in the weather	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
6	Parents should encourage children to observe and describe different weather conditions	0.082	92.31	0.838	0.962	0.992	0.931	Accepted
Recommended elements from experts:								
1	None							

4. DISCUSSION

As a result of the FDM analysis in this phase, a project-based learning module designed for home-based learning in early science (ProHomeSains) for children was produced. Initial findings using FDM have demonstrated high validity and reliability. This suggests that FDM proves effective in garnering consensus among participating experts, utilizing a quantitative approach.

Findings shown from the elements in the world of life activity, i.e. plants, get good expert agreement. Studies show that its existence various contradictions of ideas presented by children in clarify about organisms’ life like plants, animals, body parts, and unliving things seeing this, it can be stated that studies related to children’s conception at the preschool level in Malaysia are still underexplored. Therefore, hands-on activities that develop children’s scientific process skills are considered crucial in preschool education. By means of hands-on experiences, it is possible for children to develop a sense of independence and self-confidence, and the skills of asking questions and discovering [31].

Findings from activity of world of materials, namely, magnets and robots, showed good expert agreement from each item in the elements of the world of materials, such as magnets and robots. This type of activity or project approach in the elements of the world of magnetic materials and robotics can improve children's building skills and their creativity in creating robotics and dominating art and language.

The last research finding, which is the activity element of the physical world, the weather, also achieved a good expert consensus. According to Özalp [32], book text play an role important in helping increase science process skills. Recommended to have book text for children for understand science process skills deep.

The research findings underscore the necessity of including robotics in children's education, particularly in Malaysia, where it is absent from the standard school curriculum. The support from parents for robotics education emphasizes the growing awareness of its relevance in preparing children for future careers in technology-driven industries [33]. The implications of these findings suggest improvements in curriculum enhancement [34], teacher training [35], and parental involvement [36].

Relating home-based learning to business opportunities in ECE can be approached from several angles example the technology-driven solutions: children used to simply know about their pets, but now days they are also interested in animals they occasionally see but have read about in national geographic, like Pakistan's markhor animals. Pakistan's national animal is the markhor [37]. The animal has recently become the nation's mascot and symbol. For kids to comprehend animals from different countries and not simply pets, it is appropriate as foundational knowledge. Children's cognitive abilities regarding life can be enhanced with the aid of technology.

5. CONCLUSION

The application of the FDM in designing a project-based learning module for early science education in home-based learning demonstrates the effectiveness of combining expert consensus with structured analysis. FDM facilitated the identification and prioritization of essential elements in the module, ensuring alignment with early childhood development and educational standards. The iterative process of expert feedback allowed the module to be tailored specifically for young learners, emphasizing interactive, hands-on activities that foster engagement and scientific inquiry. Furthermore, the adaptability of the module to different home-learning environments enhances its relevance, making it suitable for a wide range of learners. In conclusion, FDM contributes significantly to developing a project-based learning approach that promotes early science education in home settings, resulting in more effective and flexible learning outcomes for children.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

No conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [RO], upon reasonable request.

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