Advanced digital competency assessment of vocational teachers': a new approach based on fuzzy-analytical hierarcy process

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ABSTRACT

Teachers need digital competence to adapt easily to the current digital era. This study tries to discover the perceptions of vocational high school (VHS) teachers in Indonesia related to advanced digital competencies, which include information, communication, content creation, digital security, and problem-solving competencies. The multi-criteria analytical hierarchy process (AHP) problem-solving method is used to rank the priority digital competencies that are most mastered by the respondents, and then their performance is validated by the fuzzy AHP artificial intelligence-based method. A poll was conducted with 392 respondents, with the research instrument adopting the digital competency measurement platform from DigComp. The study's results show that the fuzzy AHP method has proven that the classical AHP method is a very good way to prioritize VHS teachers' digital skills based on several factors. The two methods gave almost identical results in determining the priority order of VHS teacher digital competencies. The survey results reveal that VHS teachers in Indonesia must immediately develop their skills in terms of digital content creation and digital security. Teachers, teacher professional organizations, and decision-makers are expected to use the findings of this study as a reference in implementing VHS teacher digital competency improvement trainings.

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1. INTRODUCTION

The teacher's professional competence is very diverse and constantly changing through the years. The demands for the professional competence of teachers shifted significantly during the Industry 4.0 era. A teacher's capability to master digital technology is one of the most important attributes. Based on the 2017 World Economic Forum, "Industrial Revolution 4.0" will change the world's technology with a combination of physical, biological, and digital factors that will later intervene in all disciplines, including industry and the economy. In an effort to anticipate this destructive change, education in the Industry 4.0 era must be able to prepare teachers to be able to adapt and play an effective role in the fourth industrial revolution. Digital technology plays a role in transforming education and the role of teachers in the learning environment. Because digital competence is the most important skill mastered by teachers or prospective teachers in the twenty-first century [1], [2], it is critical for teachers to prepare to learn more about advanced technology in implementing digital learning. In addition, the aspects of communication, creativity, and problem solving are generic soft skills that must be mastered in the Industry 4.0 era [3]. During the global COVID-19 pandemic, teachers should be able to apply their digital skills, which requires teachers to conduct long distance teaching by applying digital technology [4], [5].

Previous studies conducted in the Philippines concluded that the information and communication technology (ICT) competency level of prospective teachers was still at the level of deepening knowledge [6]. Some researchers have found that the digital competence of teachers and prospective teachers is still low on average, which makes them need to update their digital competencies [7], [8], even other studies mention that students' digital competence is higher than the teachers' [9], [10]. Noticing the digital competency gap between teachers and students as well as the various technical obstacles experienced by teachers in adapting to new technology, it is very necessary to have digital competency training for relevant teachers to narrow the gap [11]. Digital competencies are divided into three groups: basic digital competencies, intermediate digital competencies, and advanced digital competencies [12]. Teachers who teach at the secondary to higher education levels, including vocational high school (VHS) teachers, must also master advanced digital competences (ADC) because they are currently facing a significant challenge. They must prepare students to face the development of Industry 4.0, in which digital technology plays a large role in the world of work and may change the work structure in everyday life, resulting in a reduction in human work [13]. Therefore, a study that looks at the essential needs of teachers' digital competencies is necessary.

As a result of rapid technological advancements across various fields [14], numerous concepts have emerged, including digital competence, media literacy, digital literacy, and information literacy. Digital competence stands out as a crucial skill necessary for individuals to effectively engage and navigate in today's digital knowledge society [15]. It encompasses a comprehensive set of attributes, including knowledge, skills, attitudes, abilities, strategies, and awareness, essential for utilizing ICT and digital media proficiently. This proficiency extends to task execution, problem-solving, information management, collaboration, content creation and sharing, as well as effective knowledge building [16]. Contrary to a mere focus on technical skills, digital competence embodies a broader spectrum, encompassing cognitive, emotional, and sociological dimensions necessary for optimal engagement with the digital environment [17]. It is a multidimensional and complex concept intertwined with 21st-century skills and sensitive to socio-cultural dynamics [18].

DigComp is a European digital competence framework that offers tools to measure citizens' digital competence. DigComp is one of the most up-to-date and comprehensive frameworks developed today regarding digital competence [19]. The DigComp framework was developed to support shaping policies for improving the digital competence of citizens across all age groups [20]. The framework consists of five competency areas such as information, communication, content creation, security, and digital problem solving, as seen detail in Table 1. The role of digital literacy in education for teachers is currently growing significantly. Digital literacy must be a set of competencies that is used as the basis for improving teachers' professional competence [21]. Digital competence in the context of learning focuses on the teacher's proficiency in using ICT professionally with proper pedagogical assessment and awareness of its implications for learning strategies and the development of students' digital abilities [22].

Current studies on determining the priority attributes of teacher ADCs are prevalent in the European Union and the USA. However, there is a significant gap in research regarding the prioritization of teacher ADC attributes relevant to the 4.0 industrial revolution in the Southeast Asia region, particularly in measuring the ADC of VHS teachers in Indonesia. Prior research has predominantly focused on identifying factors hindering and enhancing teacher quality in the future, overlooking the critical gap in identifying immediate mastery priorities for teachers. Given the vast spectrum of digital competency attributes, there is a pressing need for a systematic tool to facilitate optimal decision-making in selecting priority factors. One such tool is the multi-criteria decision-making (MCDM) method, a popular approach utilized in decision-making processes [23]. Among MCDM methods, the analytical hierarchy process (AHP) stands out for its ability to determine priority levels or weights between criteria and alternatives through comparative assessments [24], [25]. However, a novel approach integrating artificial intelligence with AHP, known as the fuzzy-AHP method, is emerging. This study proposes employing the fuzzy AHP method as a novel approach to prioritizing ADC factors for VHS teachers. The study aims to compare the conventional AHP method with the fuzzy AHP method, leveraging two prominent algorithms: Chang's extent and geometric mean. Through this comparison, the fuzzy AHP method will serve as a validation tool for the results obtained using the classical AHP method, contributing to the advancement of decision-making methodologies in educational contexts.

Table 1. Framework of digcomp digital competency [26]

Competency	Sub- Competency	Description
Information	1. Browsing, searching, and filtering information	Ability to access and search online information, articulate information needs, find relevant information, select resources effectively, navigate between online sources, and create personal information strategies.
	2. Evaluating information	Ability to collect, process, understand, and critically evaluate information.
	3. Storing and retrieving information	The ability to manipulate and store information and content for easier retrieval, to organize information and data.
Communication	1. Interacting through technology	Ability to interact through various digital devices and applications, to understand how digital communications are distributed, displayed, and managed, understand how to communicate appropriately through digital means, refer to different communication formats, and adapt communication modes and strategies for specific audiences.
	2. Sharing information and content	Ability to share with others the location and content of the information found, willing and able to share knowledge, content and resources, act as an intermediary, be proactive in the dissemination of news, content and resources, know about citation practices and integrate new information.
	3. Joining in digital community	Ability to participate in society through online engagement, seek opportunities for self-development and empowerment in using technology and the digital environment, and realize the potential of technology for community participation.
	4. Collaborating through digital media	Ability to use technology and media for teamwork, collaborative processes and co-construction and co-creation of resources, knowledge and content.
	5. Paying attention to ethics in communicating through digital media	Have knowledge of behavioral norms in online/virtual interactions, be aware of aspects of cultural diversity, be able to protect oneself and others from possible online dangers (eg cyber bullying), develop active strategies to find inappropriate behavior.
	6. Managing digital identity	The ability to create, adapt and manage one or more digital identities, to be able to protect one's reputation, to handle data generated through multiple accounts and applications.
Content creation	1. Developing content	Content creating competence in a various format including multimedia for editing and improving the content which has been created and expressing through media and digital technology creatively.
	2. Integrating and re-elaborating content	The ability to modify, enhance and combine existing resources to create new, original and relevant content and knowledge.
	3. Understanding copyright and licenses in content	Ability to understand how copyright and license apply to information and content.
	4. Understanding programming principles	Ability to apply settings, program modifications, program applications, software, devices, to understand programming principles, to understand what is behind a program.
Protection	1. Protecting the software	Ability to protect your own device and to understand online risks and threats, to know about safety and security measures.
	2. Protecting personal data	Ability to understand general terms of service, active protection of personal data, understand the privacy of others, to protect yourself from fraud and online threats and cyber intimidation.
	3. Protecting health	Ability to avoid health risks associated with the use of technology in terms of threats to physical and psychological well-being.
	4. Protecting environment	Ability to know the impact of ICT on the environment.
Problem solving	1. Solving technical problem	Ability to identify possible problems and solve them (from troubleshooting to solving more complex problems) with the help of digital tools
	2. Identifying the needs and technological response	Ability to assess own needs in terms of resources, tools and competency development, match needs with possible solutions, adapt tools to personal needs, critically evaluate possible solutions and digital tools
	3. Innovating and using technology creatively	Innovate with technology, actively participate in collaborative digital and multimedia production, express oneself creatively through digital media and technology, create knowledge and solve conceptual problems with the support of digital tools.
	4. Identifying the gap of digital competency	Ability to understand where one's own competencies need to be improved or updated, to support others in their digital competency development, and to stay up to date with new developments.

2. METHODS

2.1. Analytical hierarchy process and fuzzy logic

AHP is a MCDM method that is widely used by decision-makers and researchers related to the additive weighting process, in which various relevant parameters are presented with respect to their relative importance [27], [28]. This method was developed by Saaty to help solve problems by conducting simultaneous and integrated analysis of the parameters. The value of these parameters can be quantitative, qualitative, or a combination of both, where the qualitative parameters are previously converted into quantitative ones to develop more objective decisions. Next, pairwise comparisons were carried out to enable finding the weights of the criteria and alternative priority scales in a structured manner for each criterion [29], [30]. The advantage of the AHP method compared to other decision-making methods lies in its reliability for solving multi-objective problems with multiple criteria [31]. Meanwhile, most of the existing methods use single objectives with multiple criteria. Another advantage of the AHP method is its high flexibility, especially in making hierarchies since the calculations are simpler. This flexible nature makes the AHP model able to capture several goals and several criteria at once in a hierarchy [32].

Fuzzy AHP is a combination of the AHP method with the concept of fuzzy logic. Fuzzy AHP is used to cover the weakness of classical AHP, which is a logic that has a fuzzy value between two values and is expected to minimize uncertainty in considering decisions [33]. In many cases, the process of decision makers using classical AHP creates ambiguity in their minds, so fuzzy logic was found to make evaluations if the decision makers had contradictions [34]. To deal with the ambiguity of human thought, Zadeh first introduced fuzzy set theory in 1965, which is oriented to the rationality of uncertainty due to imprecision or ambiguity. The main contribution of fuzzy set theory is its ability to represent ambiguous data. This theory also allows mathematical operators and programming to be applied to fuzzy domains. A fuzzy set is an object class with a continuum of membership degrees. Such sets are characterized by a membership function (characteristic), which gives each object a membership level between zero and one. The triangular fuzzy number (TFN) is denoted simply as m1, m2, and m3. The parameters (m1, m2, and m3) show the smallest value, the definite value, and the largest value, respectively, that describe the fuzzy value [35]. Fuzzy AHP has several calculations with different methods, including the Chang's extent method [36] and geometric mean (Buckley) [31].

2.2. Research procedure

This research begins with determining the criteria and sub-criteria to be used in determining the priority of the ADC. In this study, the ADC criteria and sub-criteria have been decided using the DigComp and DigCompEdu frameworks, such as the research conducted by [37]–[40]. DigComp is a digital competence framework created by the European Commission that aims to assist in the development and understanding of European digital competencies. Meanwhile, DigCompEdu is a general reference framework to support the development of digital competencies specifically for educators in Europe. So, the author adopted the two frameworks to be used as a reference in making instruments and the advanced AHP hierarchical structure for the digital competencies of VHS teachers. The selected criteria and sub-criteria are described in Table 2.

Table 2. Criteria and sub-criteria

Criteria	Sub-criteria
Information (INF)	1. Browsing, searching, and filtering information
	2. Evaluating information
	3. Storing and retrieving information
Communication (COM)	4. Interacting through technology
	5. Sharing information and content
	6. Involving in online communication
	7. Collaborating through digital channel
	8. Ethics in communication through internet
	9. Managing digital identity
Content creation (CC)	10. Developing content
	11. Reintegrating and re-elaborating content
	12. Understanding copyright dan licenses in content
	13. Understanding programming principles
Safety of technological usage (ST)	14. Protecting software
	15. Protecting personal data
	16. Protecting health from technological threat on physical and psychological
	17. Protecting environment
Problem solving (PS)	18. Solving technical problem
	19. Identifying technological needs and responses
	20. Innovating and using technology creatively
	21. Identifying the gap of digital competency

A poll was conducted to obtain real information about the advanced digital competency map of VHS teachers in Indonesia. This data is then used by researchers as a basis for giving weights to the pairwise comparison matrix. Respondents assessed their own abilities (self-evaluation) against the 21 ADC sub-criteria by giving ratings ranging from expert, proficient, less proficient, and not proficient. The participants in this study were teachers who taught at VHS and had various fields of expertise and knowledge groups. The number of respondents involved in this poll was 675 people spread throughout Indonesia, which consists of 22 provinces, with most respondents coming from West Java. Demographic information about the respondents is shown in Table 3. As an incentive for their involvement in this research activity, the researcher provided a one-day webinar with the topic "Scientific article writing for VHS teachers," which was held on May 29, 2022.

Using Google Form, a questionnaire survey was designed and distributed to 675 respondents. Participants who filled out the Google Form instrument totaled 460 respondents, but only 392 were eligible to be processed.

Table 3. Respondent demographic information

Variable		Total	Percentage (%)
Gender	Male	173	44
	Female	219	56
Age	22-30	90	23
	31-40	122	31
	41-50	131	33
	51-58	49	13
Employment status	Government employees	231	58.93
	Non-government employees	161	41.07
Years of service	1-5 years	107	27.30
	6-10 years	60	15.31
	11-15 years	95	24.23
	16-20 years	76	19.39
	>20 years	54	13.78
VHS cluster	Technology	278	70.92
	Non- technology	114	29.08
School accreditation	A	308	78.57
	B	68	17.35
	C	8	2.04
	Not accredited	8	2.04

We need to determine the priority level of teacher competency using the AHP [41], [42]. This follows the establishment of criteria and sub-criteria and reviewing the outcomes of the self-assessments completed by respondents. This approach entails a thorough examination to determine the significance of each criterion and sub-criterion within the framework of teacher competency. These steps facilitate a deeper comprehension of the significance of specific variables in evaluating teacher ability comprehensively. AHP techniques can help define teacher competency priorities more clearly and in an organized manner.

Step 1: Develop and define a hierarchy of problems encountered. At this stage, the hierarchy is structured by setting the goals at the top level.

Step 2: Specify the priority of the element. Each element obtained has its own priority level. Comparing elements according to criteria can be made into pairwise comparisons in the form of a matrix. The element with the highest level is used to begin the comparison process. The arrangement of the elements will look like the following [41]:

Then the paired matrix is filled with numbers that represent the importance of the elements. Number scales 1, 3, 5, 7, and 9 are applied. If an element is compared to itself, the value of 1 will be given. If element a and element c are compared to get a certain value, then element c is the opposite value of element a. Table 4 shows the AHP Saaty scale.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & 1 & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}$$

Table 4. AHP scale

Importance Intensity	Description	Explanation
1	Equally important	Both elements have the same influence.
3	A little more important	The assessment slightly favors one element.
5	More important	The assessment strongly favors one element.
7	Very important	The evidence that one element is very influential and its dominance is clear.
9	Absolutely more important	The evidence that one element is more important than the other is very clear
2,4,6,8	The middle value of the above assessment	The value given if there is doubt between the two options.

Step 3: The results of the pairwise comparison matrix that have been obtained are then synthesized to obtain the overall priority. The synthesis process consists of several stages.

a) Add up the values of each column in the paired matrix.

b) Divide each value from the column by the number of the corresponding column to obtain a normalized matrix.
c) Add up the values of each matrix and divide by the number of elements to get the average value.
d) Calculate the eigenvalues and test their consistency.

The principle of 100% consistency is not a requirement in AHP because the calculation of elements according to decision makers sometimes changes. AHP measures the consistency of considerations with the consistency ratio (CR). The consistency requirement is that CR ≤ 0.1. If it is more than the limit ratio, the matrix comparison value is repeated. The steps for calculating the value of the CR are:

a) Multiply the value of the first column by the relative priority of the first element, the value in the first column by the relative priority of the second, and so on
b) Sum each row
c) The result of the row sum is divided by the corresponding relative priority element
d) Divide the results above by the number of elements that exist, which is commonly called the eigen value (πmax)
e) Calculating consistency index (CI)
f) Calculating CR

After obtaining and reviewing the results of the AHP calculation, the subsequent step involves understanding the stages of fuzzy AHP to ensure a more precise decision-making process and mitigate ambiguous impacts. The initial phase in this process entails converting the weight values obtained from AHP into fuzzy AHP using a TFN. The conversion scale table for TFN is presented in Table 5. This step is crucial for gaining a deeper understanding of the level of uncertainty and complexity involved in decision-making and for ensuring that decisions align with real-world conditions. By employing the fuzzy AHP approach, errors in decision-making can be minimized, and the final decisions can better reflect accurate and accountable conditions. The weights of the AHP criteria that have been converted into TFN are then analyzed by fully adapting the stages of Chang's extent analysis model [36] and geometric mean analysis [31].

Table 5. Conversion of importance level value of TFN [43]

Importance intensity	Description	TFN	Reciprocal TFN
1	Equally important	(1,1,1)	(1,1,1)
3	A little more important	(2,3,4)	(1/4,1/3,1/2)
5	More important	(4,5,6)	(1/6,1/5,1/4)
7	Very important	(6,7,8)	(1/8,1/7,1/6)
9	Absolutely more important	(9,9,9)	(1/9,1/9,1/9)

3. RESULTS AND DISCUSSION

This research attempts to apply a hybrid model of the fuzzy-AHP method with the aim of determining the ADC priority scale for vocational teachers in Indonesia. Currently, there is not much scientific literature that explores digital literacy skills in more depth, especially for teachers, with the focus generally being on analyzing the digital skills of both students and teachers in general. Therefore, determining ADC priority criteria for vocational teachers is very important. This is due to the need for them to master ICT better, considering that their roles are often directly related to the application of technology in learning contexts related to certain skills. In the vocational education environment, technological proficiency is becoming increasingly crucial because these teachers are often faced with the demand to prepare their students to be ready to enter an increasingly digitalized world of work. The process of priority determination using the conventional AHP method commences with delineating objectives, criteria, sub-criteria, and alternatives. In this study, the AHP process is employed to ascertain the priority of digital competencies based on self-evaluation by VHS teachers. Five criteria underpin the evaluation of digital competence, encompassing information, communication, digital content creation, digital security, and digital problem-solving. Concurrently, the study adopts 21 sub-criteria sourced from the DigComp and DigCompEdu frameworks. The final phase encompasses the alternatives, encapsulating the prioritization levels of digital competence. Figure 1 illustrates the hierarchical structure of digital competencies, elucidating the intricate interplay between various aspects of digital proficiency.

After compiling the hierarchy, the next step is to create a pairwise comparison matrix. The development of this matrix refers to the results of respondents' assessments of the relative importance of elements related to teacher digital competencies, which are converted into the AHP scale. In this section, pairwise comparisons are made between one sub-criteria and another. The scoring process is carried out by assigning a scale of 1, 3, 5, 7, or 9 to each important sub-criteria and a scale of 1/3, 1/5, 1/7, or 1/9 to each unimportant sub-criterion, or vice versa. As shown in Table 6, number 1 in the INF 1 row, namely browsing, searching, and filtering information, compared to the INF 1 column, namely browsing, searching, and filtering information, depicts the same level of importance between INF 1 and INF 1, while number 7 in the INF 1 row (browsing, searching, and filtering information) compared to the INF 2 column (evaluating information) shows that INF 1 is very important compared to INF 2. While the reverse scale between INF 2 row and INF 1 column is 1/7, it is obtained in the same way as other numbers in Table 6.

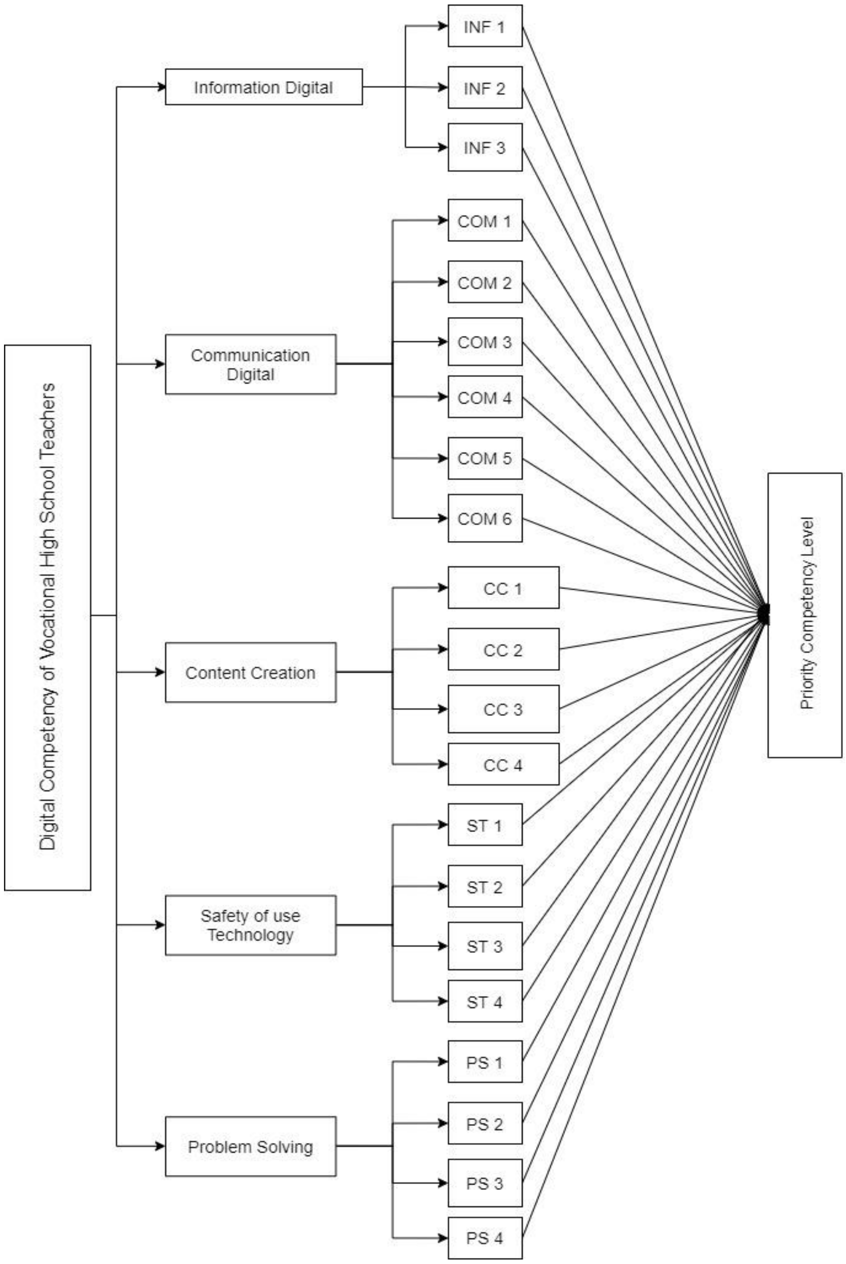

Figure 1. Digital competency hierarchy

Tabel 6. Pairwise comparison of AHP scale

	INF 1	INF 2	INF 3	....	PS 3	PS 4
INF 1	1	7	7	....	5	7
INF 2	1/7	1	1	....	1	1
INF 3	1/7	1	1	....	1	1
....	....	....	....	....	....	....
PS 3	1/5	1	1	....	1	1
PS 4	1/7	1	1	....	1	1
Total	4.89	37	39	....	29	27

After getting the pairwise comparison matrix, the next step is to normalize the matrix to get the priority vector value, as shown in Table 7. The first process to normalize the pairwise comparison matrix is by adding up the values in each row of sub-criteria in the table, then dividing the value of each line of sub-criteria by the sum of the results of each row of sub-criteria that can be seen in the table to obtain the normalized value of the matrix. Then, to get the priority vector value, the first step is to add up the normalized matrix weights in each sub-criteria column, then calculate the average for each sub-criteria by dividing each sub-criteria sum by the number of sub-criteria (n=21), then the priority vector value of each criterion will be obtained. The priority level of each sub-criteria can be seen from the priority vector value, but this value cannot be used as a reference in determining the priority level because we do not know how good the CR value is.

Table 7. Results of matrix normalization.

	INF 1	INF 2	....	PS3	PS4	Total	Vector priority
INF 1	0.20	0.19	....	0.17	0.26	3.91	0.1863
INF 2	0.03	0.03	....	0.03	0.04	0.60	0.0286
....	....	....	....	....	....	....	....
PS 3	0.04	0.03	....	0.03	0.04	0.68	0.0323
PS 4	0.03	0.03	....	0.03	0.04	0.96	0.0458
Eigen max= 24.02		CI = 0.15		RI = 1.64		CR = 0.09	

The process of determining the ratio value to determine the level of consistency is carried out in several steps. The first step is to multiply the matrix between the values in the pairwise comparison matrix and the priority vector values for each sub-competency. This matrix multiplication calculation uses the Excel function "=MMULT" and then selects all pairwise comparison matrix values with the priority vector values in each sub-competency row. The next step in getting the eigenvalues is obtained by dividing the results of the matrix multiplication in each sub-competence with the priority vector value in each sub-competence. After getting the eigenvalues, the maximum eigenvalue must be determined from the overall results and divided by the number of sub-competence elements (n=21). The next step is to determine the CI value, which is obtained from the maximum eigenvalue minus the number of sub-competence elements, then divided by the number of sub-competence elements (n=21) minus 1. The last step is to determine the CR value obtained from the CI divided by the random index. The random index value is derived from the index table developed by Alonso and Lamata [44], which yielded a random index value of 1.64 with a total of 21 matrix elements. As a result, the CR value is 0.09, which is less than 0.1 and is declared to meet the CR requirements.

After the AHP data is declared consistent, the next step is to rank the priority levels of the sub-competencies. As shown in Table 8, the highest priority sub-competence is browsing, searching, and filtering information, followed by the next rank, namely protecting personal data, interacting through technology, protecting the environment, and identifying technology needs and responses. At the 13th rank, there are two sub-competencies with the same value: paying attention to ethics in communicating through digital media and innovating and using technology creatively. In the 15th place, there are three sub-competencies that have the same value, namely evaluating information, joining digital communities, and managing digital identities; the one with the lowest priority ranking in this research is collaborating through digital media.

Fuzzy-AHP is used to improve and validate the results of classical AHP calculations. The decision value of fuzzy AHP in this research is obtained by converting the value of each sub-competence that has been obtained in the AHP pairwise comparison matrix into a TFN fuzzy scale in the form of a TFN number. The TFN number consists of three levels, namely low (l), medium (m), and up (u), where $l < m < u$. Table 9 shows an example of the AHP fuzzy scale that can be used as a reference for converting the value of the AHP pairwise comparison matrix to the AHP TFN fuzzy scale. After getting the value of the comparison fuzzy AHP matrix, the next step is to calculate the fuzzy extent synthesis value using the change extent and geometric mean methods.

The results of the calculation using the Chang extent method are deemed insufficient to display an accurate priority level because the calculation results only display one priority rank. The authors then calculate using the geometric mean method. The calculation using this method begins by multiplying each triangular fuzzy value consisting of l, m, and u in each sub-competence. After getting the results of the multiplication of each value of l, m, and u, the next step is to find the average value of the geometric mean to get the inverse value and the weight of the fuzzy value. The average value is obtained by multiplying the product of each value of l, m, and u in each sub-competence with the rank (1/n), n=21. The complete calculation results are shown in Table 10.

Table 8. AHP priority rank

Sub-competency	Priority Vektor	Rank
Browsing, searching, and filtering information (INF 1)	0.1863	1
Protecting personal data (COM 2)	0.0825	2
Interacting through technology (COM 1)	0.0619	3
Protecting environment (ST 4)	0.0577	4
Identifying technological needs and responses (PS 2)	0.0559	5
Understanding programming principles (CC 4)	0.0500	6
Identifying the gap of digital competency (PS 4)	0.0458	7
Solving technical problem (PS 1)	0.0445	8
Protecting health from technological threat on physical and psychological (ST 3)	0.0428	9
Developing content (CC 1)	0.0386	10
Protecting software (ST 1)	0.0376	11
Understanding copyright and licenses in content (CC 3)	0.0346	12
Paying attention to ethics in communicating through digital media (COM 5)	0.0323	13
Innovating and using technology creatively (PS 3)	0.0323	13
Reintegrating and re-elaborating content (CC 2)	0.0319	14
Evaluating information (INF 2)	0.0286	15
Joining in digital community (COM 3)	0.0286	15
Managing digital identity (COM 6)	0.0286	15
Storing and retrieving information (INF 3)	0.0275	16
Sharing digital information and content (COM 2)	0.0275	16
Collaborating through digital media (COM 4)	0.0247	17

Table 9. Example of fuzzy AHP comparison

	INF 1			INF 2			INF 3			....			PS 3			PS 4		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
INF 1	1	1	1	6	7	8	6	7	8	....	....	....	4	5	6	6	7	8
INF 2	0.13	0.14	0.17	1	1	1	1	1	1	....	....	....	1	1	1	1	1	1
INF 3	0.13	0.14	0.17	1	1	1	1	1	1	....	....	....	1	1	1	1	1	1
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
PS 3	0.17	0.20	0.25	1	1	1	1	1	1	....	....	....	1	1	1	1	1	1
PS 4	0.17	0.14	0.17	1	1	1	1	1	1	....	....	....	1	1	1	1	1	1

Table 10. Fuzzy geometric mean

	Multiplication			Average		
	l	m	u	l	m	u
INF1	0,448	28,125	76,700	4,04	4,7	5,88
INF2	0,000326	0,001058	0,005208	0,68	0,72	0,78
INF3	0,000081	0,000353	0,002604	0,64	0,68	0,75
....	....	....	....	....	....	....
PS3	0,010417	0,022222	0,062500	0,80	0,83	0,88
PS4	0,166667	1,285714	0,666667	0,92	1,01	0,98
Total				21,27	24,12	27,09
Invers				0,04	0,04	0,05

After obtaining the inverse value, the next step is to determine the fuzzy weight from the results of multiplying the average value for each value of l, m, and u (Table 11) with each inverse value of l, m, and u, and then the obtained fuzzy weight values are presented in Table 11. Then the weight of the fuzzy value is converted into a single value (Crisp) by adding up the values of l, m, and u in each sub-competency, then dividing by 3. Then the final weight of each sub-competency is obtained by normalizing the crisp value, namely by summing up all the crisp values, and then each sub-competency's crisp value is divided by the sum of the crisp values.

Table 11. Values of fuzzy weight, crisp, and geometric mean normalization

	Fuzzy weight			Crisp value	Normalization
	l	m	u		
INF 1	0.15	0.21	0.28	0.21	0.2065
INF 2	0.03	0.03	0.04	0.03	0.0300
INF 3	0.02	0.03	0.04	0.03	0.0286
....	....	....	....	....	....
PS 3	0.03	0.03	0.04	0.04	0.0345
PS 4	0.03	0.04	0.05	0.04	0.0399
Total				1.02	1.00

After getting the normalization value, the next step is to sort the priority levels of the sub-competencies. As shown in Table 12, the highest priority sub-competence is browsing, searching, and filtering information with a value of 0.2065, followed by the next rank, namely protecting personal data, interacting through technology, identifying technology needs and responses, and understanding the programming principles. At rank 13, there are two sub-competencies with the same value: paying attention to ethics in communicating through digital media and innovating and using technology creatively. In the 15th place, there are three sub-competencies that have the same value, namely evaluating information, joining digital communities, and managing digital identities; the one with the lowest priority ranking in this research is collaborating through digital media.

Table 12. Priority rank of fuzzy AHP geometric mean

Sub-competency	Normalization	Rank
Browsing, searching, and filtering information (INF 1)	0.2065	1
Protecting personal data (ST 2)	0.0704	2
Interacting through technology (COM 1)	0.0573	3
Identifying technological needs and responses (PS 2)	0.0567	4
Understanding programming principles (CC 4)	0.0499	5
Protecting environment (ST 4)	0.0465	6
Solving technical problem (PS 1)	0.0445	7
Protecting health from technological threat on physical and psychological (ST 3)	0.0422	8
Identifying the gap of digital competency (PMM 4)	0.0399	9
Developing content (CC 1)	0.0385	10
Protecting software (ST 1)	0.0381	11
Understanding copyright and licenses in content (CC 3)	0.0363	12
Paying attention to ethic in communicating through digital media (COM 5)	0.0345	13
Innovating and using technology creatively (PS 3)	0.0345	13
Reintegrating and re-elaborating content (CC 2)	0.0317	14
Evaluating information (INF 2)	0.0300	15
Joining in digital community (COM 3)	0.0300	15
Managing digital identity (COM 6)	0.0300	15
Storing and retrieving information (INF 3)	0.0286	16
Sharing digital information and content (COM 2)	0.0286	16
Collaborating through digital media (COM 4)	0.0253	17

This study succeeded in determining the priority factors regarding the essential digital literacy to attach to VHS teachers in Indonesia by using one of the AHP-fuzzy-based decision-making tools. According to them, the digital literacy competencies that are a priority to master are the skills of browsing, searching, and filtering information. This result is supported by the demands on teachers according UNESCO [45], where one of the competencies that must be mastered by 21st century teachers is the ability to use technology, such as multimedia and the internet, in learning. Furthermore, the argument is supported by findings from a study that emphasize the contemporary expectation for educators in the digital realm to possess a well-rounded proficiency encompassing knowledge, utilization, and a positive disposition toward digital technology [46]. This competency is important, according to the teacher, because it is the basic one that must be possessed by the teacher. Especially during the COVID-19 pandemic, teachers are required to be able to find and provide accurate information in the learning process using digital technology. On the second priority, teachers argue that the competence to protect personal data is their priority. This aligns with research indicating that among the various competency groups, the most prominent competence in each group is related to knowledge of how to protect personal data [47]. This competency is considered important because it is a form of teacher responsibility in using and protecting students' personal data so that it can be used wisely [48]. Based on the results of the research, this competency becomes essential because many crimes are committed through digital media, so teachers must be aware of the threat of crime that can occur at any time and the threat of misuse of personal data by irresponsible parties.

The ability to interact with technology is considered an important factor that teachers must possess to meet the demands of implementing digital learning, which requires high human-computer interaction skills. When teachers master this competency, it is expected that the learning process will be flexible, effective, and interesting. Researchers feel confident that learning packaged with the latest technology will attract students to deepen their learning material, especially if it is integrated with social media. The use of social media in the learning process helps improve the digital skills of teachers to provide new knowledge to students and is able to overcome the limitations of technology-based learning in the COVID-19 era [49]. However, the success of the learning process by involving technology is determined by the readiness of the technology and the need for support and cooperation from the government, teachers, and parents [50]. In addition, there are several obstacles that are felt by teachers and students in Indonesia in conducting online digital learning interactions, including: an uneven internet connection; an inability to access or use online learning and teaching tools; difficulty adjusting, especially for teachers who live in rural areas; and levels of stress and anxiety in using technology [51]. The author agrees with the teacher's perception that the competence to interact using technology is a top priority because it is a teacher's demand to involve technology in everyday life, especially in the learning process. However, in applying it, there needs to be support from various parties, such as the government, parents, and teachers, besides the main supporting factor of the availability of access to technology.

Then, this study also reveals that the competence to develop content according to VHS teachers in Indonesia is not a priority competency because this competency is only ranked 10th out of 17 existing rankings. This is in line with several previous research results that state that teachers have a low level of content development using digital technology, even showing alarming results [52], [53]. This is because new teachers are only technology users and do not have the will and ability to create and develop digital content. In fact, in this era of the COVID-19 pandemic, teachers should be able to improve their digital competence and be more active in creating learning content using digital technology as a learning resources [54], [55], but the majority of teachers find it difficult to integrate digital tools into teaching and learning practices [54], [56], [57]. When viewed based on the distribution of respondents, most respondents in this study were female, and women tended to only use technology without any desire to explore more deeply.

The findings reveal that the competence that is considered the least important by VHS teachers is the competence to collaborate through digital media, with a weight of 0.0253. In fact, these results are not in line with the research results of Porlán *et al.* [58], which state that collaboration is an important element in the learning process using digital media. There are differences in the results of this study and previous studies because there are differences in the object of research. Previous research used student respondents who took part in the teacher training program, while in this study the respondents were VHS teachers. Students are used to and are required to be able to collaborate or work together using digital media, both for academic and non-academic needs, while teachers, especially VHS teachers, are not all capable and required to be able to collaborate, especially using digital media.

In examining this research, several aspects need to be considered, as they delineate weaknesses that may affect the relevance and applicability of its findings. Firstly, regarding the generalization of results, the study is focused on vocational school (SMK) teachers in Indonesia, making it challenging to directly apply the findings to other educational contexts or beyond that geographic area. Additionally, the research methodology employing the fuzzy AHP, while robust, may be susceptible to weaknesses in sample selection, measurement instruments, or data analysis, thus compromising the validity and reliability of research outcomes. Limitations in respondent numbers and resources, both financial and temporal, also pose significant barriers, as they may impact the representation of the overall SMK teacher population and restrict the scope and depth of the research. Furthermore, the measurement of digital competency among teachers, being complex and subjective, presents its own challenges in result interpretation and recommendations. Lastly, delays in publication updates may diminish the relevance of the research amidst the latest technological advancements and educational trends. However, despite these shortcomings, it is imperative to view the research findings as a starting point for further investigation and the development of broader policies aimed at enhancing the digital competence of teachers in Indonesia.

This research can significantly enhance digital competency among VHS teachers in various crucial aspects. The report outlines essential digital abilities required by VHS teachers in Indonesia, including information exploration, searching, and filtering, personal data protection, and technology-based interaction. This knowledge can help develop focused training programs to enhance these talents in instructors. This research confirms the effectiveness of using the fuzzy AHP technique to prioritize digital abilities among teachers in vocational education, offering a strong framework for evaluating and enhancing digital competencies. This research underscores the significance of ongoing professional development for instructors to align their digital competencies with those of their students, reflecting the existing gap. This research provides practical recommendations for schools, teachers, and future educators to use as a foundation for policymaking, curriculum design, and training initiatives to enhance the digital skills of VHS teachers. Finally, this study highlights the necessity for teachers to autonomously enhance their digital abilities to keep pace with evolving technology advancements, thus fostering a culture of continuous learning among SMK educators.

4. CONCLUSION

This study identifies digital competencies that are prioritized by VHS teachers. The digital competencies identified were obtained from the adoption of the DigComp framework developed by the European Commission, which consists of five core competencies and 21 sub-competencies. In the process of determining the priority level of digital competence, an analysis is carried out using the fuzzy AHP method. Based on the research results, it can be concluded that the most priority digital competencies according to VHS teachers today are browsing, searching, and filtering information; protecting personal data; and interacting using technology. The results of this study are expected to be used as input for schools, teachers, or prospective teachers regarding the main competencies that must be possessed by a teacher. These results can also provide information to teachers about the need for the development of digital competencies for teachers, especially in content creation competencies. Based on the findings in this study, the authors provide several recommendations to related parties, namely: the school is expected to be able to develop teacher competence, especially digital competence, on a regular basis to keep up with constantly changing technological developments; and teachers and prospective teachers should continue to be updating their digital capabilities independently to keep up with the times. Several recommendations for further research can be explored to expand the use of MCDM to increase the digital competence of VHS teachers in Indonesia. First, recommendations include the application of alternative MCDM methods such as TOPSIS, PROMETHEE, or ELECTRE to evaluate and prioritize the digital competence of VHS teachers with different approaches. Furthermore, the integration of several MCDM methods, such as fuzzy AHP and analytic network process (ANP), can be applied to strengthen the analysis of selecting criteria and sub-criteria in determining digital competency priorities. The development of a custom MCDM model that is adapted to the context of vocational education in Indonesia is also needed so that the results obtained are more accurate and relevant. In addition, wider use of secondary data from various trusted sources can support MCDM analysis in evaluating and prioritizing the digital competence of VHS teachers. Further validation of the results of MCDM analysis and sensitivity analysis is also important to test the reliability and stability of the determined digital competency priorities. Through this continued research, it is hoped that a valuable contribution can be made to the systematic and effective development of assessing, prioritizing, and improving the digital skills of teachers in the vocational education sector in various countries.

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