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Article

# Developing a valid VR-based safety tool framework for hospitality TVET: A Fuzzy Delphi analysis with academic and industry experts

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**Abstract:** The research explores academia and industry experts' viewpoints regarding the innovative progression of Virtual Reality (VR)-based safety tools customized for technical and vocational education training (TVET) within commercial kitchen contexts. Developing a VR-based safety tools holistic framework is crucial in identifying constructs to mitigate the risks prevalent in commercial kitchens, encompassing physical, chemical, biological, ergonomic, and psychosocial hazards workers encounter. Introducing VR-based safety training represents a proactive strategy to bolster education and training standards, especially given the historically limited attention directed toward workers' physical and mental well-being in this sector. This study pursues a primary objective: validating a framework for VR-based kitchen safety within TVET's hospitality programs. In addition to on-site observations, the research conducted semi-structured interviews with 16 participants, including safety training coordinators, food service coordinators, and IT experts. Participants supplemented qualitative insights by completing a 7-Likert scale survey. Utilizing the Fuzzy Delphi technique, seven constructs were delineated. The validation process underscored three pivotal constructs essential for the VR safety framework's development: VR kitchen design, interactive applications, and hazard identification. These findings significantly affect the hospitality industry's safety standards and training methodologies within commercial kitchen environments.

**Keywords:** commercial kitchens; environment; holistic framework; technical and vocational education training (TVET); occupational safety and health; sustainability; Malaysia

## 1. Introduction

Commercial kitchens have entered the high-tech industry, which has long been Malaysia's economic pillar. Adopting the Fourth Industrial Revolution (IR 4.0) in commercial kitchens by applying new technology to make it global connectivity is an alternative to ensure the Agenda for Sustainable Development (2030 Agenda) comes into reality. In light of the 2030 Agenda principle of ensuring that "no one will be left behind", it is imperative to prioritize the well-being of individuals working in high-tech commercial kitchens, particularly concerning sustainable development goal (SDG) 3, which focuses on promoting good health and well-being.

Therefore, it is imperative to recognize Occupational Safety and Health (OSH) as a crucial guideline. The creation of the OSH Act 1994 aims to prioritize workplace health and safety. The Act offers 10-hour and 30-hour training to empower workers to recognize and mitigate hazards (Ibrahim et al., 2023). These regulations universally apply, encompassing sectors such as commercial kitchens, which are known for frequent workplace injuries. The accident rate in food industry kitchens stands at approximately 87.2%, with nine out of 10 reported kitchen accident cases attributed to them, signifying a notably high occurrence. The most prevalent kitchen injuries include knife cuts (84.7%), burns from hot water and oil (74.4%), and slips and falls (28.1%) (Oh and Suk Tea, 2015). The demanding nature of kitchen work, characterized by a high workload, extreme environmental conditions (high temperatures and slippery floors), and a high prevalence of labor, contributes significantly to this elevated injury rate.

Additionally, improper kitchen design and layout and inadequate equipment maintenance contribute to kitchen injuries. Repetitive kitchen activities exaggerate abdominal pain, including hand, wrist, elbow, shoulder, and neck, and directly damage tendons. The repetitive movement due to repetitive bending while taking utensils or ingredients from the lower shelf, movements of the wrist while chopping, stretching to reach the ingredients to cook, vibration with overuse of mixer, sustained or constrained postures due to very high or low height of the cooking area, forceful movement while carrying heavy loads as rice packets or while chopping meat will lead to repetitive strain injuries. The surge in gastronomy tourism staff correlates with a rise in workplace accidents. Novice employees struggle with identifying hazards, leading to an inability to recognize perilous situations (Saad et al., 2022).

Worldwide reports indicate workplace injuries, particularly in the food service sector. In Singapore, accommodation and food service cases have increased from 2019 to 2021 (Ministry of Manpower Singapore, 2022). Similarly, Canada has observed a rise in accidents, with slips, trips, and falls being the top three causes (Chawla and Papp, 2022). Consequently, kitchen injuries are identified as significant contributors to workplace injuries in both countries. In contrast, the hospitality industry in the United States experiences relatively fewer accidents than other sectors (U.S. Department of Labor, 2022). However, it remains a concern due to the potential hazards resulting from inadequate kitchen safety management (Makhtar et al., 2017). Modern cooking equipment and sophisticated food processing tools pose a high risk of burns, cuts, crushes, mangles, and amputations (Nayl et al., 2022). Jeinie and Nor (2022) stressed the need to improve understanding of food microorganism best practices, which is crucial for safeguarding kitchen workers' health during food storage. The statistics on kitchen injuries indicate the failure of conventional OSH training. Hence, innovation in kitchen safety training may reduce kitchen injuries.

Yamaguchi et al. (2012) highlighted that VR integration in training has proven to be an innovative tool to ensure continuous training anytime at the workers' convenience, contributing to risk and hazard reduction in the kitchen. VR technology integration into kitchen safety training underscores its adaptability and flexibility in addressing various kitchen safety concerns through diverse digital tools and platforms (Yamaguchi et al., 2012). VR provides a comprehensive sensory illusion that transports trainees into an alternate environment. The three-dimensional virtual environment allows trainees to be in the kitchen virtually through computer-generated imagery.

Additionally, VR allows trainees to interact with and provides an immersive experience in the virtual world (Wohlgenannt et al., 2020). With the setting, the user can move around and experience the virtual environment (Aasekjær et al., 2022). Technology-integrated kitchen training may offer opportunities to improve the understanding and knowledge of kitchen potential hazards due to the simultaneous engagement of multiple senses that can create an experience for the users (Crofton et al., 2019).

The literature emphasizes prioritizing compatibility with diverse VR hardware and software in commercial kitchens for broad acceptance and user-friendliness. VR integration enhances training, particularly in food safety and hygiene, offering promising opportunities for improved effectiveness compared to traditional methods. While e-learning platforms have been used, VR provides a more engaging alternative, enabling active participation in simulated scenarios to better understand food safety protocols (Azlan et al., 2020).

As statistics on kitchen injuries increased, VR training integration has the potential to overcome some of the issues, as reported in various studies, due to the ability to provide a higher level of immersion than other technologies, which could enhance student achievement. However, its effectiveness in kitchen safety needs to be revised in the literature; therefore, the potential of VR as an alternative to the conventional kitchen safety training tool is valuable and should be explored.

Regarding this research topic, we argued that instructional design in TVET involves tailoring training programs to meet the needs of learners and industry demands. Fundamental principles include conducting needs assessments, defining clear learning objectives, focusing on competency-based learning, employing active learning strategies, using authentic assessment methods, offering flexible delivery modes, fostering industry partnerships, and continually improving the training program. These practices aim to equip learners with practical skills and knowledge relevant to the commercial kitchen fields, enhancing their employability and success in the workforce.

Recognizing the urgency in coping with the mentioned issues, this study pursues the primary objective of validating a VR-based kitchen safety framework within TVET's hospitality programs.

## 2. Research objective, materials and methods

This study aims to validate a VR-based kitchen safety framework within TVET's hospitality programs. This article demonstrates the Fuzzy Delphi method as one of the scientific analysis techniques to consolidate consensus agreement within a panel of experts about each item's appropriateness related to the VR-based framework of Manakandan et al. (2017). This study employed Fuzzy Delphi as a systematic method to decide on the constructs and components required to develop a holistic framework for the VR-based safety tool for commercial kitchens. Based on the phenomenological approach, delved into individuals' experiences, perceptions, and the significance they attach to those experiences (Alhazmi et al., 2022), particularly in the context of IR 4.0. It utilizes a mixed-method design, using qualitative semi-structured interviews to address the formulation of the framework and quantitative questionnaire surveys to address the framework's validation. However, this paper presents the framework's validation using the Fuzzy Delphi technique.

## 2.1. Population and sample of the study

For the Fuzzy Delphi method, Rejab et al. (2019) recommended 10–15 participants for interviews, while achieving excellent uniformity requires a sample size of 10–50 experts (Al-Rikabi and Montazer, 2023). As a sample size of this study, the total number of participants involved was 12 experts during interviews and another nine respondents, 21 of whom participated in answering the Fuzzy Delphi questionnaire with experience five or more five years of experience in the selected fields. According to Berliner (2004), expertise is valued by those who have served for more than five years, especially in education. The researchers opt for purposive sampling to ensure specific cases relevant to the survey are included, moving away from random sampling (Campbell et al., 2020). This study employs purposive sampling that has selected criteria based on their background and their expertise. The reason for purposive sampling is that it better matches the sample to the aims and objectives of the research (Campbell, 2020). The selection criteria for the experts for this study are from TVET institutions, Safety and Health Officers (SHOs), and Information Technology (IT) experts specializing in VR, mainly focusing on kitchen usage in hospitality programs. TVET educators/trainers are chosen for their firsthand experience with kitchen challenges, aiding hazard identification. SHOs assess safety needs per regulations, while IT experts address VR framework development.

Therefore, the researchers engaged the same 12 experts for this study, including educators and trainers.

## 2.2. Validity of instruments

This study employs semi-structured interview questions adapted and modified from Baldev (2006) consisting of five items related to worksite safety, workers' attitudes towards safety, risk perception, hazard recognition and prevention, and work practices items. Additionally, it utilizes a voice recorder, note-taking, and a facilitator during interviews. After forming a theme from interviews like Braun et al. (2019), this study converted the theme into questions for experts to assess via 7-Likert scales on Google Forms.

This study later validated three participants: lecturers from Universiti Malaysia Sabah (UMS), who focused on food and beverage services; Universiti Teknologi MARA (UiTM), which specializes in occupational safety and health; and Universiti Teknikal Melaka Malaysia (UTeM), which offers IT courses. Their involvement in the pre-test helped identify errors or inappropriate questions before distributing the pilot, ensuring question clarity and participant suitability. This study piloted the questionnaire to SHO, food handlers, and IT experts from UiTM. Based on the comments, changes are made to the questionnaire instrument.

## 2.3. Design and development procedure

Distinct methods were employed for data collection to address the two study objectives. For the first objective, the formulation phase involved qualitative semi-structured interviews that themed the data. Semi-structured interviews were conducted either offline or online based on the preferences of the interviewees after setting the interview dates.

Subsequently, the constructs derived from themed data were validated using quantitative Fuzzy Delphi techniques, relying on consensus among experts. Specifically, this study utilizes the Fuzzy Delphi technique to achieve expert consensus across various fields, including extended reality (XR) technology assessment and safety evaluation for industry workers in a virtual setting compared to regular classroom training (Shringi et al., 2023). Following Rahman et al. (2021), the Fuzzy Delphi technique's effectiveness extends to material selection, teaching evaluation, and curriculum design. In this study, the Fuzzy Delphi technique is the final validation step, ensuring alignment with development objectives. Further, Microsoft Excel identifies data strengths and weaknesses, while the defuzzification process converts Likert scale responses to percentage scores, with items above 75% accepted and those below 0.5 considered unsuccessful.

### 2.4. Data analysis for Fuzzy Delphi techniques

The data analysis of this study follows a systematic approach. Researchers use the Fuzzy Delphi 2.0 analysis template for validation using Microsoft Excel, recommended by Jamil et al. (2017) and Ramlie et al. (2014). Fuzzy Delphi techniques rely on Triangular Fuzzy Numbers and the Defuzzification Process. For Triangular Fuzzy Numbers, two conditions are crucial. First, the threshold ($d$) value should be ≤ 0.2, ensuring expert consensus (Cheng and Lin, 2002; Chen, 2000). These numbers mitigate ambiguity in expert judgments, surpassing the limitations of Likert scales (Zamzuri et al., 2022). The second condition involves expert consensus, with acceptance criteria exceeding 75% (Yusoff et al., 2021). The Defuzzification Process determines the ranking fuzzy score value ($A$)/Amax value, with α-cut threshold ≥0.5 indicating consensus (Yusoff et al., 2021). A higher Amax value suggests a higher attribute ranking. Acceptance is based on whether Amax is ≥0.5, calculated by $A = (1/3) \times (m1 + m2 + m3)$.

## 3. Results and discussion

### 3.1. Demographic profiles

**Table 1** shows the participants' profiles for this study. The demographic findings suggest that participants were experienced professionals. These professionals are characterized as individuals with an industry health/food safety background and possess adequate skills in managing commercial kitchens. Despite some having less than five years of experience, the IT experts were meticulously selected for their VR application development expertise.

**Table 1.** Demographic profile.

| No. | Gender | Age | Occupation | Education | Working experience | Fuzzy Delphi responses | |
|---|---|---|---|---|---|---|---|
| | | | | | | Formulation | Validation |
| **Occupational Safety and Health Officer (OSH Officer) and Safety Coordinator** | | | | | | | |
| 1 | Female | 56 | Director of Chemical Management | Master's degree | >15 years | | / |
| 2 | Female | 47 | Lecturer and OSH Officer | PhD | 14 years | / | / |
| 3 | Male | 40 | Lecturer and Security Officer | PhD | 4 years | / | / |
| 4 | Male | 34 | Lecturer | PhD | 9 years | / | / |
| 5 | Female | 38 | Sr HSE Executive | Master's degree | 14 years | / | / |
| **Food Handler** | | | | | | | |
| 6 | Female | 38 | Small-scale food business owner | Master | >15 years | | / |
| 7 | Female | 33 | Manage | SPM | 5 years | / | / |
| 8 | Female | 28 | Kitchen Helper | SPM | 8 years | / | / |
| 9 | Male | 44 | Chef | Diploma | 21 years | / | / |
| 10 | Female | 48 | Lecturer of Food Science and Technology | PhD | 4 years | / | / |
| **IT experts** | | | | | | | |
| 11 | Female | 43 | Lecturer | PhD | >15 years | / | / |
| 12 | Male | 29 | Programmer | Master's degree | 4 years | / | / |
| 13 | Male | 30 | Programmer | Master's degree | 3 and ½ years | / | / |
| 14 | Female | 29 | Lecturer and Programmer | Master's degree | 2 years | / | / |
| 15 | Male | 27 | Programmer | Bachelor's degree | 2 years | / | / |
| 16 | Male | 28 | Software engineer, data platform developer | Master's degree | 7 years | / | / |
| 17 | Female | 51 | Lecturer | PhD | >15 years | / | / |
| 18 | Female | 53 | Lecturer | Master's degree | >15 years | / | / |

## 3.2. Thematic analysis results

From the result displayed in **Table 2**, the researchers identified six themes considered as the framework's initial components. This section focuses on the classification of components required for the VR-based kitchen safety training, which is designed based on thematic analysis.

**Table 2.** Thematic analysis results.

| Construct | Elements |
|---|---|
| 1 | Technology infrastructure configuration |
| 2 | Testable prototype creation |
| 3 | Engagement craft |
| 4 | Personalized and adaptive learning support (feedback and guidance) |
| 5 | Personalized and adaptive learning support (dynamic difficulty adjustment) |
| 6 | Skill development through realistic simulations |

**Table 3** displays the results of the hardware and software specifications required for VR-based safety training. According to the findings, this research can conclude that all items for this construct, except item A4, recorded a threshold value ($d$) of ≤0.2.

This result indicates that consensus has been achieved among all items. Furthermore, the consensus among items suggests that all items, except A4, surpass the 75% threshold. On the other hand, item A4, which displays contrast results, can be found in other situations where the threshold value is greater than 0.2 and the consensus is lower than 75%, which is 0.660. In other words, the items are rejecting A4 as part of hardware and software specifications.

**Table 3.** Technology infrastructure configuration—Defuzzification process and analysis.

| **Item** | **Condition of triangular fuzzy numbers** | | **Condition of defuzzification process** | | | | **Experts consensus** | **Accepted elements** | **Position** |
|---|---|---|---|---|---|---|---|---|---|
| | **Threshold value, *d*** | **Percentage of experts group consensus, %** | ***m*1** | ***m*2** | ***m*3** | **Fuzzy Score (*A*)** | | | |
| A1 | 0.128 | 100.00% | 0.760 | 0.910 | 0.980 | 0.883 | Accepted | 0.910 | 9 |
| A2 | 0.132 | 100.00% | 0.780 | 0.920 | 0.980 | 0.893 | Accepted | 0.910 | 9 |
| A3 | 0.174 | 90.00% | 0.780 | 0.910 | 0.960 | 0.883 | Accepted | 0.937 | 1 |
| A4 | 0.265 | 70.00% | 0.660 | 0.820 | 0.910 | 0.797 | Rejected | 0.920 | 3 |
| A5 | 0.200 | 90.00% | 0.740 | 0.880 | 0.950 | 0.857 | Accepted | 0.893 | 21 |
| A6 | 0.132 | 100.00% | 0.800 | 0.930 | 0.980 | 0.903 | Accepted | 0.873 | 22 |
| A7 | 0.172 | 90.00% | 0.760 | 0.900 | 0.960 | 0.873 | Accepted | 0.920 | 3 |
| A8 | 0.087 | 90.00% | 0.840 | 0.960 | 0.990 | 0.930 | Accepted | 0.920 | 3 |
| A9 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.910 | 9 |
| A10 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.910 | 9 |
| A11 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.930 | 2 |

**Table 4** shows that all of the items for this construct have achieved consensus, as they have all recorded a value of threshold (*d*) that is less than or equal to 0.2. Furthermore, the consensus among s indicates that every single item is above the threshold of 75% and that each defuzzification value for each item surpasses the threshold of α-cut = 0.5. Following the table, the elements are shown in the order of their respective priorities. In the order of ranking, item B7 is at the top, followed by items B8, B2, CB and B6. B3 and B9 came in at four and five, respectively. As for the final ranking, it is simply B10 and B1 correspondingly. It shows that items C10 and C1 rank last on the priority list, even those scoring a defuzzification value greater than 0.9. To summarize, each of these components is essential for developing a VR safety framework capable of demonstrating the capacity to identify potential dangers.

**Table 5** depicts that all items within this component fulfill the acceptance criteria, demonstrating a consistent level of expert consensus with threshold values below 2.0, ranging from 0.68 to 0.162. Experts unanimously agree on all items, surpassing the 75% threshold for expertise consensus. Defuzzification values, required to exceed α-cut = 0.5, are also attained within this component, ranging from 0.86 to 0.93. Regarding item ranking, elements are being presented based on their relative priorities. C11 secures the top position in the ranking, followed by C12, C15 and C16, all sharing the same score and being placed in second. Lastly, C5 is selected as the lowest-ranked item among the others. In conclusion, each component is essential for developing a VR safety framework capable of identifying potential hazards while enhancing the overall experience with fascination and enjoyment.

**Table 4.** Testable prototype—Defuzzification process and analysis.

| Item | Condition of triangular fuzzy numbers | | Condition of defuzzification process | | | | Experts consensus | Accepted elements | Position |
|---|---|---|---|---|---|---|---|---|---|
| | Threshold value, *d* | Percentage of experts group consensus, % | *m*1 | *m*2 | *m*3 | Fuzzy Score (*A*) | | | |
| B1 | 0.155 | 100.00% | 0.740 | 0.890 | 0.970 | 0.867 | Accepted | 0.867 | 25 |
| B2 | 0.103 | 90.0% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.910 | 9 |
| B3 | 0.101 | 100.0% | 0.780 | 0.930 | 0.990 | 0.900 | Accepted | 0.900 | 18 |
| B4 | 0.094 | 100.00% | 0.760 | 0.920 | 0.990 | 0.890 | Accepted | 0.910 | 9 |
| B5 | 0.094 | 100.00% | 0.760 | 0.920 | 0.990 | 0.890 | Accepted | 0.910 | 9 |
| B6 | 0.103 | 90.00% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.910 | 9 |
| B7 | 0.049 | 100.00% | 0.860 | 0.980 | 1.000 | 0.947 | Accepted | 0.937 | 1 |
| B8 | 0.103 | 90.00% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.920 | 3 |
| B9 | 0.103 | 90.00% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.893 | 21 |
| B10 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.873 | 23 |

**Table 5.** Engagement—Defuzzification process and analysis.

| Item | Condition of triangular fuzzy numbers | | Condition of defuzzification process | | | | Experts consensus | Accepted elements | Position |
|---|---|---|---|---|---|---|---|---|---|
| | Threshold value, *d* | Percentage of experts group Consensus, % | *m*1 | *m*2 | *m*3 | Fuzzy Score (*A*) | | | |
| C1 | 0.064 | 100.00% | 0.840 | 0.970 | 1.000 | 0.937 | Accepted | 0.920 | 3 |
| C2 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.920 | 3 |
| C3 | 0.073 | 100.00% | 0.820 | 0.960 | 1.000 | 0.927 | Accepted | 0.910 | 9 |
| C4 | 0.132 | 100.00% | 0.780 | 0.920 | 0.980 | 0.893 | Accepted | 0.910 | 9 |
| C5 | 0.103 | 100.0% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.867 | 12 |
| C6 | 0.155 | 100.0% | 0.740 | 0.890 | 0.970 | 0.867 | Accepted | 0.910 | 5 |
| C7 | 0.162 | 100.0% | 0.760 | 0.900 | 0.970 | 0.877 | Accepted | 0.900 | 9 |
| C8 | 0.128 | 100.00% | 0.760 | 0.910 | 0.980 | 0.883 | Accepted | 0.910 | 5 |
| C9 | 0.132 | 100.00% | 0.780 | 0.920 | 0.980 | 0.893 | Accepted | 0.910 | 5 |
| C10 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.910 | 5 |
| C11 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.937 | 1 |
| C12 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.920 | 2 |
| C13 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.893 | 10 |
| C14 | 0.166 | 90.00% | 0.740 | 0.890 | 0.960 | 0.863 | Accepted | 0.873 | 11 |
| C15 | 0.172 | 90.00% | 0.760 | 0.900 | 0.960 | 0.873 | Accepted | 0.920 | 2 |
| C16 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.920 | 2 |

**Table 6** shows construct 4, personalized and adaptive learning Support, which focuses on feedback and guidance and comprises thirteen items. Analysis of the components reveals that all items within this construct have achieved consensus, with threshold (*d*) values ranging from 0.13 to 0.20. Expert consensus ranges from 90% to 100%, indicating unanimous agreement on all items except for E10. E10 fails to meet the criteria, as its threshold value exceeds 0.2, registering at 0.29, almost 0.3. Defuzzification values fall short at 0.59, posing a significant risk. Despite being slightly below the required value, the percentage still exceeds 75%. Consequently, the

defuzzification process excludes this item. In summary, only 12 items are selected based on the analysis results.

**Table 6.** Personalized and adaptive learning support (feedback and guidance)—Defuzzification process and analysis.

| Item | Condition of triangular fuzzy numbers | | Condition of defuzzification process | | | | Experts Consensus | Accepted Elements | Position |
|---|---|---|---|---|---|---|---|---|---|
| | **Threshold value, *d*** | **Percentage of experts group consensus, %** | ***m*1** | ***m*2** | ***m*3** | **Fuzzy Score (*A*)** | | | |
| D1 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.920 | 3 |
| D2 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.920 | 3 |
| D3 | 0.103 | 90.00% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.820 | 26 |
| D4 | 0.103 | 90.00% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.737 | 27 |
| D5 | 0.087 | 90.00% | 0.840 | 0.960 | 0.990 | 0.930 | Accepted | 0.873 | 23 |
| D6 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.903 | 17 |
| D7 | 0.103 | 90.00% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.910 | 9 |
| D8 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.900 | 18 |
| D9 | 0.203 | 90.00% | 0.680 | 0.840 | 0.940 | 0.820 | Accepted | 0.920 | 3 |
| D10 | 0.293 | 50.00% | 0.590 | 0.750 | 0.870 | 0.737 | Rejected | 0.910 | 9 |
| D11 | 0.172 | 90.00% | 0.760 | 0.900 | 0.960 | 0.873 | Accepted | 0.900 | 18 |
| D12 | 0.132 | 100.00% | 0.800 | 0.930 | 0.980 | 0.903 | Accepted | 0.883 | 22 |
| D13 | 0.132 | 100.00% | 0.780 | 0.920 | 0.980 | 0.893 | Accepted | 0.900 | 18 |

The findings from **Table 7** reveal that all items achieved a threshold value (*d*) of ≤0.2. All the items, therefore, were considered acceptable. This determination stems from the consensus reached by most individuals regarding these items. Analysis of the agreement percentage indicates that each item surpasses 75%, and each defuzzification value for items exceeds the value of α-cut = 0.5. The members have agreed on the items included in the framework design.

**Table 7.** Personalized and adaptive learning support (dynamic difficulty adjustment)—Defuzzification process and analysis.

| Item | Condition of triangular fuzzy numbers | | Condition of defuzzification process | | | | Experts consensus | Accepted elements | Position |
|---|---|---|---|---|---|---|---|---|---|
| | **Threshold value, *d*** | **Percentage of experts group consensus, %** | ***m*1** | ***m*2** | ***m*3** | **Fuzzy Score (*A*)** | | | |
| E1 | 0.103 | 100.0% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.867 | 4 |
| E2 | 0.101 | 100.0% | 0.780 | 0.930 | 0.990 | 0.900 | Accepted | 0.910 | 1 |
| E3 | 0.098 | 90.0% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.900 | 3 |
| E4 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.910 | 1 |

Based on **Table 8**, the findings show that the percentage of the total agreement that exceeds 75% indicates the extent to which the terms of the expert agreement on this item have been met, with a value of 90%. The maximum value of defuzzification evaluation is 0.95, while the minimum value is 0.72. Furthermore, the defuzzification of all Alpha-Cut (averaging of fuzzy response) for all items surpasses α-cut ≥0.5. The researchers decided not to discard any item.

**Table 8.** Skill development through realistic simulations—Defuzzification process and analysis.

| Item | Condition of triangular fuzzy numbers | | Condition of defuzzification process | | | | Experts consensus | Accepted elements | Position |
|---|---|---|---|---|---|---|---|---|---|
| | **Threshold value, *d*** | **Percentage of experts group consensus, %** | ***m*1** | ***m*2** | ***m*3** | **Fuzzy Score (*A*)** | | | |
| F1 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.920 | 3 |
| F2 | 0.101 | 100.00% | 0.780 | 0.930 | 0.990 | 0.900 | Accepted | 0.920 | 3 |
| F3 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.820 | 25 |
| F4 | 0.103 | 90.00% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.737 | 26 |
| F5 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.873 | 22 |
| F6 | 0.098 | 90.00% | 0.820 | 0.950 | 0.990 | 0.920 | Accepted | 0.903 | 17 |
| F7 | 0.103 | 90.00% | 0.800 | 0.940 | 0.990 | 0.910 | Accepted | 0.910 | 9 |
| F8 | 0.155 | 100.00% | 0.740 | 0.890 | 0.970 | 0.867 | Accepted | 0.900 | 18 |
| F9 | 0.162 | 100.00% | 0.760 | 0.900 | 0.970 | 0.877 | Accepted | 0.920 | 3 |
| F10 | 0.128 | 100.00% | 0.760 | 0.910 | 0.980 | 0.883 | Accepted | 0.910 | 9 |

Experts rearranged the agreed-upon items in **Table 9** based on their ranks. These items, labeled from A to F, form the constructs required for framework development. The ranking of these items is determined by analyzing the average consensus percentages provided by the experts, reflecting the importance of each item within the framework. The study’s ranking of constructs and elements offers significant insights into the effectiveness and importance of various components within the VR food safety training application. “testable prototype creation” and “engagement craft” secured the top positions (95%), underlining the critical role of realistic environments and interactive features in ineffective training. Close behind, “personalized and adaptive learning support (dynamic difficulty adjustment” (95%) underscores the importance of personalized learning experiences. The recognition of “skill development via realistic hazard simulations” (94%) emphasizes the necessity of practical hazard identification skills. While “technical infrastructure configuration “(91%) remains highly valued,” personalized and adaptive learning support (feedback and guidance)” (88.5%) slightly trails yet still highlights its crucial role in learner support. These findings guide further application refinement, emphasizing the need for immersive design, interactivity, adaptive difficulty, hazard recognition, and robust feedback mechanisms to enhance training efficacy and user experience.

**Figure 1** illustrates the overall process of designing the VR-based safety tool framework as outlined in this study

**Table 9.** Rank of components.

| Construct | Elements | Average experts’ consensus percentage of all items | Rank |
|---|---|---|---|
| A | Technology infrastructure configuration | 91% | 5 |
| B | Testable prototype creation | 95% | 1 |
| C | Engagement craft | 95% | 2 |
| D | Personalized and adaptive learning support (feedback and guidance) | 88.5% | 6 |
| E | Personalized and adaptive learning support (dynamic difficulty adjustment) | 95% | 3 |
| F | Skill development through realistic simulations | 94% | 4 |

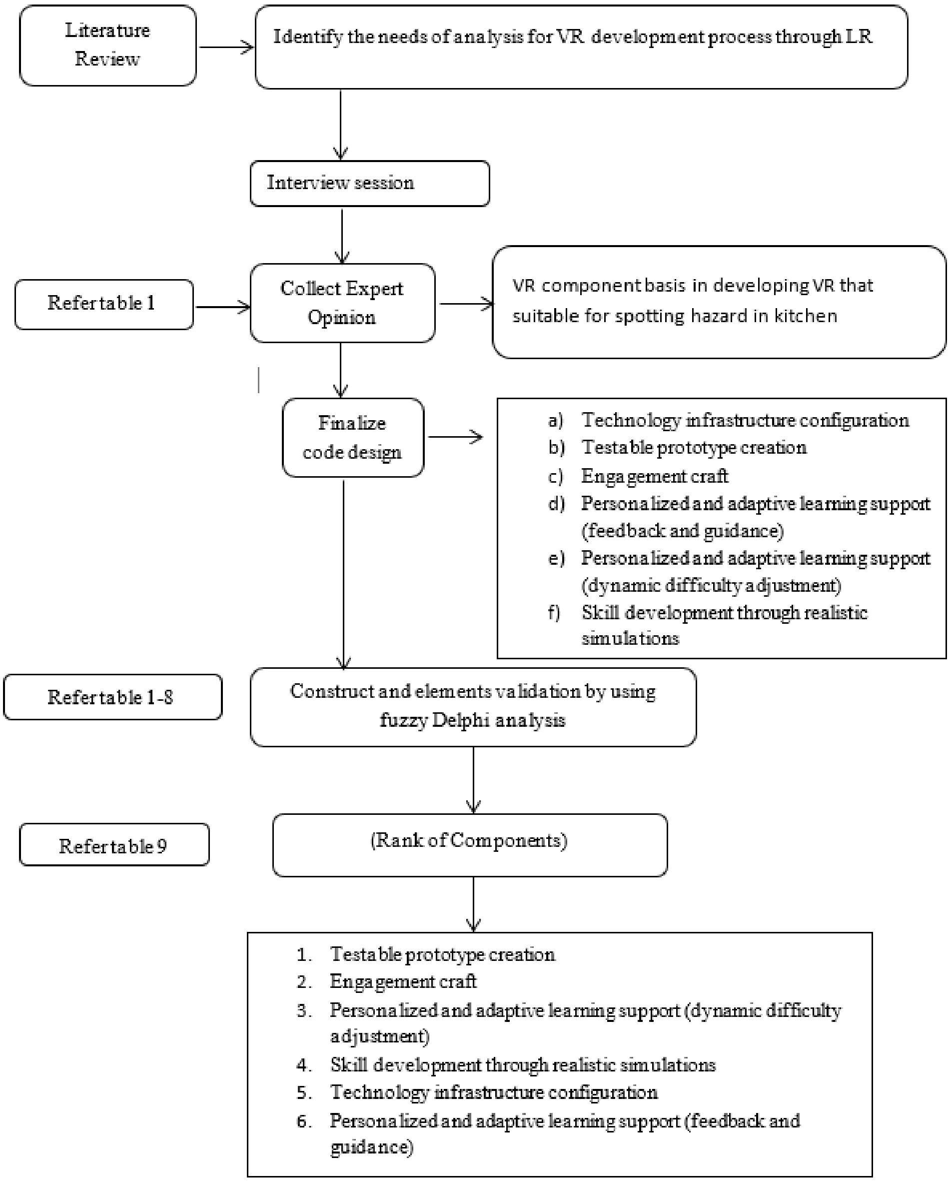


**Figure 1.** VR-based safety tool framework.

## 4. Discussion

The findings of this study have an impact on the development of a framework for VR-based kitchen safety in improving the hospitality industry's safety standards and training methodologies within commercial kitchen environments in a few scopes as the following:

- Integrating an inclusive framework based on the perspectives of both academia and industry experts in hospitality TVET

Exploring the perspectives of both academia and industry experts on the progressive development of VR-based safety tools tailored for TVET in commercial kitchen settings offers valuable insights for enhancing safety standards and training methods. These VR-based tools are crucial in addressing various risks workers encounter in commercial kitchens, including physical, chemical, biological, ergonomic, and psychosocial hazards. Furthermore, integrating VR-based tools into TVET's hospitality programs can create a more immersive and engaging learning experience, fostering a culture of safety awareness and adherence among trainees (Jeinie and Nor, 2022; Lee et al., 2023; Saad et al., 2023).

The findings from a thematic analysis show six themes: technology infrastructure configuration, testable prototype creation, engagement/engage craft, personalized and adaptive learning support (feedback and guidance), personalized and adaptive learning support (dynamic difficulty adjustment), and skill development through realistic simulations. Twelve experts agreed that these six components suit the VR-based safety training framework for TVET hospitality. Our findings are aligned with those of Belanich et al. (2022), except for testable prototype creation and engagement craft, which are new components.

- Formulation of a validated VR-based safety training framework as a practical VR-based industry's safety standards for both academia and industry experts in hospitality TVET

The Fuzzy Delphi technique validated the six components of VR-based safety training frameworks. Twenty-one experts agreed that all components should be rearranged. The results show that the highest rating is testable prototype creation, followed by engagement craft, personalized and adaptive learning support (dynamic difficulty adjustment), skill development through realistic simulations, technology infrastructure configuration, and personalized and adaptive learning support (feedback and guidance). Interestingly, besides the last two components, the defuzzification process reveals that all experts agreed to accept all items in the constructs. For the technology infrastructure configuration, the defuzzification process rejected the item "equipping motion controllers to enable trainees to interact with the visual environment effectively". The feedback and guidance of the rejected item were "stimulating activities like following recipes and preparing ingredients to add substantial value to VR safety training".

In our findings, the first ranked component, which is the testable prototype creation, is selected to be crucial because it focuses on the visual of prototypes or designs to enhance the immersive learning experience for the user, as highlighted by Chu and Kao (2020) and Mast and Van Den Berg (1997) in the design of the prototype in a VR environment must focus on constructing, communicating, and evaluating the overall performance of prototypes. The second rank from the results is engagement craft, a new component of this framework. Engagement craft is essential as it shows users' attitudes toward experiencing the technology and being more engaged in learning, as Irshad and Perkis (2020) mentioned. This study also supported Moore (2023), who stated that interactive applications influence engagement by creating interactive digital storytelling that humans can experience with realistic scenarios that capture learners' attention and increase engagement.

Furthermore, the experts identified personalized and adaptive learning support as the third component, which entails tailoring difficulty levels according to individual evaluations and emphasizing real-time performance assessment. The study echoed the findings by Peng et al. (2019) in highlighting how this approach generates personalized learning pathways driven by AI and machine learning, enhancing motivation and satisfaction, and Sun (2023) in highlighting the critical role this component plays a crucial role in monitoring the environment's learning process. In addition, the fourth component generated by this study, which focuses on development through realistic simulations involving direct physical interaction between the object and the trainee, is consistent with Chu and Kao (2020), Magar and Suk (2020) and Xie et al. (2021) in emphasizing the importance of skill development progresses through training phases requiring physical setups such as classrooms and laboratories, the inclusion of this component aims to offer real-world training with authentic design via virtual environments, leveraging VR for increased effectiveness and immersion.

The second last component of the VR-based safety training framework is the technical infrastructure configuration, which emphasizes the importance of robust hardware and software specifications. It highlights the need for dedicated hardware implementations to optimize performance for safety training tasks within the constrained nature of task processing, as emphasized by Purwanto and Tawar (2024) and added by Cieri et al. (2021) in considering the technical infrastructure as a valuable tool that improves the efficiency of coloring, translating, and scaling in VR systems, which can create excitement among users. This study also aligns with Purwanto and Tawar (2024) in emphasizing the necessity of designing dedicated hardware to overcome processing constraints. Similarly, Cieri et al. (2021) recognize technical infrastructure as a valuable tool for enhancing efficiency in VR systems, potentially fostering user excitement through improved coloring, translating, and scaling capabilities. In short, our findings provide insights into enhancing safety standards. Our framework addresses various hazards and improves learning experiences.

## 5. Conclusion

In summary, this paper has established a VR-Based safety tool framework for Hospitality TVET based on Fuzzy Delphi Analysis among academics and industrial experts. Based on examining viewpoints from academia and industry experts regarding the innovative advancement of VR-based safety tools customized for TVET within the commercial kitchen settings of the hospitality industry has yielded invaluable insights for enhancing safety standards and training methodologies. This research contributes practical guidelines for implementing effective VR-based safety training in TVET hospitality programs, fostering a culture of safety awareness and adherence among trainees. The study successfully achieved its objectives of crafting an all-encompassing framework for VR-based kitchen safety within TVET hospitality programs and validating its credibility.

By meticulously analyzing expert viewpoints, the research identified six essential components for constructing the VR safety framework: technical infrastructure configuration, testable prototype creation, engagement craft, personalized and adaptive learning support, and skill development with realistic simulation for hazard identification. This continuous research seeks invaluable insights into the most recent advancements in VR-based safety tools tailored for TVET within commercial kitchen settings. This study also supported the TAM model that aims to foster a lively exchange of scholarly ideas propelled by innovative technology, outstanding service, and unwavering dedication. Industry engagement is essential for propelling safety protocols forward in culinary environments, delivering substantial advantages to aspiring learners and experienced professionals.

In summary, establishing the formula for a VR-based safety tools framework represents a notable stride in improving safety protocols and training methods in hospitality TVET. The hospitality sector must promptly acknowledge the study's outcomes, which have been reviewed by academia and industry experts, regarding the significance of VR-based visualization technologies in safety training planning and management within TVET commercial kitchens. Future research could delve into the enduring effectiveness and scalability of VR-based safety training programs, identifying barriers to implementation and strategies to overcome them.

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