CHAPTER III
RESEARCH METHOD

This section describes the research process of this study, including the design, subjects or participants, population, sample, instruments, detailed procedures, and how the data would be analyzed to produce research outcomes. The following sections provide details of the research method used in this dissertation.

3.1 Research Paradigm

This study aims to develop a digital competency model for general and vocational educators, proposing it as a recommendation for enhancing digital competency in education in Indonesia and globally, with a focus on both general and vocational areas. The development is based on the urgent need for a new framework in the world of work that requires workers to master digital-based competencies and the increasing development of technology in the AI era. In contrast, the digital competency framework or model for educators has not been updated and was last created in 2017 by the European Commission. Therefore, this study conducted a preliminary analysis to incorporate the previous framework components into this new framework, but it will be strengthened with the vocational field.

The creation of this research paradigm refers to several identified problems such as ethical issues in the use of digital technology, especially the emergence of AI, the issue of digital competency needs for educators who must integrate technology in learning and for vocational educators who must prepare technology readiness for students to be ready to work, Sustainable Development Goals (SDGs) 4 quality education, challenges in implementing vocational education that must adapt to industrial developments, the need for digital competency development in general and vocational education.

The research paradigm used is based on a pragmatic approach, which integrates quantitative and qualitative research methods to achieve research objectives holistically (Brézillon et al., 2023). This approach allows for in-depth exploration of the concept of digital competencies through literature and surveys to understand the practical needs, perceptions, and experiences of stakeholders, such as educators and experts in the field of digital competencies. In addition, expert assessment in qualitative research through FGD ensures its validity (trustworthiness) and empirical validity. This pragmatic approach is in line with the nature of development research that is oriented towards practical and applicable solutions, especially in integrating digital competencies into the implementation of learning and vocational education curricula as mandatory competencies that must be mastered by teachers in the technological era (Ambrož, 2024). This paradigm also reflects a commitment to real-world relevance, contributing to solving global problems such as the need for a digitally and technologically competent workforce. The research paradigm is illustrated in Figure 3.1.

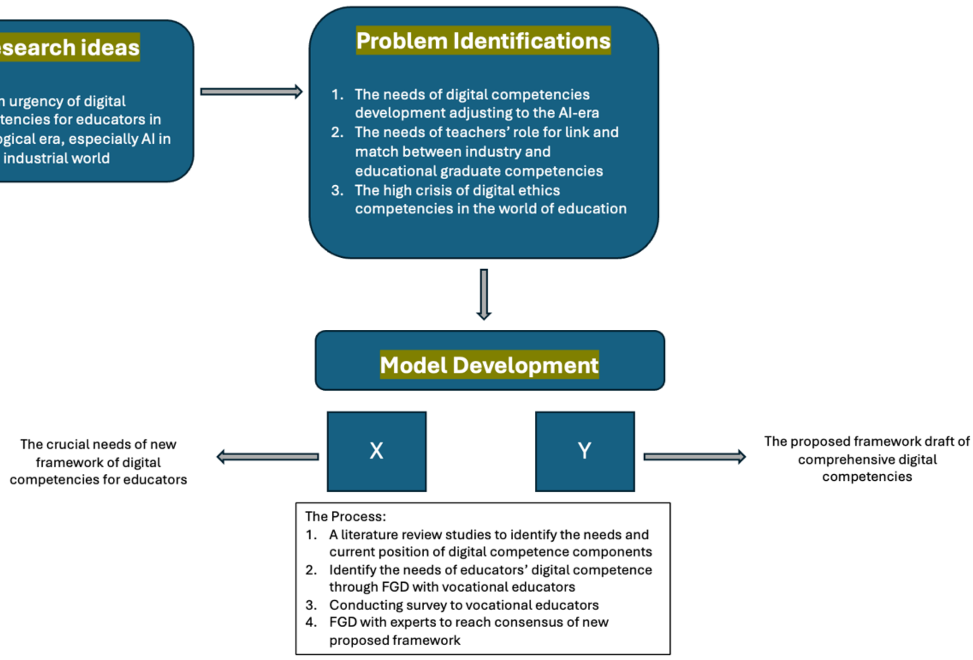


Figure 3.1 Research Paradigm

3.2. Research Design

This study starts with the global urgency for educators, especially in vocational fields, to develop digital competencies alongside their teaching skills and expertise aligned with industrial development. Vocational education plays a crucial role in equipping graduates with the technical skills, awareness, and competence needed to adapt to technological advancements, particularly in the industrial sector, which is referred to as digital competencies, especially for educators. The digital competence framework for educators is a product of this research.

The DBR cycle was selected as the main approach because it aligns well with the evolving context of competency development in vocational education, which must stay current with research progress and maintain a strong connection between education and industry. The components of digital competence identified through the Systematic Literature Review (SLR) serve as references for creating survey instruments, including pairwise comparison surveys for experts to reach consensus on developing a new framework. Additionally, a survey was conducted with vocational teachers across Indonesia to gather insights on the demand for digital competencies in various aspects of technology implementation within vocational settings, especially for educators.

The digital competence applied in a pairwise survey includes 11 main components: information and data literacy, communication and collaboration, digital content creation, digital safety, problem solving, professional engagement, digital resources, digital teaching and learning, digital assessment, empowering learners' digital skills, and facilitating learners' digital competence. The components were combined from the two most cited digital competence frameworks developed by the European Commission, namely DigComp and DigCompEdu. Each component is designed to serve as a standard for educators to achieve a certain level of digital competence. Effective integration of digital competence in vocational education requires a systematic and evidence-based approach.

This study proposes developing a conceptual model using the Multi-Criteria Decision Making (MCDM) approach, specifically employing AHP, TOPSIS, and SAW. This approach is chosen because of its ability to handle complexity and uncertainty in decision-making and to prioritize dimensions and indicators of digital competence based on input from experts and teachers as stakeholders. The development of the model relies on the weighting results from the Fuzzy results, which are then analyzed using the sensitivity analysis. The constructed model is subsequently validated by experts through FGD to gather feedback and suggestions for improving competencies based on their experience and insights.

The result of this framework is the latest version of the digital competence framework for educators. This newest version covers a broader range, including both general education and vocational education. Therefore, the competence for general education remains the same as in the previous version but has been revised with new competency components based on recent findings. Researchers also included a specific section of competencies that teachers in vocational education must master.

This model not only helps align teachers' digital competence needs with the overall educator competencies but also offers guidance for policymakers. Additionally, it supports educational institutions in integrating technology into learning and provides supporting documents or references for enhancing digital competence to promote lifelong learning. Consequently, this model is expected to increase the relevance of vocational education in addressing global challenges and meeting the needs of a sustainable workforce with skilled educators in the digital age. The figure 3.2 visualizes the development process of this model framework.

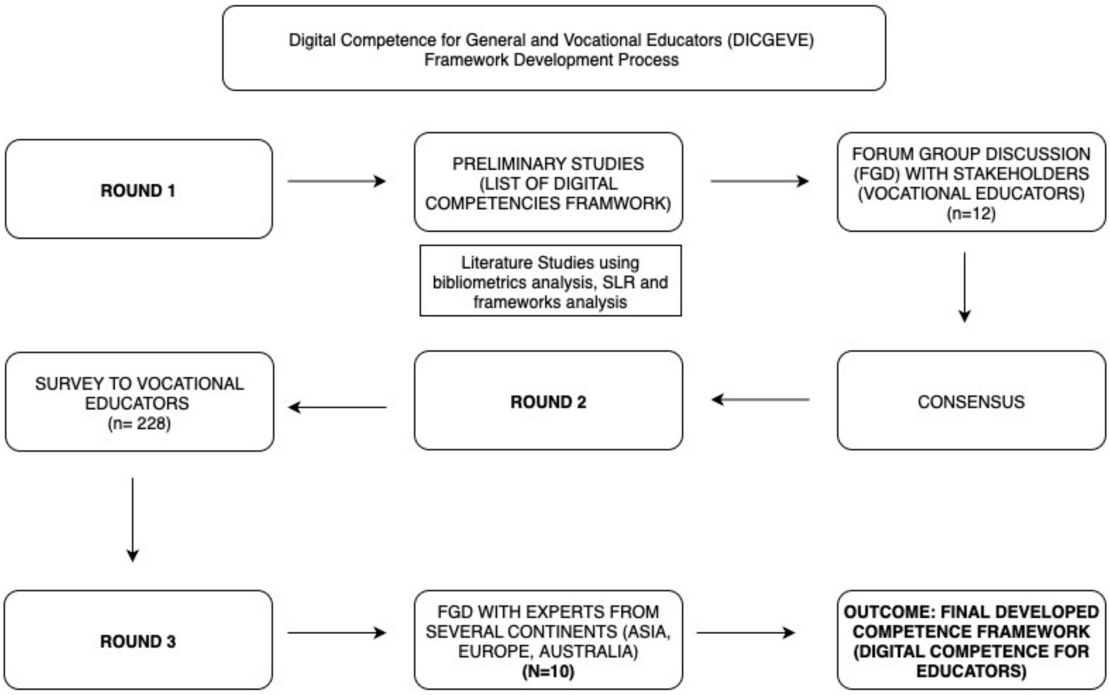


Figure 3.2 Development Process

3.3. Participants

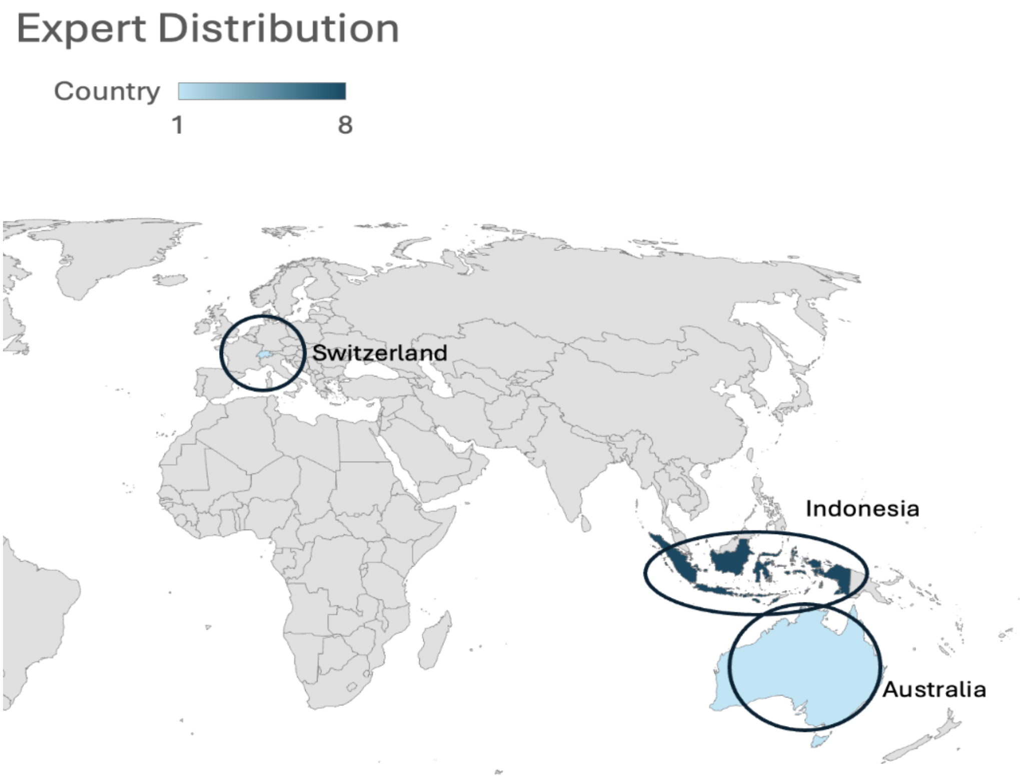
This research involves various parties in its stages, each stage using different methods and participants. The following section describes the participants involved, based on the research approaches employed during the research stages. This survey included participants from various backgrounds, including educators and experts. The educators involved are individuals from diverse levels and specializations who are officially registered as vocational education teachers in both public and private institutions across Indonesia. These teachers instruct either general or vocational subjects and may be employed in various types of schools. Additionally, some participants hold administrative positions within educational institutions, such as principals, vice principals, responsible for curriculum, student affairs, industrial relations, and infrastructure. Such roles may involve both direct and indirect participation in the survey, thereby enhancing the reliability and validity of the research. Furthermore, vocational education teachers originate from multiple regions throughout Indonesia, allowing the findings to reflect the diverse characteristics of vocational high schools nationwide. Figure 3.3 visualizes the distribution of the participant sample.

The study involved 10 vocational high school teachers from two schools, each specializing in electrical engineering, audio-visual engineering, and creative and entrepreneurial products (see Table 2). No teachers from general subjects took part. Purposive sampling was used to select participants for the FGD, ensuring that the data collected matched the research goals and participant criteria (Campbell et al., 2020). The researcher specifically targeted educators with a minimum of ten years of professional experience and holding relevant qualifications. To ensure the reliability and validity of the data, the study employed participant triangulation within FGD.

Participants were deliberately selected to encompass a diverse range of educational backgrounds, including vocational teachers with bachelor's and master's degrees, as well as individuals who have completed the teacher professional certification program. This heterogeneous composition of participants facilitated a comprehensive exploration of digital competence, spanning from fundamental pedagogical techniques to advanced instructional strategies. Such diversity enhanced the robustness of data analysis through cross-validation processes and mitigated the potential for biased interpretations.

A prolonged engagement with the participants was undertaken to establish trustworthiness prior to the FGD. This engagement occurred one week in advance and involved visits to the schools, where participants were provided with invitation letters along with the terms of reference for the FGD meeting. Culturally representative pseudonyms have been used for confidentiality. There were more females than males, representing the TVET teaching workforce. There were 6 females and 4 males in this study.

The selection of experts was using convenience sampling method through the researchers' relation but selectively chose the incredible expert in their field (Education, TVET, and IT). Those fields of expertise were purposively chosen to broaden the insight of digital competence urgency in vocational educational field. The prolonged engagement of the experts was comparable to that of the educators. The researcher had prior personal interactions with these individuals before the FGD and personally invited them to participate. Additionally, the researcher met with the Australian expert in person and regularly conducted virtual meetings with the European expert to facilitate collaboration, emphasizing his prominence as a specialist in TVET digital competence across different continents. The experts in this FGD totaled 10, with eight from Indonesia, one from Australia, and one from Switzerland.



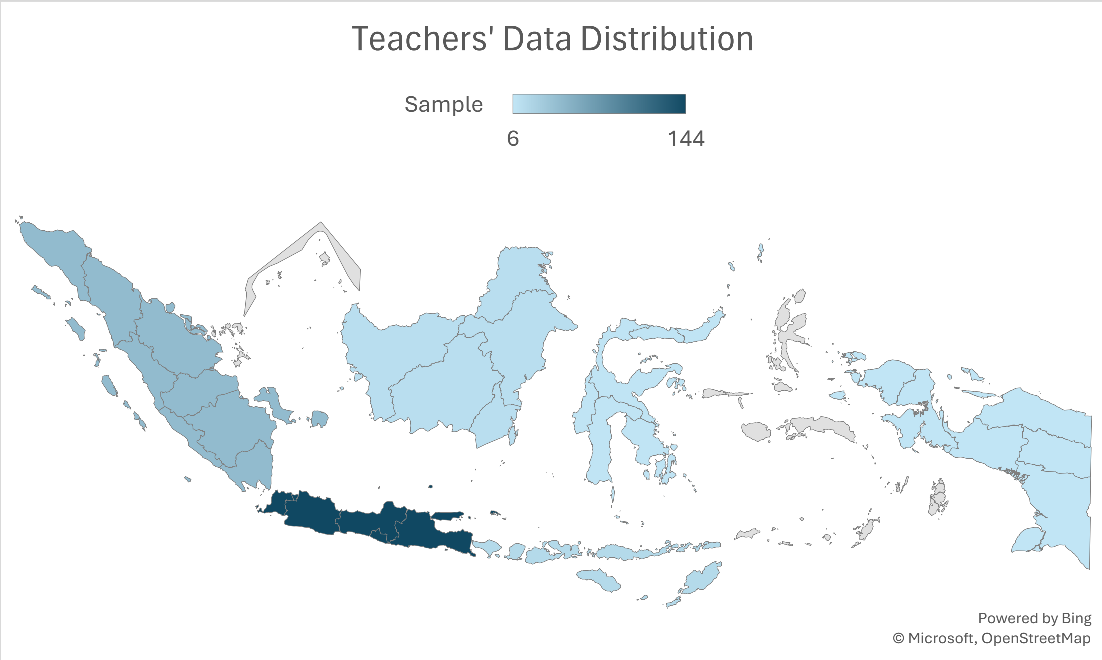


Figure 3.3. Sample Distribution of Vocational Educators and Experts

3.4 Data Collection

The data collection will be divided into four stages, starting from preliminary studies using SLR and bibliometrics analysis, FGD phase 1, Survey to vocational educators, FGD phase 2 followed by pairwise survey.

Preliminary Studies

The present study conducted systematic literature reviews and bibliometric analyses to elucidate research trends pertaining to the digital competence of vocational high school educators. Notably, the bibliometric and review components predominantly utilized data derived from the Scopus database to ensure robustness and credibility. A systematic review is characterized by an exhaustive evaluation of all pertinent research related to a defined question, topic, or phenomenon, with the objective of providing an objective, comprehensive, and transparent synthesis of the research landscape through a methodologically rigorous approach (Barbara

Kitchenham & Charters, 2007). Furthermore, bibliometric analysis is emerging as a progressively recognized and esteemed methodological approach for the investigation and evaluation of extensive scientific datasets. This technique enables a nuanced examination of the subtle transformations that have occurred throughout the historical development of a specific field, while also providing light on the developing aspects of that discipline (Donthu et al., 2021).

Preliminary studies, comprising two comprehensive literature reviews, were undertaken as part of this dissertation. These reviews utilized systematic literature review methodologies and bibliometric analysis techniques, initiated during the period of 2021-2022. The systematic review of the literature facilitates the identification and synthesis of relevant prior findings, thereby enabling a comprehensive understanding of the research problem within the context of the study (Barbara Kitchenham & Charters, 2007). The following are the eligibility criteria for the systematic literature review:

Table 3.1 Eligibility Criteria of SLR Data

The inclusion criteria:
• The articles are related to the vocational educators' digital competence;
• The articles use English as its language;
• The articles are not a pre-proof type of paper; and
• The articles are published in a journal;
The exclusion criteria:
• The articles are not related to the vocational educators' digital competence;
• The articles do not use English as its language;
• The articles are a pre-proof type of paper; and
• The articles are not published in a journal;

This study used keyword construction for the bibliometric analysis as follows:

(TITLE-ABS-KEY ("Digital literac" OR "digital skill*" OR "digital abilit*" OR "digital competenc*") AND TITLE-ABS-KEY ("vocational*

high school" OR "secondary vocational school*" OR "vocational*" OR "engineering edu*" OR "technical edu*" OR tvet OR vet OR "career technical education (CTE)") AND TITLE-ABS-KEY (teacher* OR educator*)) = **238 Documents***

FGD Phase 1 with Vocational Educators

The FGD phase 1 was conducted for collecting the data for the vocational educators' insights, experiences, and challenges. The FGD lasted 1.5 hours in a single room where all participants, moderators, and research team members gathered. The moderator asked a question to 2-3 randomly selected participants, who responded while others wrote their answers on notes. The process then repeated with new questions, each directed to 2-3 participants, with others writing their responses. This cycle continued until everyone had answered all questions. The procedure was repeated three times, following a method similar to Nyumba's for FGDs (O.Nyumba et al., 2018).

FGD enables detailed discussions among participants, allowing a thorough exploration of the topic through lively and interactive conversations (Belzile & Öberg, 2012). The initial FGD took place in person in Bandung on October 6, 2023. This research adhered to ethical standards outlined in Statement No. 29/UN40.K/PT.01.01/2024. A convenience sampling method was employed to select participants for the FGD, ensuring that the data collected were relevant to the research objectives and participant criteria (Campbell et al., 2020).

Bandung was designated as the site where participants of vocational educators engage with peers across Indonesia through an online community, thereby fostering continuous knowledge exchange. Additionally, vocational educators in Bandung are positioned to function as representatives for their colleagues, given their operation within a common curriculum framework and governance system. This congruence enhances their capacity to advocate for shared interests and address prevalent challenges within the vocational education sector. Although the geographic scope is limited, the presentation of findings employs detailed descriptions to enhance their transferability to other vocational education contexts within Indonesia.

Four research members took part in an FGD alongside three researchers and one PhD student. The session was moderated by a PhD student with experience in vocational education and digital competence research, who is currently conducting this study as the principal investigator. Several PhD students from the TVET study program also served as administrators, and recording the meeting minutes. Prior to the FGD, the research team convened to prepare the questions for the teachers. Several days before the meeting, teachers and experts received a guide outlining the topics to be discussed. The FGD questions were designed and developed by a team of four researchers, three of whom have substantial expertise in the field. This development process was guided by the European Commission's Digital Competence for Educators (DigCompEdu) framework (Redecker, 2017).

National Survey of Vocational Educators

The second phase of data collection in this study was conducted through an online survey targeted at vocational education teachers in Indonesia. This survey was designed to gather teachers' perceptions of their digital competence and to identify priority dimensions relevant to the vocational education context. The survey was distributed via Google Forms, allowing efficient outreach to respondents across diverse regions.

The survey instrument consisted of a series of statements derived from a validated digital competence framework developed through literature reviews and expert validation. Before being widely distributed, the instrument underwent a pilot test involving 50 vocational teachers to assess the clarity of language, structure of questions, and estimated completion time. Based on the pilot, the instrument was refined and analyzed for both validity and reliability, resulting in a Cronbach's Alpha score of 0.905, indicating a high level of internal consistency.

All items in the questionnaire employed a five-point Likert scale. Although the data collected were ordinal, they were treated as interval data for the purpose of conducting descriptive and inferential statistical analysis. The survey was conducted over a one-month period, from September 1 to 30, 2023, and collected 228 responses from vocational teachers.

FGD Phase 2 and Pairwise Survey with Experts

The experts for the FGD phase 2 were carefully selected from different continents to provide insights based on their expertise and experience, enriching this research's findings. An Australian expert was included because Australia has a strong vocational education and training system. Additionally, the Australian expert's contributions to this study are supported by their research outputs and their recognized roles in the global vocational education and industrial sectors. The European and Australian experts made a significant contribution to the advancement of this study's findings due to his specialized expertise in digital competence within vocational education. In the European context, vocational education often serves as a key model for other nations, thereby increasing the study's relevance and applicability.

The process of FGD as data collection was similar to the FGD phase 1. The FGD phase 2 was conducted on October 6, 2024, at the meeting room attended by 10 experts from Indonesia. However, due to time constraints, the experts from Europe and Australia did not attend on the same day or at the forum. Therefore, the researcher conducted a semi-structured interview with the same questions asked to the experts in the FGD through a virtual meeting. They also fulfilled the pairwise survey for further analysis.

Three researchers participated in a focus group discussion (FGD) alongside three researchers and a PhD student. The session was led by a PhD student with expertise in vocational education and digital competence research, who is leading this study as the principal investigator. Several PhD students from the TVET study program also served as administrators, taking notes on the meeting. Before the FGD, the research team met to prepare questions for the experts. A few days before the meeting, the experts received a guide outlining the topics to be discussed.

The FGD questions were designed and developed by a team of three researchers, three of whom have significant expertise in the field. The questions centered on topics such as insights and recommendations for implementing technology integration in the classroom, the importance of digital competence in both general and vocational education, and suggestions for future competence for digital. The pairwise survey for the MCDM results was created using a Jotform tool to build the pairwise survey, resulting in a countable MCDM survey.

3.5 Population and Sample

This study used a purposive sampling method, which involves selecting samples based on specific criteria relevant to the research goals. Purposive sampling was chosen because this study specifically focused on vocational education teachers with experience in using digital technology in their teaching. The respondents were drawn from various regions across Indonesia, though the distribution was uneven. Out of a total of 228 respondents, most were from Java (63.2%), with fewer from Sumatra, Bali and Nusa Tenggara, Kalimantan, Sulawesi, and Papua. This imbalance was due to limited access and different levels of teacher participation in each region. As a result, while the study aimed to describe the digital competence of vocational teachers nationwide, the data primarily reflect the conditions of teachers in Java and other more accessible areas, due to the availability of networks and professional communities.

Ideally, the sampling process should target a geographically and demographically diverse population of Indonesian vocational teachers through stratified random sampling, thereby ensuring proportional representation across various regions. However, due to practical constraints in accessing all regions of Indonesia and the exploratory nature of this study, purposive sampling was employed as the most feasible method to gather data from teachers actively engaged in technology-enhanced learning initiatives. As a result, the findings predominantly reflect the conditions of vocational educators in regions with relatively advanced educational infrastructure and may not fully capture the heterogeneity of the national context. This limitation should be carefully considered when interpreting the implications and generalizability of the research outcomes.

In this study, purposive sampling is based on the characteristics of vocational education teachers involved in digital technology use, influenced by accessibility and professional networks. Accessibility pertains to researchers' ability to reach respondents across Indonesia, considering constraints like time, resources, and communication infrastructure in remote areas, which hinder online access. Data collection primarily focused on regions with stable internet, active teacher communities on social media and online platforms, and established collaborative networks with professional associations.

Moreover, the researcher's personal and professional ties with teacher groups and vocational networks in Indonesia facilitated respondent recruitment, especially in areas connected through training, seminars, or professional development events. These relationships helped identify teachers with relevant experience and interest in digital competency development. However, reliance on this relational network may introduce selection bias, as respondents often come from groups active in self-development and digital access, potentially underrepresenting teachers in remote areas or those with limited technology access. Consequently, accessibility and relationships significantly influence sample characteristics and are limitations when generalizing research findings.

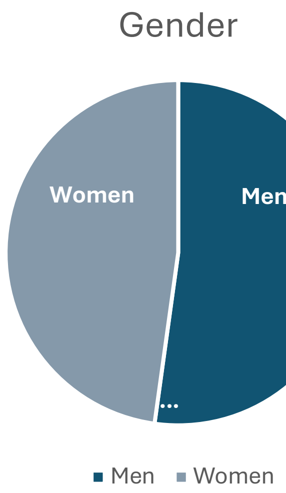


Figure 3.4. Gender Distribution

The study's population consisted of vocational educators and experts in vocational and general education in Indonesia, whose expertise encompassed teaching and learning processes across various educational institutions. To accurately represent the characteristics of vocational education in Indonesia, a convenience sampling method was employed for the FGD, while a purposive sampling technique was utilized for the survey. This combined approach was intended to enhance the representativeness of the sample and minimize potential biases in data collection. Figure 3.4 determines the ratio of gender distribution of the participants in this research.

The convenience sampling method was meticulously employed to select participants for the FGD, ensuring the inclusion of individuals with relevant expertise and experience. The selected participants comprised seasoned educators and subject matter experts. This strategic selection aimed to facilitate meaningful engagement and facilitate the sharing of in-depth insights and experiences within a conducive environment. Additionally, participant consent was obtained, as evidenced by the ethical clearance granted by the Ethics Committee of Universitas Pendidikan Indonesia, thereby ensuring adherence to ethical research standards.

3.6 Research Instruments

There are several instruments used in this study regarding data collection. The first data collection was from an FGD with vocational educators, asking for their insights and experiences during the implementation of their digital competence at school. The questions asked to the vocational educators were based on the components and sub-components of selected digital competence frameworks. The second data collection was using research instruments comprising questionnaires for vocational educators which was collected through google form. This questionnaire was derived and based on from the results of first FGD with vocational educators which then explain through the results.

A guideline for the FGD with experts also comprises the questions from the selected frameworks. Then, the pairwise survey instruments are constructed into 55 pairwise questions that should be filled by the experts at the last session of FGD. All instruments have undergone rigorous validity and reliability testing, as well as expert validation, to ensure their appropriateness and relevance within the context of vocational education in Indonesia. The survey instrument was developed in questionnaire form, derived from the identification of dimensions and subdimensions in the initial conception. The FGD pairwise questions set includes 11 competencies, organized into dimensions of digital competencies, which serve as the basis for item of survey.

A survey was conducted using a pairwise method by combining various components from previous literature. This survey was then directly counted as a pairwise result for expert, which was then analyzed using multicriteria decision making (MCDM) method through three analyses of AHP, TOPSIS, and SAW as explained in the methodology process.

3.7 Data Analysis

The analysis of this dissertation employed a range of methods that combined quantitative and qualitative approaches, utilizing various materials and data collection techniques. These included FGD with stakeholders, surveys of stakeholders (vocational teachers in Indonesia), and FGD with digital competence experts across different continents (Asia, Australia, Europe). The data included both quantitative and qualitative information, which would be further analyzed. However, the research initially began with preliminary studies using two methods: literature reviews, SLR and bibliometrics analysis. The following process describes the data analysis for each material.

3.7.1 Preliminary Studies

The data extracted from the Scopus database, as the beginning of the preliminary study process, was processed using OpenRefine software and subsequently analyzed through VOSviewer. The subsequent phase of the research involves problem identification, which allows for a more targeted focus on the research issue; this is facilitated by establishing research limitations that narrow the scope and refine the outcomes. The third phase involves developing a theoretical framework to clarify the research objectives. The theoretical foundations considered in this study include digital competence for vocational educators and digital competence for educators. Furthermore, the researcher conducted a systematic literature review to gain a deeper understanding of previous studies on digital competence needs in vocational education, based on literature reviews. An SLR is employed to define the concept of digital competencies from a worldwide viewpoint.

This method facilitates a comprehensive examination of the various dimensions and subdimensions of digital competencies through the analysis of relevant articles, using both manual and digital techniques. This study's SLR adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). This study involves a document analysis of reputable scientific journals and proceedings articles. Activities in the SLR method include selecting, identifying, and synthesizing. The PRISMA flow diagram in Figure 3.5. visualizes the process of the literature studies in this research. The preliminary studies also conducted to collected the prominent previous frameworks to be selected as the suitable guiding framework.

3.6.2. Survey Studies

This survey was conducted among vocational educators in Indonesia to assess their acceptance of various technologies and to evaluate their digital competencies across multiple dimensions. The analysis included inquiries regarding the infrastructural resources available to teachers for technology integration, pedagogical practices, and their digital proficiency levels, with a particular focus on vocational education contexts. Additionally, the study examined demographic distributions to provide a comprehensive overview of the participating educators. The survey instrument was created based on the framework of digital competence for educators. The survey instrument was developed based on the digital competence framework for educators and validated by expert supervisors. A descriptive study was conducted to analyze the survey results.

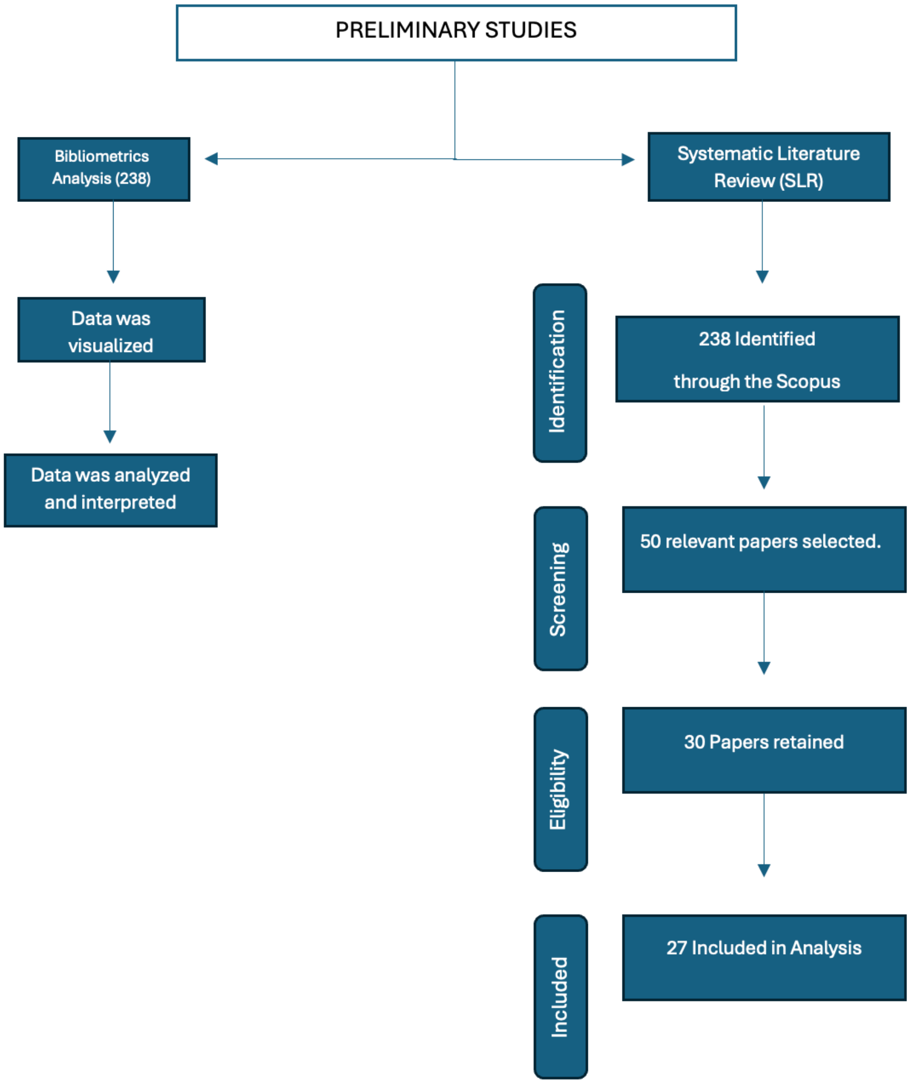


Figure 3.5 PRISMA Flow

3.6.3. Focus Group Discussion (FGD) analysis (Thematic Analysis and MCDM Studies)

In order to answer our three last research questions, including:

a. What are vocational educators' perceptions, needs, and challenges regarding digital competence in classroom practice?

b. Which components of digital competence are prioritized by vocational educators and educational experts?
c. How reliable are digital competence indicator prioritization results using Fuzzy AHP, SAW, and TOPSIS under various weighting scenarios?

A qualitative and quantitative research method using Focus Group Discussions (FGDs) and Survey were chosen.

Qualitative analysis

The data analysis process for the FGD was similar between the FGD phases 1 and 2. Therefore, in this section of qualitative analysis, the researcher explains two processes of qualitative results from FGD. The TAM model was used to analyze the results of both FGD phases 1 and 2 through thematic analysis.The FGD was transcribed, and participant notes or reflections were digitized. All transcripts were systematically translated from Bahasa Indonesia to English. To ensure translation accuracy and integrity, team members fluent in both languages reviewed them. This review confirmed that the translations accurately reflected the original content.

Table 3.2 Vocational Educators' demographic data and sampling size

School	Teacher	Education Level	Expertise	Years of teaching
School A	Kurnia	Master's degree	Audio-Video Engineering	17
	Nia	Undergraduate Degree	Electrical Installation Engineering	16
	Yosafat	Undergraduate Degree	Electrical Installation Engineering	28
	Nadia	Master's Degree	Electrical Installation Engineering	17
	Eni	Undergraduate Degree	Electrical Installation Engineering	17
	Yudha	Teacher Professional Certificate	Electrical Engineering	11
	Candra	Master's degree	Technology and Engineering	10
	Ruslan	Undergraduate degree	Electrical Engineering	17

School	Teacher	Education Level	Expertise	Years of teaching
School B	Sofyan	Teaching professional certificate	Design and Visual Communication	16
	Ninda	Undergraduate degree	Creative and Entrepreneurial Products	15
			Mean	16.34
			Standard Deviation	4.57

Table 3.3 Question categories for stakeholders and experts

	Categories	Sub-categories	Questions for stakeholders (vocational educators)
1	*Perceived Usefulness*	Enhancing digital competency	How do teachers enhance their digital competence?
		Developing digital competency	What are the difficulties for developing digital competence?
2	*Perceived ease of use*	Support of digital competency	What are the supports needed by the teachers' to enhance digital abilities?
3	*Attitudes towards technology*	Evidence of digital competency implication	How did teachers adopt online teaching during pandemic?

	Categories	Sub-categories	Questions for experts
1	*Perceived Usefulness*	Digital competencies urgency	How is the urgency of digital competence for educators, especially in the era of generative AI?
2	*Perceived ease of use*	Digital competencies components	What are the most important digital competencies for educators to be mastered and are there any proposed new competencies that are important to be mastered (in addition to existing competencies)?
3	*Attitudes towards technology*	The complexity of digital competencies in each area	what are the crucial differences between the implementation of digital competencies for general educators and educators in the field of vocational education?
4	*Perceived ease of use*	The needs of specialization in digital competencies	Is it important to distinguish the digital competence of educators in general education from vocational education?

One transcript combined the 12 verbal responses and 28 written answers to each question. The FGD included 4 questions, with a total of 40 responses (both written and verbal). The researcher analyzed the entire transcript to gain a thorough understanding of all responses. Clarifications were also obtained by directly contacting participants to clarify any ambiguities about terminology or specific answers. Data were subsequently examined through an inductive thematic analysis process (Naeem et al., 2023).

During the data analysis phase, the researcher systematically examined all responses to each item, utilizing the three categories derived from the Technology Acceptance Model (TAM): perceived usefulness, perceived ease of use, and attitudes towards technology. Initial coding was performed by highlighting salient phrases pertinent to the research objectives. These preliminary codes were subsequently organized into subcategories based on conceptual similarities. For instance, a statement referencing the use of personal devices and internet access due to limited school resources was classified under "Increasing digital competence," whereas expressions of enthusiasm for technology in conjunction with a lack of formal training were categorized as “Developing digital competence." Throughout this process, the researcher identified key remarks made by participants and collaborated with other researchers to discuss and refine the results.

The axial coding procedure facilitated the transition from subcategories to overarching themes. For instance, the theme labeled "Hardware and Internet" emerged from issues pertaining to infrastructure and accessibility. Additional themes, including “Government Training,” "Social Online Community," “Time Constraints,” and “Age Differences,” illustrate various factors influencing technology usability and professional support mechanisms. The coding process was informed by the Technology Acceptance Model (TAM), employing core constructs such as Perceived Usefulness and Perceived Ease of Use as analytical frameworks. Participant quotations were systematically assigned to respective themes through an iterative process that considered both the content and intent of the data, thus ensuring internal consistency. The resultant themes underwent collaborative review and refinement to ensure alignment with the research objectives.

Quantitative analysis

In quantitative analysis, this research conducted a survey instrument. Validity and reliability tests are two important components in evaluating the quality of research instruments. A valid instrument ensures that the measuring instrument actually measures what it is supposed to measure, while a reliable instrument ensures that the measurement results are consistent over time or between tests. Validity refers to the extent to which an instrument can measure the intended construct or variable. Validity indicates the validity of the measurement results in representing theoretical concepts (Philippi, 2021). In this study, the Pearson (Product Moment) correlation tests the relationship between the score of each item and the total score. An item is valid if the correlation value ("r") is greater than the critical value in the distribution table. The following are the steps for the product-moment correlation test:

a. Calculate the sum of each respondent's answer scores for each question.
b. Calculate the correlation coefficient for each score per item with the sum of each respondent's answer scores using the product-moment correlation.

$$r_{xy} = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{\left(n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right)\left(n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right)}}$$

Formula:

r_{xy} = correlation coefficient between variables X and Y

x_i = the i-th data value for variable group X

y_i = i-th data value for variable group Y

n = lots of data

c. Compare the value of the validity coefficient of the results (r count) with the value of the Pearson correlation constant/Pearson table (r table) at the significance level.α = 0.05 with n (appendix).

Criteria:

- The questionnaire is valid if r count ≥ r table
- The questionnaire is invalid if r count < r table.

If all the questions in the questionnaire are declared valid, then a reliability test is carried out. Reliability is the level of accuracy of an instrument in measuring what should be measured. There are three ways to test the reliability of a test, namely: (1) a single test, (2) a retest (test retest), and (3) an equivalent test (alternate test). In this case, the author uses a single test with the Split-Half Technique. This is done by dividing the test into two relatively equal parts (the number of questions is the same), so that each test has two types of scores, namely the first half score (beginning / odd-numbered questions) and the second half score (end / even-numbered questions). The test half reliability coefficient is denoted by $r_{\frac{1}{2}\frac{1}{2}}$ and can be calculated using the Spearman-Brown formula. The steps for testing the questionnaire reliability are as follows. The steps for testing the reliability of the questionnaire are as follows:

a) Calculate the number of answers for each odd and even question.
b) Calculate the correlation between the number of answers for odd and even questions using the product-moment equation to calculate the hemispheric reliability value.
c) Calculate the total reliability value using the equation (Guilford, 1950)

$$r_{11} = \frac{2r_{\frac{1}{2}\frac{1}{2}}}{1 + r_{\frac{1}{2}\frac{1}{2}}}$$

d) Then compare it with the coefficient category criteria. The reliability coefficient categories are as follows (Guilford, 1950):

$0,80 < r_{11} \leq 1,00$ Extremely high reliability

$0,60 < r_{11} \leq 0,80$ High reliability

$0,40 < r_{11} \leq 0,60$ Moderate reliability

$0,20 < r_{11} \leq 0,40$ Low reliability

$-1,00 < r_{11} \leq 0,20$ Extremely low reliability

Moreover, this study conducted an MCDM analysis to identify the key competencies that This study performed an MCDM analysis to determine the essential competencies for vocational education educators, considering stakeholder and expert viewpoints. The analysis employed three MCDM methods: AHP, TOPSIS, and SAW, with sensitivity analysis used to assess the impact of varying conditions on the results. This study employs three MCDM methods: AHP, TOPSIS, and SAW, which were subsequently analyzed for their sensitivity of change using sensitivity analysis.

Fuzzy Analytical Hierarchy Process (F-AHP) is an innovative extension of the AHP model developed by Satty, and it has been applied across different research fields in MCDM models (Asuquo & Onuodu, 2016). The fuzzy AHP technique utilizes fuzzy numbers to represent decision-making criteria, taking into account imprecise and uncertain information. The fuzzy AHP method employs fuzzy numbers to capture decision-making criteria, accommodating imprecise and uncertain data. It is extensively applied across diverse fields, including vocational education. Numerous prior studies have explored its applications, such as in this context, where it is widely used across various fields, including vocational education, with several previous studies conducted (Islami et al., 2024) which used Fuzzy AHP to determine the level of priority of advanced digital competencies of vocational education teachers.

In this study, the Geometric Mean Method (GMM) F-AHP was used to determine priorities, this decision was taken because GMM is suitable for determining priorities from various choices. The selection of the Fuzzy AHP method is the right consideration because it is relevant to research needs, especially in analyzing survey data produced in the form of rankings from three main criteria that cause complexity. This method allows data generalization by producing priority levels as the final output. The combination of AHP with the Fuzzy approach aims to improve the accuracy of information and reduce bias through the use of Triangular Fuzzy Numbers (TFN). In addition, this method has advantages in terms of simplicity of analysis, making it easy to understand by non-statisticians. The analysis process can also be done using simple applications that are widely available, such as Microsoft Excel. Here are some stages in the decision-making process using GMM F- AHP as seen in Figure 3.6.

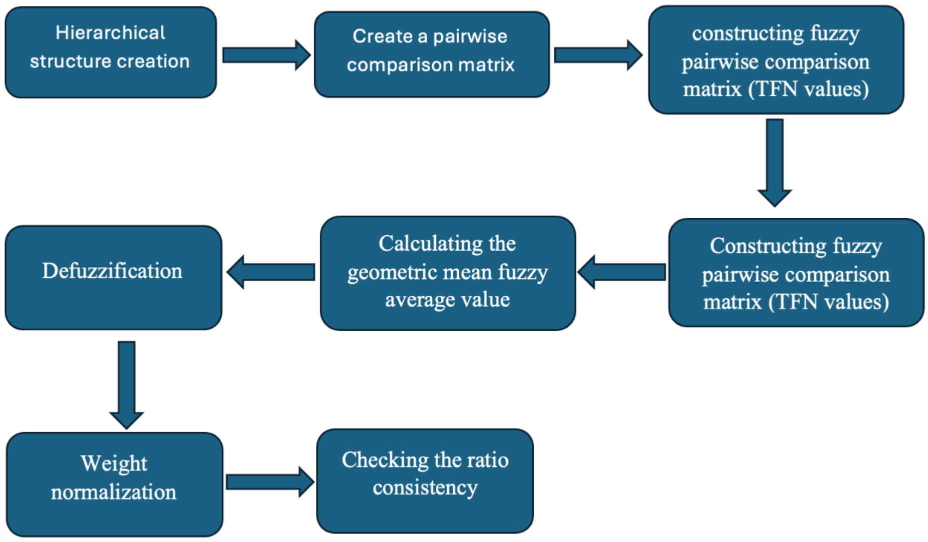


Figure 3.6 Fuzzy Process based on the data of expert panels

The process of defining criteria and sub-criteria is based on literature from various frameworks discussing the dimensions and sub-dimensions of digital competence for educators. These dimensions serve as references for developing instruments that gather expert input, which informs decision-making among multiple options. The study started with designing a questionnaire, grounded in previously identified dimensions and sub-dimensions of digital competence. This pairwise questionnaire includes 55 pairwise questions across 11 digital competency variables, allowing participants to select responses that suit their needs from several options. It was intentionally distributed to vocational educators and experts both in Indonesia and internationally through an online pairwise survey on Jotform, ensuring broad respondent reach. Subsequently, the Triangular Fuzzy Number (TFN) method was employed to perform pairwise comparisons within a matrix, facilitating the identification of prioritized competencies within the GC model. The TFN scale utilized in this study is detailed in Table 3.4.

Table 3.4. Triangular Fuzzy Number (TFN)

	Linguistic variable	Positive triangular fuzzy numbers	Positive reciprocal triangular fuzzy numbers
1	*Equally strong*	(1, 1, 1)	(1, 1, 1)
2	*Intermediate*	(1, 2, 3)	(1/3, ½, 1)
3	*Moderate Strong*	(2, 3, 4)	(1/4, 1/3, ½)
4	*Intermediate*	(3, 4, 5)	(1/5, ¼, 1/3)
5	*Strong*	(4, 5, 6)	(1/6, 1/5, ¼)
6	*Intermediate*	(5, 6, 7)	(1/7, 1/6, 1/5)
7	*Very Strong*	(6, 7, 8)	(1/8, 1/7, 1/6)
8	*Intermediate*	(7, 8, 9)	(1/9, 1/8, 1/7)
9	*Extremely strong*	(9, 9, 9)	(1/9, 1/9, 1/9)

The pairwise comparison matrix for each level of criteria and sub-criteria is an n x n matrix, where n represents the number of sub-criteria. The comparison relies on respondents' judgments and is then converted into the TFN scale. Next, a Fuzzy Pairwise Comparison Matrix is constructed. In this step, the actual values of A are transformed into fuzzy numbers to obtain the fuzzy comparison matrix.

$$A = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix} \quad (1)$$

The subsequent step involves the computation of the Fuzzy Geometric Mean (FGM) for each criterion. This process employs the GMM, originally introduced by Buckley (1985), which is utilized to determine the geometric mean of the fuzzy criteria comparisons for each criterion, as outlined in Equation (2).

$$\tilde{r}_i = \left((r_{11} * r_{21} * \cdots * \ r_{n1})^{\frac{1}{n}}, (r_{12} * r_{22} * \cdots * \ r_{n2})^{\frac{1}{n}} \cdots \cdots (r_{1n} * r_{2n} * \cdots * \ r_{nn})^{\frac{1}{n}}\right) = (r_{i1} * r_{i2} * \cdots * \ r_{in}) \quad (2)$$

The next step is to calculate the fuzzy weights. This phase involves applying a formula to determine the fuzzy weights for each criterion.

$$\widetilde{w}_i = \ \tilde{r}_i \oplus \{\tilde{r}_i \oplus \tilde{r}_2 \oplus \ldots\ldots \oplus \tilde{r}_n\}^{-1} \quad (3)$$

The next phase is defuzzification, which involves converting fuzzy data (vague or uncertain values) into precise, definite numbers. This process defuzzified the fuzzy weights using the Center of Area (COA) and Best Non-fuzzy Performance (BNP) formulas.

$$Centre\ of\ Area\ (COA) = w_i = \left(\frac{l + m + u}{3}\right) \quad (4)$$

$$BNP_{Ci} = \frac{[(U_{Wi} - L_{Wi}) + (M_{Wi} - L_{Wi})]}{3} + L_{Wi} \quad (5)$$

In the process of weight normalization, the individual weights assigned to values must collectively sum to unity. If the aggregate weight of the criteria exceeds one, the weighting scheme is deemed invalid. Consequently, weights are typically normalized to ensure that their total equals one, thereby maintaining consistency and comparability across the criteria. The final step involves conducting a consistency check to evaluate the usability of the calculated weight values. This process requires utilizing the same unnormalized pairwise comparison matrix. Initially, the Consistency Index (CI) is computed using the following formula:

$$Consistency\ Index\ (C.I) = \frac{\lambda_{max-}n}{n - 1} \quad (6)$$

$$\text{when } \lambda_{max} = \frac{\sum_{i=1}^{n} \frac{WSV_i}{CW_i}}{n} \quad (7)$$

Subsequently, 'n' denotes the total number of elements under comparison. In this context, WSV and CW correspond to the Weighted Sum Value and the Consistency Weight, respectively. The next step involves calculating the Consistency Ratio (CR) using the following formula:

$$Consistency\ Ratio = \frac{Consistency\ Index\ (C.I)}{Random\ Index\ (R.I)} \quad (8)$$

The researcher references the Random Index (RI) value from the RI table provided by Alonso and Lamata (2006). If the Consistency Ratio (CR) is under 0.10, the pairwise comparison matrix is deemed to exhibit acceptable consistency. This threshold of 0.10 is standard within the Analytic Hierarchy Process (AHP), as it permits an inconsistency level of up to 10%. Should the inconsistency exceed this threshold, the matrix must be re-evaluated and reconstructed accordingly. When the consistency check is within acceptable limits, the derived weights of the criteria may be utilized by decision-makers for subsequent analyses. Conversely, if the matrix fails the consistency test, it necessitates reconstruction to ensure valid decision-making.

Following the determination of the criteria weight, the subsequent step involves calculating the alternative weights using steps 1 to 8 for each phase. If each alternative has an associated weight for each criterion, the next phase entails computing the overall alternative weight by aggregating the products of the alternative weights and the respective criterion weights, as outlined by S. X. Tang and Mohammad (2023). The calculation of the global weight is executed through a five-step process: (1) calculating the criteria weight; (2) computing the alternative weight for criterion 1; (3) computing the alternative weight for criterion 2; (4)

computing the alternative weight for criterion 3; and (5) determining the overall (global) alternative weight. The following are steps of the data analysis using MCDM.

Comparison test

A comparative test is an analytical method used to compare the results of several approaches or methods in solving a problem, especially in multi-criteria decision-making. The purpose of a comparative test is to evaluate the consistency, reliability, and accuracy of the results obtained from different methods (Susilo, 2024). As a comparative test, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Simple Additive Weighting (SAW) methods are used as comparisons. In this context, methods such as Fuzzy AHP, TOPSIS, and SAW are often compared to determine the suitability of alternative rankings or criteria weights.

Simple Additive Weighting

Simple Additive Weighting (SAW) is a simple and frequently used multi-criteria decision-making method. This method works by adding up the scores of each alternative based on weighted criteria. SAW is often referred to as the weighted sum method because its basic principle is to multiply the weight of each criterion by the value of its alternative, then add the results to obtain a total score. This method is suitable for use in problems that require evaluating alternatives based on several criteria that have numerical values (Nami et al., 2023). Some of the advantages of the SAW method are: (a) Ability to compensate between criteria; (b) Intuitive for decision makers; (c) Simple calculations; (d) Does not require complicated programming; € helps determine differences between objects being compared visually by using normalized values. Then some of the disadvantages of the SAW method are: (a) The results obtained are not always logical; (b) Must provide attribute weights and decision matrices.

Finding the weighted sum of the performance ratings of each alternative, considering all attributes, is the basic concept of the SAW method. To do this, a normalized decision matrix must be prepared. This normalization process produces a scale that allows for comparing all alternative ratings (Sari & Suslu, 2018). The steps of the SAW method are as follows:

Step 1. Prepare the Matrix

This is an optional step that helps execute the following steps better. An initial matrix is prepared based on the values for m criteria and m alternatives/objects. Therefore, in this $m \times n$, r_{ij} is the value of the i for the object of j, where:

$$i = 1,2, \dots m$$

$$j = 1,2, \dots m$$

Another point is to determine the weight of the criteria (w_i) to indicate its importance. This weight can be considered as a number between zero and one (or as a percentage) and consider $\sum_{i=1}^{n} w_i = 1$

Step 2. Normalizing the i-th Criterion Value for the alternative j (Counting $\tilde{r}_{ij}$)

$\tilde{r}_{ij}$ s known as the normalized $i-$th criterion value for the $j-$th alternativ. This value should be calculated in this step by considering whether the problem is of the cost or benefit type. The difference is that in a cost problem, the object is minimizing, on the other hand, maximizing is the object of the benefit problem. This difference is reflected in the calculation $\tilde{r}_{ij}$ as follows:

$\widetilde{r_{ij}} = \frac{\min_j r_{ij}}{r_{ij}}$; If j is cost attribute

$$\widetilde{r_{ij}} = \frac{r_{ij}}{\max_{j} r_{ij}}$$; If j is benefit attribute

Where r_{ij} is the value for i criterion for the object j. The value of $\frac{r_{ij}}{\max_{j} r_{ij}}$ is the highest value from the i-th when all the criteria are compared, or reverse, the value of $\frac{r_{ij}}{\max_{j} r_{ij}}$ is the smallest criteria of i-th. Therefore, $\tilde{r}_{ij}$ is the normalized value for the i -th criteria and alternative j-th.

Step 3. Integrating Criteria Values and Weights

The integration of criteria and weights helps to obtain a single quantity which is the final performance value for each alternative. For this, the following equation can be used for the j-th alternative object:

$$Sj = \sum_{i=1}^{n} w_i \, \tilde{r}_{ij}$$

Step 4. Ranking Alternatives to Select the Best Alternative

In the final step, the best alternative is selected based on the largest performance value of the maximization criterion *Sj*, and the smallest for the minimization criterion.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision-making method used to rank alternatives based on their proximity to the ideal solution. This method is widely applied in various fields because it can facilitate decision-making involving the evaluation of multiple criteria and helps in determining the most optimal choice (Galgali et al., 2024).

TOPSIS is based on the concept of the distance between each alternative and two primary reference points: the positive ideal solution and the negative ideal solution. The positive ideal solution represents the best possible value for each criterion, while the negative ideal solution represents the worst possible value. Alternatives are then evaluated and ranked based on their geometric distance from these two reference points. The alternative with the closest distance to the positive ideal solution and the furthest distance from the negative ideal solution is considered the optimal solution (Nami et al., 2023). To ensure fair comparisons between criteria with different scales or units, the TOPSIS method applies data normalization. This normalization process aims to bring the criteria values to a uniform scale, allowing for a comprehensive and accurate evaluation. By considering all these factors, the TOPSIS method is a highly effective approach in helping decision-makers analyze various alternatives and determine the most optimal solution amidst the complexity of the many criteria that need to be considered (Nami et al., 2023).

The steps of the TOPSIS method are illustrated explicitly as follows (Çelikbilek & Tüysüz, 2020):

Step 1. Building a decision matrix

Determine the alternatives and criteria, arrange the performance of each alternative on each criterion into a matrix $X = [x_{ij}]$, where x_{ij} is the performance score of alternative i for criterion j.

Step 2. Normalizing the decision matrix

Normalization to allow comparison between different units. The normalized value r_{ij} for each elemen x_{ij} in the decision matrix is calculated by::

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

Where n is the total of alternative. This scales the values to a range [0,1].

Step 3. Constructing a weighted normalized decision matrix

Multiply each r_{ij} with the weight ω_j based on criterion j to create a normalized weight v_{ij}

$$v_{ij} = \omega_j . r_{ij}$$

Step 4. Determine the ideal solution and the negative ideal solution

Identify the best ideal solution of A^+ and the anti-ideal solution of A^- (anti-ideal). For the benefit criterion (where higher values are better), ideal and anti-ideal values:

$$A^+ = \{(max\ v_{ij})|j\epsilon J\}$$

For cost criteria (where lower values are better), reverse the max and min conditions:

$$A^- = \{(min\ v_{ij})|j\epsilon J\}$$

Step 5. Calculate the separation steps

Calculate the Euclidean distance of each alternative from the ideal solution A^+ and anti-ideal solution of A^-. Separation from ideal solution S_i^+ i and from anti-ideal solution S_i^- i for each i alternative is:

$$S_i^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - A_j^+)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - A_j^-)^2}$$

Where m is the total of criterion

Step 6. Calculate the relative closeness to the ideal solution

Determine the relative closeness C_i^+ i of each alternative to the ideal solution given by:

$$C_i^- = \frac{S_i^-}{S_i^+ + S_i^-}$$

where C_i^+ is ranged from 0 to 1, with values closer to 1 indicating alternatives that are closer to the ideal solution

Step 7. Rate alternatives

Rank the alternatives based on their relative proximity to the ideal solution. The alternative with the highest C_i^+ i is considered the best choice.

Sensitivity analysis

Sensitivity analysis is an evaluation technique used to understand how changes in input variables (e.g., weights or parameters) affect the final outcome of a model or system. In the context of multi-criteria decision-making, sensitivity analysis aims to assess the extent to which changes in criterion weights affect the priority or ranking of alternatives. Sensitivity analysis is used to validate the robustness of a proposed framework and eliminate the possibility of human judgment bias that could influence the results (Gupta & Barua, 2017). This concept is important for (1) Ensuring Result Stability: Assessing whether the final result remains consistent despite small changes in the input. (2) Identifying Critical Criteria: Revealing the criteria that most influence the result so that they can be the focus in the decision-making process. (3) Testing Model Robustness: Ensuring that the model can produce reliable decisions in various scenarios.

This analysis is often applied in decision-making methods such as Fuzzy AHP, TOPSIS, and SAW, where criterion weights can be changed to observe their impact on the ranking of alternatives. In this context, sensitivity analysis is used to measure whether the developed model responds to various changes in time, needs, industry developments, and other factors when implemented. The formula used in sensitivity analysis depends on the method used. In general, sensitivity is calculated based on the change in criterion weights relative to changes in alternative rankings. The general form of a sensitivity calculation is as follows:

1. Percentage Change in Criteria Weights:

$$\Delta W_i = \frac{W_i' - W_i}{W_i} \times 100\%$$

Formula:

W_i': Initial weight of criterion iii.

W_i: Changed weights for criterion iii.

$\varDelta W_i$: Percentage change in weight.

2. Percentage Change in Rating Value:

$$\Delta R_j = \frac{R_j' - R_j}{R_j} \times 100\%$$

Formula:

R_j' = Alternative initial ranking value jjj.

R_j = Alternative ranking value jjj after weight change.

$\varDelta R_i$ = Percentage change in rating value.

3. Sensitivity coefficient:

$$S = \frac{\Delta R_j}{\Delta W_i}$$

Formula:

s= Sensitivity coefficient (impact of weight changes on rating values).

$\varDelta R_i$ =Change in alternative ranking value jjj.

$\varDelta W_i$= Changes in the weight of criteria iii.

The sensitivity coefficient describes the extent to which a criterion influences the ranking of alternatives. Sensitivity Analysis Process:

1. Identify Criteria: Determine the main criteria used in decision making.
2. Change the Criteria Weight: Vary the weight of each criterion gradually starting from 0.1 to 1 (Balusa & Gorai, 2019; Tsai et al., 2010) in this case the value used is around ±4%, ±8% considering the smallest weight limit of the criteria is 8% so if using 10% the result will be negative.
3. Calculate Ranking Change: Use a decision model (Fuzzy AHP, TOPSIS, SAW) to recalculate the ranking of alternatives.

4. Result Analysis: Compare the initial results and the results after changing the weights to assess the stability and sensitivity of the model.

By using these steps, sensitivity analysis provides deeper insights into the reliability and stability of the decision-making system.

External Validity as the consensus

Several strategic steps have been taken to ensure the external validity of this study. First, data triangulation was conducted by integrating information from various sources, such as Focus Group Discussions (FGDs) with teachers and experts, and literature reviews from various policy sources, such as UNESCO-UNEVOC on TVET guidelines, as well as surveys with teachers as stakeholders regarding the need for implementing digital competencies in vocational education. This approach aims to produce more consistent and relevant findings across various contexts. Furthermore, research replication is crucial to ensuring the generalizability of the findings.

The data obtained will be compared with the results of other studies in the ASEAN region, particularly those based on UNEVOC, UNESCO, or European Commission guidelines on digital competencies, to test the suitability and relevance of the findings in the regional context. This study also provides a detailed description of the sample characteristics, research procedures, and the context in which digital competencies are implemented in learning, enabling other researchers to assess the relevance of the findings in different contexts or populations.

The research instrument used has been validated by vocational education experts and has passed validity and reliability tests, ensuring that the instrument can be used in various vocational schools with a high level of reliability. To ensure the reliability of the research, a pilot test of the instrument was conducted prior to the main study, and revisions were made based on the pilot test results to ensure data consistency and reliability. These steps are expected to maintain the external validity of the research, ensuring that the findings are relevant not only to the vocational schools used as the research sample but also to the broader context of vocational education.