UTILIZATION OF THE FUZZY DELPHI METHOD TO VALIDATE EDUCATIONAL MATERIALS FOR INFECTION PREVENTION AND CONTROL

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ABSTRACT: *The increase in healthcare-associated infections points out the necessity for an infection prevention and control education program. This study illustrates the scientific validity of the Fuzzy Delphi Method in attaining consensus among experts about educational material. Seven experts were selected through purposive sampling according to the inclusion criteria. The content of the IPC-related educational materials was assessed by specialists through a questionnaire. Triangular Fuzzy Numbers and Defuzzification mitigate ambiguity arising from expert interpretations. Experts responded 100% with an average Likert score of 4–5. Fuzzy Delphi analysis showed that the seven constructs met the first pre-requisite (threshold value (d) ≤ 0.2) with a threshold value (d) ranging from 0.075 to 0.109. The expert consensus met the second pre-requisite (≥ 75%) and ranged from 86% to 93% for all questionnaire constructs. The items' average fuzzy scores (A) ranged from 0.571 to 0.714, meeting the third pre-requisite of ≥ 0.5. The Fuzzy Delphi Method improved the quality and validation of A Comprehensive Approach to Infection Prevention and Control for Nursing.*

Key Words: Fuzzy Delphi Method, validation, healthcare-associated infections.

1. INTRODUCTION

Infection prevention and control (IPC) is essential for healthcare quality and patient safety, intending ways to lower the risk of healthcare-associated infections (HAIs) that adversely affect patient outcomes and burden healthcare systems [1]. The World Health Organization emphasizes that effective infection prevention and control strategies are essential for ensuring safe healthcare delivery and protecting both patients and healthcare workers [1]. The development and distribution of evidence-based training resources are essential to improve healthcare practitioners' comprehension and compliance with IPC recommendations [2]. Nevertheless, the validation of these materials is frequently neglected, potentially compromising their intended impact and efficacy.

The Fuzzy Delphi Method (FDM) is an advanced approach that integrates expert opinion with fuzzy logic, enabling a structured framework for the validation of instructional resources in IPC [3]. FDM provides a thorough evaluation of instructional materials aimed at improving IPC practices by including input from several stakeholders, including clinicians, infection control specialists, and educators [4]. This approach mitigates the intrinsic subjectivity of expert assessments by integrating uncertainty and ambiguity, common in healthcare settings, into the review process [5].

Nursing educators must develop educational materials that align with nurses' requirements and their scope of practice, given that nurses are accountable for delivering patient care. *A comprehensive strategy for infection prevention and control in nursing* was established utilizing Intervention Mapping (IM), a prevalent methodology for creating extensive IPC-related educational resources for an intervention program grounded in health behavior change theories [6]. After developing IPC-related education content, validity evidence is needed to assess its applicability to the target group and objectives. Determining IPC-related education material suitable for its intended use is the biggest issue. One way to address this difficulty is to get an expert's assessment of the educational material's legitimacy. The current tendency is to get expert feedback on IPC-related education material in their profession using the FDM.

This research article aims to validate IPC education materials utilizing the Fuzzy Delphi Method. The intention is to synthesize expert feedback to identify critical themes and areas for improvement in the educational content. The results will offer valuable insights that will be used to refine IPC training resources, thereby promoting greater compliance, and reducing the occurrence of HAIs in healthcare settings.

2. LITERATURE REVIEW

Infection prevention and control (IPC) is crucial in healthcare environments to mitigate the occurrence of healthcare-associated infections (HAIs) and alleviate their detrimental effects on patient safety. Effective IPC procedures necessitate that healthcare personnel maintain current knowledge and skills, typically acquired through educational resources. Consequently, the validation of these instructional tools is crucial to assuring their efficacy in conveying critical information and fostering positive behavioral change.

Numerous studies have underscored the significance of education in IPC. Berrios-Torres et al. (2017) examine how thorough training programs can markedly improve adherence to IPC standards [2]. They assert that effective educational interventions are essential for promoting a culture of safety inside healthcare organizations. Despite the acknowledged necessity for validation, numerous educational resources lack precise evaluation procedures, which may result in inefficient training and a continual possibility of healthcare-associated infections [7].

Olaf Holmer and Norman Dalkey developed the Fuzzy Delphi Method (FDM) as a modified version of the traditional Delphi method to obtain the opinions of experts through structured questionnaires [8]. The Delphi Method was designed to gain the panel of experts' opinions by utilizing a succession of questionnaires to gather feedback [9]. In the Delphi Method, the selected experts do not meet or even know each other to avoid fear of being judged by others as they give their opinions [10]. Mistranslation of expert responses caused by ignoring fuzziness and time- and money-consuming repetitive survey rounds are two examples of the traditional Delphi Method's limitations that led to the necessity to modify it [11]. Fuzzy Delphi is an adapted version of the traditional Delphi method that emphasizes the significance of addressing expert uncertainty. [12]. FDM uses Triangular Fuzzy Numbers (TFN) with values ranging from 0 to 1 [13]. The application of FDM in obtaining experts' opinions using structured questionnaires reduces the cost and time that result from multiple rounds of the traditional Delphi method [11, 14].

In the past, traditional Delphi methods have been extensively used to collect opinions and achieve consensus. However, they may not be effective in environments with high variability in judgments. The validation process is enhanced by the FDM's structured approach, which enables the incorporation of ambiguity and divergence in expert assessments, thereby overcoming this limitation [15]. The FDM's adaptability facilitates the identification of critical themes and discrepancies in educational content [4], thereby increasing the relevance and applicability of IPC training materials.

This study focuses on the application of FDM in validating an IPC-related educational material aimed at reducing HAIs. HAIs are a critical concern impacting patients worldwide as they lead to patient mortality and economic burden for health systems [16]. Despite all efforts and interventions to tackle this critical issue, the health sector still records high prevalence rates of HAIs [17]. The most effective method to reduce HAI prevalence rates is through effective training and practices of infection control standards and precautions [18], and improving knowledge on IPC has been significantly affected by effective education programs [19, 20]. The investment in developing an IPC program is especially important, and it is cost-effective in comparison to the cost of HAI treatment [21].

In conclusion, the literature reveals that the validation of educational materials is a neglected area, even though IPC education is essential for the reduction of HAIs. Using the Fuzzy Delphi Method offers a unique method for systematically evaluating and improving these materials by achieving expert consensus. By employing the FDM to validate IPC education materials, this study aims to enhance patient safety and support enhanced training outcomes in this evolving field.

3. CONCEPTUAL FRAMEWORK

The IPC-related education material was developed on IM protocol [6]. The six-step IM protocol started with a needs assessment (Step 1) and identified individual and external change behavior determinants. (Step 2) established a matrix of change linking performance objectives (POs) and change objectives (COs) for each behavioral change determinant. Social Cognitive Theory (SCT) is used to foster behavioral change in nurses and complete the matrix of change through theory-based education and practical implementations (step 3). Step 4 defined the instructional material's core constructions, themes, and subtopics based on the requirements assessment and objectives. Steps 5 and 6 ensured the adoption, implementation, and sustainability of the IPC-related education content and established an evaluation plan for its process and efficacy. After developing IPC-related education content, confirm it meets objectives and is appropriate for nurses. This study will only examine FDM validation of IPC-related education material.

4. METHODOLOGY

Experts' opinions were collected through questionnaire survey and analyzed using FDM. The Fuzzy Delphi analysis was based on two main factors, TFN and Defuzzification Process [13].

Triangular Fuzzy Number (TFN)

TFN comprises three values, each ranging from 0 to 1: the average minimum value (n1), the most reasonable value (n2), and the maximum value (n3) [13]. The values of TFN are the results of the conversion of the Likert scale scoring into fuzzy scoring. The five-point Likert Score system used in the questionnaire is converted into three values of TFN (refer Table 1). If an expert assesses a specific item with a score of 4 (agree), the Fuzzy score will be 0.4, 0.6, and 0.8, representing the least, most reasonable, and highest values, respectively. The expert approval for this item is 40%, 60%, and 80%, respectively.

Table 1: The Likert Scale Scoring and Fuzzy Scoring for A Five-Point Scale

Likert Scale Scoring	Linguistic Variable	Fuzzy Scoring
5	Strongly Agree	0.6, 0.8, 1.0
4	Agree	0.4, 0.6, 0.8
3	Neither Agree nor Disagree	0.2, 0.4, 0.6
2	Disagree	0.0, 0.2, 0.4
1	Strongly Disagree	0.0, 0.0, 0.2

Defuzzification Process

The Defuzzification process (Amax) analyzes data by employing the mean of fuzzy numbers to derive the fuzzy score (A). The fuzzy scores (A) must be greater than or equal to the median value (α – cut value) of 0.5 [22]. This signifies the expert agreement accepted the item, and it is calculated by using the formula below [11]:

$$A_{max} = \left(\frac{1}{3}\right) \times (m1 + m2 + m3)$$

Determinants of acceptance

In order to determine the acceptance of the constructs and their respective items by the experts, three pre-requisites must be met [6]: (1) the threshold value (d) and ≤ 0.2 [23] (2) the percentage of experts' agreements $\geq 75\%$ [24], and (3) the value of the fuzzy scores (A) must be ≥ 0.5 (α – cut value) [22].

The application of FDM in validation of the *A Comprehensive Approach to Infection Prevention and Control for Nursing* material and the Fuzzy Delphi analysis is discussed in detail in the next sub-topic.

Conducting Validation Process Using FDM

The application of FDM in the validation of the developed IPC-related education material is described in a framework of procedures that have collectively contributed to the decision-making on the appropriateness of the education material by measuring the level of consensus among experts.

Step 1: Selection of Experts

A panel of professionals should validate IPC-related education material. It is vital that the chosen expert can accurately assess the IPC-related education material's context. This study used seven experts, the minimum recommended [25]. The seven specialists in medical education, microbiology, infection control, nursing education, and environmental health were chosen for this study using purposeful sampling. Experts were chosen using criteria: (1)

5 years or more expertise in their profession; (2) study topic involvement; (3) interest in participating and responding; (4) active communication. To obtain the approval of the nominated experts to participate in the validation process they were contacted, by the researcher, by phone call and then by E-mail to provide brief description about the developed IPC-related education material and the validation process using FDM.

Following selection of the experts' panel, the consent form explained the validation process's purpose and objectives, a brief description of the IPC-related education material, the expert's responsibility, methods of communication between the researcher and the expert, and the response deadline. Validation began 30 days after obtaining the IPC-related education material. All seven experts completed consent papers to participate in FDM validation and emailed them back.

The validation panel was anonymous, saw no one, and did not know how many experts participated. This prevents self-influence and encourages objectivity.

Step 2: An expert questionnaire

To evaluate the acceptability of each construct in the expert questionnaire and its respective items, the first thing is to measure the threshold value (d) which should be less than or equal to 0.2 [23], The threshold value (d) reflects the consensus of the experts for each construct in the expert questionnaire. A threshold value

(d) was determined for each item in the construct by calculating the disparity between the average fuzzy number and the fuzzy number assigned by each expert using the formula below. [11]: active communication. To obtain the approval of the nominated experts to participate in the validation process they were

$$(\underline{m}, \underline{n}) = \sqrt{3}[(m1 - n1)^2 + (m2 - n2)^2 + (m3 - n3)^2]$$

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Following the selection of the experts' panel, the consent form explained the validation process's purpose and objectives, a brief description of the IPC-related education material, the expert's responsibility, methods of communication between the researcher and the expert, and the response deadline. Validation began 30 days after obtaining the IPC-related education material. All seven experts completed consent papers to participate in FDM validation and emailed them back.

The validation panel was anonymous, saw no one, and did not know how many experts participated. This prevents self-influence and encourages objectivity.

Step 3: Dissemination of the IPC-related education material and validation forms

The IPC-related education material and the expert's validation questionnaire was shared by seven files between September and October 2024 via OneDrive, whereby each file was named after one of the names of the experts.

Step 4: Conversion of Likert scale to Fuzzy scale

For analysis, the Likert scale values of experts were converted to Triangular Fuzzy Numbers (TFN) (Table 1).

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Each expert response in TFN considered the average lowest (n1), most reasonable (n2), and maximum (n3) values. TFN was employed to demonstrate the expert's ambiguity or imprecision. Due to its set value, a Likert scale cannot show ambiguity in expert opinions. When an expert scores an item 4 (agree), the Fuzzy score is 0.4, 0.6, 0.8, respectively, for least, most reasonable, and maximum. This item received 40%, 60%, and 80% expert approval. The fuzzy scores were averaged using m1, m2, and m3.

Step 5: Threshold value (d)

To evaluate the acceptability of each construct in the expert questionnaire and its respective items, the first thing is to measure the threshold value (d) which should be less than or equal to 0.2 [23], The threshold value (d) reflects the consensus of the experts for each construct in the expert questionnaire. A threshold value (d) was determined for each item in the construct by calculating the disparity between the average fuzzy number and the fuzzy number assigned by each expert using the formula below. [11]:

$$d(\underline{m}\,\underline{n}) = \sqrt{\frac{1}{3}[(m1 - n1)^2 + (m2 - n2)^2 + (m3 - n3)^2]}$$

After calculating the threshold value (d) for each item, a threshold value (d) for the construct was determined using the following formula [11]:

$$Threshold\ value\ (d)\ construct = \frac{\sum Average\ Threshold\ Value\ (d) for\ each\ item}{Total\ Experts\ \times Total\ Items\ in\ Constructs}$$

Step 6: Percentage value of the expert's agreement

The second requirement for evaluating the acceptability of each construct in the expert validation form and its respective items is determining the expert agreement percentage value. The percentage of consensus among experts must be at least 75% [24]. Obtaining an expert consensus equal to or greater than 75%, then this item is accepted. Item with a consensus of less than 75% consensus of experts is not approved and needs to be modified in the light of expert's suggestions.

Step 7: Percentage value of the expert's agreement

As Defuzzification process (Amax), the data analysis used average of fuzzy numbers to get the score of fuzzy score (A). The fuzzy scores (A) must be greater than or equal to the median value (α – cut value) of 0.5 [22]. This signifies the expert agreement accepted the item. The fuzzy score (A) was calculated using the formula below [11]:

$$A_{max} = \left(\frac{1}{3}\right) \times (m1 + m2 + m3)$$

RESULTS

Following 30 days of sharing the IPC-related education material and its validation questionnaire with the experts' panel, all the seven experts responded and sent the completed questionnaires back to the researcher via e-mail, representing 100% response rate. After assessing the completeness of the questionnaires obtained, analysis was conducted using Microsoft© Excel. All experts' responses scored average Likert scoring of four to five (agree to strongly agree) and were converted to triangular fuzzy numbers for further analysis steps. Table 2 shows the results of the Fuzzy analysis and the pre-requisites for the education material validation.

Table 2: Description of Fuzzy Delphi Analysis and All Requirements for Educational Material Validation

Item assessed	Threshold (d) average for item	Threshold (d) average for construct	Percentage of threshold (d) ≤ 2 for each item	Total percentage of threshold (d) ≤ 2 for construct	Average of Fuzzy number	Verdict
1. Content						
1.1 The content is appropriate for the critical care nurses	0.075		86%		0.571	
1.2 Sufficient background information is provided	0.075		86%		0.629	
1.3 The content covered is relevant for the healthcare associated infections	0.187		86%		0.657	
1.4 The content is sufficient to meet the needs of critical care nurses	0.075	0.109	86%	90%	0.571	**Accepted**
1.5 The division of the headings and subheadings of the material is relevant	0.075		86%		0.629	
1.6 The key passages (starred) are important and noteworthy	0.125		100%		0.657	
1.7 The sequence of the topics is logic	0.150		100%		0.714	
2. Language						
2.1 The writing style is compatible with the critical care nurses	0.075		86%		0.571	
2.2 The writing used is attractive	0.075	0.091	86%	90%	0.629	**Accepted**
2.3 The language is clear and objective	0.125		100%		0.657	
3. Illustration						
3.1 The illustrations are relevant to the content of the material and clarify the content	0.125		100%		0.657	
3.2 The illustrations are clear and transmit ease of understanding	0.075		86%		0.571	
3.3 The subtitles applied are appropriate and help the reader to understand the picture	0.125	0.1	100%	93%	0.657	**Accepted**
3.4 The number of illustrations is suitable for the educational material content	0.075		86%		0.629	
4. Layout						
4.1 The typeface used facilitates reading	0.075		86%		0.629	
4.2 The colours applied to the text are relevant and makes the reading easy	0.075		86%		0.571	
4.3 The visual composition is attractive and well organized	0.075		86%		0.629	
4.4 The format (size) of the educational material and the number of pages is appropriate	0.075	0.075	86%	86%	0.571	**Accepted**
4.5 The text layout is adequate	0.075		86%		0.629	
4.6 The font size of the titles, subtitles and text is appropriate	0.075		86%		0.629	

Table 2: Continued

Item assessed	Threshold (d) average for item	Threshold (d) average for construct	Percentage of threshold (d) ≤ 2 for each item	Total percentage of threshold (d) ≤ 2 for construct	Average of Fuzzy number	Verdict
Layout						
4.7 The typeface used facilitates reading	0.075		86%		0.629	
4.8 The colours applied to the text are relevant and makes the reading easy	0.075		86%		0.571	
4.9 The visual composition is attractive and well organized	0.075	0.075	86%	86%	0.629	**Accepted**
4.10 The format (size) of the educational material and the number of pages is appropriate	0.075		86%		0.571	
4.11 The text layout is adequate	0.075		86%		0.629	
4.12 The font size of the titles, subtitles and text is appropriate	0.075		86%		0.629	
5. Motivation						
6.1 The content is motivating and encourages continuing reading	0.075		86%		0.629	
6.2 The content aroused interest to the reader	0.075	0.075	86%	86%	0.629	**Accepted**
6.3 The content addresses the questions, clarifies, and educates the critical care nurses.	0.075		86%		0.629	
6. Culture						
7.1 The text is appropriate to the target audience and the various knowledge-level profiles	0.075	0.075	86%	86%	0.571	**Accepted**
Overall assessment	0.075	0.075	86%	86%	0.571	**Accepted**

The Fuzzy Delphi analysis of the expert responses showed that the six constructs and their respective questionnaire items were accepted. The six constructs had threshold value (d) ranging from 0.075 to 0.109 which fulfils the first pre-requisite for determining the validity of the construct having threshold value (d) construct ≤ 0.2 [23]. The second pre-requisite is an expert consensus of ≥ 75% [24] which was attained by an expert consensus of 86% to 93% for all six constructs. The Defuzzification process (Amax) revealed that the average fuzzy numbers for the items ranged from 0.571 to 0.714 which matches the third pre-requisite for fuzzy scores (A) must be ≥ 0.5 [22]. The six constructs and their respective items met the three prerequisites for determining the validity of the developed education material with little modifications in terms of wording, based on the experts' comments and suggestions for improvement. There were some minor changes, but they did not alter the content or construction of the educational material.

The results indicated the appropriateness of *A Comprehensive Approach to Infection Prevention and Control for Nursing* material for development purposes and the target group by applying Fuzzy Delphi analysis of experts' panel responses using the adapted version of the Delphi method.

5. DISCUSSION

This study focuses on the application of FDM to validate the developed education material. FDM provides a statistical way to obtain experts consensus agreement and enhance content validity regarding the structure of *A Comprehensive Approach to Infection Prevention and Control for Nursing* material. The developed educational material was shared with the panel of experts who were selected based on certain criteria to ensure that their opinions in the respective fields would enhance the validation process of the developed educational material. The uncertainty that is usually present during the research procedure could be resolved by applying TFN to experts' assessments. To

ensure an exceptionally reliable outcome of FDM a panel of seven experts were selected to the study field. An adapted version of the Sousa and Turrini expert questionnaire [26] was used to obtain expert panel opinions on the developed education material. The questionnaire used consists of six constructs that ensure an adequate assessment of the suitability and comprehensiveness of the IPC-related education material developed to be used for an intervention program for the target group in the respective fields. The questionnaire evaluates the education material in six aspects (refer to Table 2). Fuzzy Delphi analysis was performed after converting the experts' responses from Likert scale scoring to triangular fuzzy numbers. The FDM analysis showed all the questionnaire constructs and their respective items fulfilled all the prerequisites for determining their acceptability.

Verbal phrases have weaknesses to reflect fully experts' respondents' mental latencies, as the same phrase "Agree" for one expert is different for another expert [10]. Every expert will have ambiguity concerning a specific item, the use of FDM is to resolve this uncertainty, which will ensure a credentialed analysis outcome. This method catered to all experts' opinions, considering that experts have differences in their knowledge, experience, and skills relevant to the developed education material.

FDM proves that it is a reliable method to use in the validation of educational material because it is time-efficient and cost-effective. In many studies, the FDM was widely applied to obtain expert consensus on different topics including the development of disease-related questionnaire [27, 28], community public health services evaluation [29], development of health educational programs related to childhood obesity [30], development of organization policies, framework, and strategic planning [31, 32]. This study demonstrated the efficacy of utilizing FDM in validating IPC-related education material tailored to the needs of nurses.

Fuzzy Delphi analysis indicated that the six constructs and their respective questionnaire items met the prerequisites for assessing the validity of the developed education material with little wording modifications, based on the experts' comments and suggestions to improve the quality of the material. There were some minor changes, but it did not alter the content or construction of the educational material.

The selection of an expert panel is considered the key point to ensure the successful and effective application of FDM. The selection of an appropriate expert panel optimized the implementation of FDM and ensured their responses and evaluation of the developed education material.

This study was carried out using FDM to benefit from its advantages, which represented the possibility of obtaining experts' opinions by email at their convenience without the need to find a suitable time for all of them to hold a session or maybe different sessions of discussions, such efforts would consume time and money. In addition, the FDM, which is characterized by anonymity of the expert's identity, ensures their responses are completely independent without fear of being judged by others that would have occurred at any group meeting.

The limitation of the FDM application that was experienced while conducting this study was the need to constantly remind the experts to respond, as the process was done through online communication. Repetitive reminders could lead to emotional bias which may affect their response and evaluation.

6. CONCLUSION

This study has proven the effectiveness of FDM application in validating *A Comprehensive Approach to Infection Prevention and Control for Nursing* material by obtaining and analyzing their responses. Experts' responses assured the suitability of the developed educational material to be used for an intervention program for the nurses that aimed to improve their knowledge and practice levels toward IPC to reduce HAIs.

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