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Chemistry students' digital literacy skills on thermochemistry context "hydrogen fuel issue"

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Abstract

Living in the era of the Internet of things makes students familiar with the use of digital platforms in their daily life. However, several studies show that familiarity with digital platforms does not merely indicate that students are digitally literate. Students are still vulnerable to unreliable news, only mastering digital social platforms, and are unfamiliar with specific digital applications of expertise. This study aims to examine chemistry students' digital skills related to thermochemical content integrated with the global dilemma of using hydrogen fuel. This research utilized a mixed-methods design, a sequential explanatory type. Quantitative data was obtained through surveys and structured interviews to obtain qualitative data. Research participants included 74 chemistry students from seven state universities in Indonesia. The research instrument was a two-tier digital literacy questionnaire (r=0.947) consisting of 13 items, with self-assessment as the first tier and knowledge-based assessment (verification questions) as the second tier. Digital literacy profiles from surveys and interviews show that most students' skills are at the foundation and intermediate levels. The research implication is that students' digital literacy skills need to be improved, especially explicitly teaching several competencies related to digital literacy.

Keywords: chemistry education, digital literacy global framework, digital literacy two-tier assessment, misinformation

INTRODUCTION

Digital literacy is accepted internationally as one of the 21st century skills necessary for students and essential in formal learning activities in higher education (Le et al., 2022). The learning environment in higher education is now integrated with digital technology, so students need the ability to take advantage of learning technology developments (Wekerle et al., 2022) by being active, independent, and responsible for their learning achievements (Greene et al., 2017; Limniou et al., 2021). Digital literacy is more than students' ability to find and identify digital information, but also to assimilate and evaluate information from various digital sources (Margaryan et al., 2011; Ng, 2012; Tang & Chaw, 2016). Students' success in obtaining the proper knowledge is expected to be strongly influenced by their skills when searching and sorting information from hypermedia (like the Internet) because the most recent information is found on the Internet. Thus, students must have the right competencies and attitudes such as comprehensive digital literacy skills (Margaryan et al., 2011).

All students need comprehensive digital literacy skills to properly operate devices, applications, or websites to support learning needs, master how to access information from digital media, have *netiquette* (etiquette on the Internet), disseminate correct information with appropriate digital content, and filter information from credible sources only. It is so that they are not affected by misinformation that leads to misconceptions. In reality, students are vulnerable to being affected by misinformation in digital media and find it challenging to evaluate online information effectively (McGrew et al., 2018; Nygren et al., 2020).

The result of students' lack of digital literacy skills is learning loss in students such as chemistry students (Turner et al., 2020). Chemistry learning in higher education requires relatively high self-regulation skills,

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Contribution to the literature

- This study provides a reference for measuring chemistry students' digital literacy skills using a two-tier digital literacy assessment. The first tier is a self-assessment, and the second tier is a knowledge-based assessment to verify students' answers in the first tier.
- The global problem of hydrogen fuel related to the sustainable development goals is used to measure chemistry students' digital literacy skills, where most of the research is themed on daily life.
- This study provides information about the proficiency level of chemistry students' digital literacy skills from several universities in Indonesia.

so students must have adequate digital literacy skills. Along with building knowledge from digital learning resources, students are expected to evaluate information seriously and ensure the reliability of the information source (Demirbag & Bahcivan, 2021).

Research on students' digital literacy skills has been carried out several times in various parts of the world. Abdollahyan and Ahmadi (2011) surveyed students at the University of Tehran (Iran) using a questionnaire with five-point self-reported ratings of familiarity with computers and the Internet. The results showed that 62.2% of respondents were "not at all familiar" and "very little familiar" with digital literacy variables. Adeoye and Adeoye (2017) examined the digital literacy skills of 595 students at three universities in Nigeria using a 37-item digital literacy scale (1-4 Likert scale). The results showed that most students expressed confidence in their skills. In the following year, Kaeophanuek et al. (2018) conducted a digital literacy skills survey research on 400 students from 12 universities in Thailand using self-assessment and interviews. The aspects measured are information skills, digital tool usage, and digital transformation with daily and school life themes. The results showed that students reached the intermediate category of information skills and digital transformation and the high category of digital tool usage. Dadaczynski et al. (2021) conducted a cross-sectional study of digital health literacy and students' habits in searching for website-based information at 130 universities in Germany using the validated digital health literacy instrument. Each includes three items to be answered on a 4-point scale (e.g., one, very difficult; four, very easy), and the results showed that students' digital health literacy skills are relatively high. Kayaduman et al. (2022) measured the digital literacy skills of 195 education students at a Turkish university to identify the correlation of digital literacy with self-regulation. Digital literacy skills were collected using 17 items of the digital literacy scale by Ng (2012).

In general, the type of assessment to measure digital literacy skills is based on self-assessment with a general theme (daily life). Some notes regarding self-assessment in the literature are very subjective, so it has the potential to be biased. For example, the definition of the categories "poor," "adequate," "good," and "excellent" can be different according to each individual (Cote & Milliner, 2018). Ahmed and Roche (2021) also revealed that there is often a mismatch between students' self-perception and ability, so a self-report needs to be completed with a survey of academic staff or a direct measure of students' digital literacy skills (performance test). However, the performance test is also not free from limitations. Environmental conditions need to be equalized (updated level of digital devices, completeness of features, and the Internet network speed) so that the test must be carried out in the same place and requires a relatively long time to measure many samples (van Deursen & van Diepen, 2013). Furthermore, van Deursen and van Diepen (2013) also stated that suitable topics must be used on test instruments to increase motivation and relevance to learning activities or other efforts to improve digital literacy.

An effective digital literacy improvement program must be implemented, starting with a diagnostic test of initial digital literacy skills in global and local contexts, developing a strategy guide for implementing activities, and constantly conducting evaluations (UNICEF, 2019). This research aims to answer the problem formulation: What is the proficiency level profile of chemistry students' digital literacy skills? The proficiency level of chemistry students' digital literacy skills can be identified through how they interact with digital technology while solving chemistry problems. Living in the 21st century requires students to use their chemical skills and knowledge to solve global problems. Therefore, the chosen chemistry topic can be adapted to the context of relevant global problems. One of the topics that can be researched is thermochemistry by integrating the context of the dilemma about the effectiveness of hydrogen fuel as a future fuel. The search for alternative fuels to replace gasoline has become a meaningful discussion on a global scale to support the sustainable development goals (SDGs) (United Nations Development Program, 2022), so it will become an exciting topic for research.

THEORETICAL BACKGROUND

Definition of Digital Literacy

Digital literacy is defined in various ways in the educational literature. However, the initial definition put forward by Paul Gilster in 1997 (see Audrin & Audrin, 2022) is "the ability to understand and use information in various formats from various sources on digital platforms." The term digital literacy has developed as time goes by and with the development of digital technology. Digital literacy, according to Eshet-Alkalai (2004), involves more than the ability to use software or operate a digital device; it includes a large variety of complex cognitive, motor, sociological, and emotional skills, which users need to function effectively in digital environments. Buckingham (2010) argues that digital literacy is closely related to media and information literacy because each needs to obtain and filter information from various media, especially digital media (social networking sites). Erstad (2015) focuses on using digital technology in different aspects and categories of media literacy, such as basic skills, downloading, searching, navigating, classifying, integrating, evaluating, communicating, and creating.

Currently, digital literacy is believed to be a multidisciplinary field that broadly covers various other types of literacy, including information literacy, information and communication technology (ICT) literacy, media and the Internet literacy, digital science literacy/nursing/health/education, and computer literacy (Demirbag & Bahcivan, 2021; Eshet-Alkalai, 2004; Katz et al., 2008; Park et al., 2021). Falloon (2020) argues that digital literacy should be understood holistically and broadly as a result of the development of an all-digital environment, which includes all the skills needed by the younger generation to be productive while maintaining security and following applicable ethics.

In particular, this study refers to the definition of digital literacy by Ng (2012) and UNESCO-UIS (Law et al., 2018). Ng (2012) defines digital literacy as a technological, cognitive, and socio-emotional skill. Ng (2012) further proposed several abilities or skills that digitally literate individuals must possess:

(a) perform basic operations on computers and other digital media as part of daily life,

(b) seek, identify, and evaluate information to support learning and research activities effectively,

(c) determine and explore digital technology features that are most suitable for needs, for example, to do tasks, solve problems, and develop specific product innovations, and

(d) behave well in the online community and anticipate the dangers that may occur in the online environment (cyber-crime).

In line with Ng (2012), UNESCO-UIS defines digital literacy as a skill to access, manage, understand, integrate, communicate, evaluate, and create relevant and secure information through digital technology (Law et al., 2018).

Assessing Digital Literacy

Research on digital literacy has received more attention in the last decade, especially in higher education. Measuring digital literacy skills must use instruments per the characteristics of digital innovation. Several factors should be considered when designing digital literacy skills assessment instruments, such as how to use digital technology for formative and summative assessments; increase diversity and suitability of assessment formats and approaches; generate, select, critically analyze, and interpret digital evidence about student activities, performance, and progress in digital literacy (Caena & Redecker, 2019; Redecker, 2017). In general, there are three categories of digital literacy assessment: performance assessment, knowledge-based assessment, and self-assessment (Carretero et al., 2017). Performance assessment assesses an individual monitored by an observer (human or software) in solving authentic real-life problems using standard software (e.g., browser, word, and spreadsheet) or simulation. Knowledge-based assessment assesses individuals in response to test items carefully designed to measure an individual's declarative and procedural knowledge. In comparison, self-assessment assesses individuals by evaluating their knowledge and skills through various instruments, from a questionnaire with a structured scale to free reflection.

Literature review shows that most of the assessments to measure digital literacy skills are self-assessments, for example, the digital skills indicator by Eurostat (Laanpere, 2019), the digital literacy scale using Likert scale (Alt & Raichel, 2020; Pala & Basibuyuk, 2021), the self-report digital literacies questionnaire (Peled, 2021), and the digital online media literacy assessment (Hallaq, 2022). In the context of global digital literacy assessment, performance and knowledge-based assessments are likely not practical because they are relatively expensive, require much energy, and are challenging to measure large-scale digital literacy skills. Self-assessment is the easiest to implement and the most cost-effective. However, it cannot be denied that self-assessment has low internal reliability and validity (Laanpere, 2019).

Hydrogen Fuel Issue and Thermochemistry

Chemistry students' digital literacy skills can be identified through their interaction with digital technology while studying and solving chemistry-related problems. One of the problems related to chemistry that has received international attention is the issue related to energy (global goals for sustainable development area 7) and climate change (SDGs area 13). The children and youth would be the generation most affected by climate change and responsible as future leaders, citizens, and policymakers for making difficult energy-related decisions in response to climate change (Jorgenson et al., 2019). Focusing on everyday contexts and actions was also conceptualized as a way to empower students by increasing their understanding and engagement towards sustainable development and global climate change (Nam et al., 2020). Currently, various efforts are being made to achieve the SDGs, such as improving the quality of education, increasing awareness and capacity of humans or various organizations in the world regarding climate change mitigation, finding ways to adapt to change, and reducing the impact and prevention efforts that can be done around climate change (United Nations Development Program, 2022).

Thermochemistry is the study of energy change - especially in the form of heat- in chemical reactions (Chang, 2010). Through thermochemistry content, students can identify the effectiveness of hydrogen fuel as part of green chemistry efforts to achieve the SDGs. Why hydrogen fuel? First, the climate crisis, the energy transition, and the search for renewable energy, where hydrogen fuel is included, are of great urgency (United Nations, 2022). The hydrogen fuel context is suitable to be used as an engagement in learning about the properties of matters used as an energy source, the chemical reactions that accompany them, and their efficiency as an energy source (for example, in terms of the chemical aspect of the enthalpy value of combustion) (Eubanks et al., 2009; Flowers et al., 2015). Second, since the subject of hydrogen fuel is not frequently included in chemistry curricula and textbooks (Johnson et al., 2019; Subahi, 2020), students must conduct online research and develop their information and data literacy abilities to study it as a component of digital literacy.

Zumdahl and Zumdahl (2017) suggested that hydrogen gas from water decomposition can substitute natural gas, primarily methane gas. Experiments using a bomb calorimeter with a heat capacity of 11.3 kJ/°C can be carried out to compare the combustion energy of the two fuels. The energy released in the combustion of 1 gram of hydrogen gas is approximately 2.5 times that of one gram of methane, indicating that hydrogen gas is a potentially effective long-term fuel. Furthermore, students can be directed to compare the heat of combustion of hydrogen gas with fossil fuels, for example, gasoline (isooctane) as one of the determining factors for the effectiveness of hydrogen gas as fuel. In the implementation of chemistry learning, integrating chemistry content (thermochemical principles) with the context of global problems can be an exciting approach to making chemistry learning meaningful.

METHODS

This research utilized mixed-methods design with a sequential explanatory type (Creswell, 2014), with quantitative data collection techniques in the form of surveys. Several findings were deemed necessary to be re-confirmed through structured interviews to obtain sufficient qualitative data to support the credibility of the survey results. This approach includes a two-phase project. In the first phase, the researcher collects quantitative data, analyzes the results, and uses those results to plan the second phase. The second phase is the collection of qualitative data through structured interviews.

Participant

The participants were 74 first to fourth-year chemistry students (61 females and 13 males) from chemistry education study programs (n=65) and chemistry study programs (n=9) from seven public universities in Indonesia. The majority of participants were 2nd year students (n=37). The rest were 1st year (n=18), 3rd year (n=12), and 4th year (n=7) students. Participants have a relatively similar background of familiarity with the use of ICT because the lecture system at the seven universities adopts a face-to-face and online combination system with integrated use of digital technology to support lectures. Lectures are conducted through face-to-face activities (direct communication between lecturers and students), structured activities (guided assignments), independent learning, and online-based learning. All activities are recorded in the learning management system (LMS) facilities of each university. Participants also have access to digital devices (for example, laptops, tablets, and mobile phones) and the Internet. Learning methods commonly used at universities in Indonesia include lectures, group discussions, and laboratory activities.

Data Collection Instruments

The researcher developed the instrument concerning the digital literacy global framework (DLGF) by UNESCO-UIS (Law et al., 2018). DLGF covers seven literacy competence areas (**Table 1**):

(a) fundamentals of hardware and software (area 0),

(b) information and data literacy (area 1),

(c) communication and collaboration (area 2),

(d) digital content creation (area 3),

(e) safety (area 4),

(f) technical problem solving (area 5), and

(g) career-related competencies (area 6).

The instrument developed and used consisted of 13 two-tier question items (except for item 13 because it required a performance test). The first tier is a self-assessment, and the second tier is a knowledge-based assessment to confirm the answers to the first tier. The first tier requires participants to independently assess their digital literacy skills on a scale of 1 to 4, according to the instructions. In the second tier, participants were asked to answer questions in the form of essays or upload digital content (item 8). The participant's response is then categorized as **"confirmed"** if the

Table 1. Competence area of digital literacy global framework

Competence area	Description
0. Fundamentals of hardware & software*	Understand, determine, & operate digital devices & applications needed to meet needs (e.g., to search for information)
1. Information & data literacy	Identify, find, & filter data or information from digital media Evaluate credibility & relevance of digital information sources Group data or information from digital media
2. Communication & collaboration	Select & identify digital applications used to communicate & collaborate with others online Identify & define digital applications used to share data or information online Understand & implement *netiquette*, for example, maintaining confidentiality of identity, using proper language, not supporting discrimination, & not being biased
3. Digital content creation	Create digital content in various forms in a good & informative manner Understand & implement rules regarding copyright of digital information & content (related to citation rules & the like) Share digital content online on digital media
4. Safety	Understand & manage privacy of data or information from digital content (privacy, accessibility, & the like)
5. Technical problem-solving	Identify, search, & solve technical problems related to frequently used digital devices
6. Career-related competencies*	Identify & understand applications related to chemistry & its learning Operate applications related to chemistry & its learning

Note. *Competency areas 0 and 6 are additions made to DigComp 2.0

participant's answer in the second tier supports the level chosen in the first tier and **"unconfirmed"** if the participant does not answer or the participant's answer in the second tier does not support the level selected in the first tier.

Two validators from the digital literacy field declared the instrument with a percentage agreement of 0.97. Test item validity and reliability with IBM SPSS version 25 stated that the 13 item items were valid ($r>0.227$; sig.<0.05) and reliable (Cronbach's alpha's $r=0.947$) so that the survey instrument was feasible to collect data (Tavakol & Dennick, 2011).

Integrated blog-based article: "BERALIH KE HIDROGEN: BENARKAH SOLUSI?" (Switching to hydrogen: Is it really the solution?)

The researcher measured the seven competence areas by adjusting the topic of the instrument with chemistry learning in universities regarding the idea of developing alternative hydrogen fuel as a long-term substitute for fossil fuels. This topic was integrated into the survey instrument as an anonymous post on a blog entitled "*BERALIH KE HIDROGEN: BENARKAH SOLUSI?*" (https://greenhydrogenforlife.blogspot.com/2022/04/bahan-bakar-hidrogen.html). The blog posts are intentionally designed to be uncredible, do not include clear sources, and contain some misinformation to identify participants' ability to evaluate the information.

Digital literacy skills generally utilize digital media to obtain information to solve problems (Katz et al., 2018; Pala & Basibuyuk, 2021). These skills can be identified through searching, evaluating, and integrating information into knowledge-construction activities. (Greene et al., 2014). The data collection section explains that the researcher integrates blog-based articles with the title "*BERALIH KE HIDROGEN: BENARKAH SOLUSI?*" to test students' digital literacy skills. Specifically for information and data literacy competence, the blog post can be used to assess students' proficiency in distinguishing credible sources of information, misinformation, opinions, and facts and check whether students with high digital literacy levels also have difficulty evaluating information.

There are three categories of information presented in the blog:

(a) facts without sources,

(b) uncertain public opinion, and

(c) false information or hoax.

The three categories of information are arranged in such a way as to become a blog post. Although there was initially a dilemma about using hydrogen fuel, the article primarily focused on the disadvantages of hydrogen fuel and did not mention the advantages. Students are expected to critically evaluate the shortcomings of blog posts and not use them as sources of information.

At the end of the article, there are main problems that students must answer in the comment section: "Do you agree with the ideas in the article? As a chemistry student, is the idea of using hydrogen fuel as an alternative long-term energy source an effective solution compared to fossil fuels and needs to be implemented? Look for the information you need on the Internet!" Specifically, students are directed to find information online and examine problems from the chemistry perspective.

Data Collection Procedure

Quantitative data is collected through the three-part survey on Google Forms. The first part contains a general description of the survey: the form, purpose, and importance of the survey; the second part includes the

Table 2. Proficiency level of "confirmed" & "unconfirmed" chemistry students' digital literacy skills

Competence area	IN	Proficiency level							
		1 (F)		2 (I)		3 (A)		4 (HS)	
		C	UC	C	UC	C	UC	C	UC
0. Fundamentals of hardware & software	1	10	0	10	26	5	14	3	6
1. Information & data literacy	2	8	0	35	8	12	4	3	4
	3	8	0	7	27	4	15	3	10
	4	6	0	28	12	10	9	5	4
	5	7	0	15	24	7	11	1	9
Communication & collaboration	6	9	0	22	9	7	12	7	8
	7	8	0	24	4	17	10	7	4
3. Digital content creation	8	18	0	13	20	1	12	2	7
4. Safety	9	15	0	11	15	3	17	4	6
	10	19	0	4	20	1	15	2	8
5. Technical problem-solving	11	17	0	15	21	0	17	0	4
6. Career-related skill	12	21	0	13	21	2	11	1	4
	13	29	0	14	12	3	11	0	4

Note. IN: Item number; C: Confirmed; UC: Unconfirmed; F: Foundation; I: Intermediate; A: Advanced; & HS: Highly specialized

participant's identity: name, gender, university, education degree, and personal contact, which will be kept confidential; and the third part, which contains survey items for digital literacy skills along with guidelines for selecting the proficiency level scale. Students were given written information at the beginning that survey was voluntary and confidential, so they agreed to become research participants.

Furthermore, structured interviews with several participants were conducted to confirm the survey results. Six participants were selected and willing to be interviewed voluntarily. Structured interviews are carried out directly using a conference call application via Zoom or Google Meet for approximately 10 minutes per participant. The participants were asked questions according to the list of questions prepared. The question emphasizes the response of participants who are "unconfirmed" in the second tier to confirm the digital literacy proficiency level of the participants they report in the questionnaire.

Data Analysis

Assessment of students' digital literacy levels refers to the DigComp 2.1 rubric, The digital competence framework for citizen: With eight proficiency levels (Carretero et al., 2017). Modifications are made by adjusting the needs and limitations of the study, where the level or scale is determined using categories and not the original scale (1-8). According to DigComp 2.1, proficiency levels 1 and 2 are in the foundation category, levels 3 and 4 are in the intermediate category, levels 5 and 6 are in the advanced category, and levels 7 and 8 are in the highly specialized category. Proficiency levels used in this survey instrument are foundation level (level 1), intermediate (level 2), advanced (level 3), and highly specialized (level 4), not levels 1-8 (**Appendix A**). The modification is because the difference in skills per level in each category is so thin that it can only be optimally identified with a performance test.

The participants' responses classified into the criteria of "confirmed" and "unconfirmed" were then tested for interrater reliability. The answers in the second tier are open-description answers, so an agreement from several raters is needed to confirm the categorization of responses. Three raters were selected based on their expertise and familiarity with digital literacy research. The assessment results by all raters were then statistically tested using Cohen's kappa to obtain the degree of agreement from the other raters' assessment.

RESULTS

Profile of Chemistry Students' Digital Literacy Skills

The results of the survey data analysis of the chemistry students' digital literacy skills using a two-tier digital literacy instrument are presented in **Table 2**. The results show that most of the responses are classified as "unconfirmed" after going through verification using the second tier. The results in **Table 2** are tested for interrater reliability with Cohen's kappa coefficients of 0.873 (rater 1 to rater 2) and 0.926 (rater 1 to rater 3), which indicates that the categorization of responses by two raters reached an agreement of 87.3% and 92.6% (very high) (McHugh, 2012).

Skills in Operating Digital Devices and Applications

The first thing in digital literacy that students must have been familiarity with hardware, software, and digital applications, especially for learning purposes. Like DLGF, Ng (2012) also argues that one of the essential slices of digital literacy skills is technical skills: physical and software operations in digital devices. This skill is measured in **item 1** on the survey instrument. Participants are asked to rate their skills in understanding and operating digital devices and applications in the first tier. Then in the second tier, they are asked to write down as many digital devices and/or applications as to find information related to the dilemma of using hydrogen fuel. The survey showed that most participants rated their skills at level 2 (intermediate). In a row, the self-assessment results on the first-tier items are level 1 (13.51%), level 2 (48.65%), level 3 (25.68%), and level 4 (12.16%). However, based on the results from the second tier, it turned out that only 37.84% of all responses in the first tier were confirmed.

Skills in Accessing and Evaluating Information from Digital Media

The younger generation often relies on the Internet for information (Lea & Jones, 2011; Tsai, 2018). This habit is an excellent thing if they have adequate digital literacy skills. Some of the competencies that students must master in searching for information through digital devices are knowing the keywords needed to obtain information (item 2), using information only from reliable sources (item 3), choosing the required information from various sources on the Internet (item 4), and assessing or evaluating the usefulness of the information (item 5).

In **item 2**, the survey results show that most participants rate their skills at level 2 (intermediate). Respectively, the self-assessment results in the first tier are level 1 (10.81%), level 2 (58.11%), level 3 (21.62%), and level 4 (9.46%). Based on the second-tier results, 78.38% of all responses in the first tier are "confirmed." In **item 3**, the survey results show that most participants rate their skills at level 2 (intermediate). In a row, the results of self-assessment in the first tier are level 1 (10.81%), level 2 (45.95%), level 3 (25.68%), and level 4 (17.57%). However, based on the results from the second tier, it turned out that only 29.73% of all responses in the first tier were "confirmed." Furthermore, in **item 4**, the survey results showed that most participants rated their skills at level 2 (intermediate). In a row, the self-assessment results in the first tier are level 1 (8.11%), level 2 (54.05%), level 3 (25.68%), and level 4 (12.16%). Based on the second-tier results, 66.22% of all responses in the first tier are confirmed. Likewise, with **item 5**, the survey results showed that most participants rated their skills at level 2 (intermediate). In a row, the self-assessment results in the first tier are level 1 (9.46%), level 2 (52.70%), level 3 (24.32%), and level 4 (13.51%). However, based on the second-tier results, only 40.54% of all responses in the first tier were confirmed. The data analysis results show that students' skills in accessing and evaluating information from digital media are still at the intermediate level.

Skills in Communicating and Collaborating Through Digital Devices

Students must participate in online communication and collaboration with colleagues by consistently applying *netiquette* (etiquette on the Internet) (Hobbs, 2010). The Internet can eliminate distance, which means that people all over the world can connect with the Internet. Therefore, students must determine and operate appropriate digital communication technology (item 7) and understand and apply the Internet etiquette when interacting online (item 6).

In **item 6**, participants' internet etiquette was assessed by their comments on a blog post entitled "*BERALIH KE HIDROGEN: BENARKAH SOLUSI?*" *(Switching to hydrogen: Is it really the solution?)*. Most participants rated their skills at level 2 (intermediate) based on self-assessment results in the first tier. In a row, the self-assessment results in the first tier are level 1 (12.16%), level 2 (41.89%), level 3 (25.68%), and level 4 (20.27%). Based on the second-tier results, 60.81% of all responses in the first tier are confirmed. In **item 7**, participants were asked to mention what digital communication media are known and would be chosen to work with colleagues. The survey results showed that most participants rated their skills at levels 2 (intermediate) and 3 (advanced). In a row, the self-assessment results in the first tier are level 1 (10.81%), level 2 (37.84%), level 3 (36.49%), and level 4 (14.86%). Based on the second-tier results, 75.68% of all responses in the first tier are confirmed. The data analysis results generally show that chemistry students' communication and collaboration skills through digital devices are intermediate.

Skills in Creating Digital Learning Content

Digital content is essential for students to obtain information and build knowledge. Students acquire information through digital platforms in the form of narratives on websites, journal articles, infographics, YouTube videos, etc. However, the truth of digital content is one of the crucial keys in disseminating information and forming knowledge to become one of the digital literacy competencies. Participants' skills in creating engaging, informative, and persuasive digital learning content were tested on survey item number 8. In **item 8**, participants were asked to rate their skills in creating digital content, which was proven by uploading digital content of their work. Most participants rated their skills at the first-tier level 2 (intermediate). In a row, the self-assessment results in the first tier are level 1 (24.66%), level 2 (45.21%), level 3 (17.81%), and level 4 (12.33%). However, only a tiny percentage of participants with level 2 uploaded their digital content results, so only 46.58% of all responses in the first tier were confirmed. The analysis results from the first and second tiers show that students' skills in creating digital content are still at the foundation level.

Safety Skills

The device safety skills section in the digital literacy skills instrument is still closely related to the skills to create digital content. Skills for maintaining device safety can be identified through the participants' ability to understand and manage data or information privacy from digital content, for example, managing privacy and accessibility of digital content. In items 9 and 10, there is only one second-tier question for both items, where participants are asked to demonstrate their skills in managing the privacy of uploaded content by giving researchers access to view and download the content.

In **item 9**, the survey results show that most participants rated their skills at level 2 (intermediate). In a row, the self-assessment results in the first tier are level 1 (21.13%), level 2 (36.62%), level 3 (28.17%), and level 4 (14.08%). However, based on the second-tier results, only 46.48% of all responses in the first tier were confirmed. In **item 10**, the data also showed that most participants rated their skills at level 2 (intermediate). In a row, the self-assessment results in the first tier are level 1 (27.54%), level 2 (34.78%), level 3 (23.19%), and level 4 (14.49%). However, based on the second-tier results, only 37.68% of all responses in the first tier were confirmed. The data analysis results generally show that students' skills in maintaining digital media safety are at the foundation level.

Skills in Solving Technical Problems

With digital devices, students cannot be separated from the emergence of technical problems such as unstable internet networks (Njoki, 2020; Tigaa & Sonawane, 2020) and files or applications that do not respond. In using technology for chemistry and its learning, several technical problems are encountered, such as technical errors when operating video conference calls and lagging and not responding digital applications. In **item 11**, participants were asked to rate their skills in solving technical problems that commonly occur in technology around chemistry and its learning. The survey results show that most participants chose level 2 (intermediate). In a row, the results of self-assessment in the first tier are level 1 (22.97%), level 2 (48.65%), level 3 (22.97%), and level 4 (5.41%). However, based on the second-tier results, only 43.24% of all responses in the first tier were confirmed. The analysis results show that students' skills in solving technical problems of digital devices or applications are still at the foundation level.

Specific Skills in Chemistry and Its Learning

In addition to the chemistry context, the specific nature of this digital literacy skill instrument is one of the questions that specifically identify participants' skills in digital technology in chemistry. Item 12 identifies participants' knowledge of digital technology in the field of chemistry, while item 13 identifies participants' mastery or proficiency in operating some of these technologies. In **item 12**, survey results showed that most participants rated their skills at level 2 (intermediate). In a row, the self-assessment results in the first tier are level 1 (28.77%), level 2 (46.58%), level 3 (17.81%), and level 4 (6.85%). However, based on the second-tier results, only 50.68% of all responses in the first tier were confirmed. While in **item 13**, unlike other items, the survey results show that most participants rate their skills at level 1 (foundation). Respectively, the survey results were level 1 (39.73%), level 2 (35.62%), level 3 (19.18%), and level 4 (5.48%). Item 13 is the only item with one tier on this instrument because it measures participants' proficiency in operating chemistry digital technology that requires performance tests.

Table 3. Response criteria per item after interview

Participant code	Response criteria per item after interview	
	Remain unconfirmed	Verified confirmed
R-07	3 & 12	1 & 10
R-14	3, 5, & 8	6 & 10
R-22	1, 3, 8, & 12	-
R-28	3, 5, 7, & 11	-
R-33	1, 3, 5, & 10	-
R-45	5, 8, 11, & 12	6
R-48	3, 7, & 12	-

Structured Interview

The high discrepancy between respondents' answers on the first tier and the second tier on almost every item makes it necessary to conduct structured interviews to confirm the findings. The interview subjects were participants with many "unconfirmed" answers, so their actual digital literacy skills needed to be investigated more deeply.

In general, the results of the interviews verify the responses of the participants in the first and second tiers. Of the total 29 responses from 7 participants, 82.8% of the "unconfirmed" responses remained unconfirmed, while 17.2% of the "unconfirmed" responses were verified as "confirmed." The summary of participant response status verification is presented in **Table 3**.

DISCUSSIONS

A literate society in the 21st century requires reading, interpreting, giving meaning, and communicating skills in an all-digital environment (Bravo et al., 2021). These skills then produce a new umbrella in the form of digital literacy. In the literature, there is a plurality of terms related to digital literacy, where researchers tend to use "digital literacy," "digital skills," "digital competence," and "21st century digital skills" interchangeably (Audrin & Audrin, 2022). In general, students referred to as "digital natives" have high confidence in interacting with digital technology, but some research results show that they are not necessarily digitally literate (Caverly et al., 2019; Le et al., 2022). The results of this study support the statement that there are many discrepancies between the results of the first tier (self-assessment) and the second tier (knowledge-based assessment) in the survey results. Many chemistry students assess their digital literacy skills at levels 3 (advanced) to 4 (highly specialized), but the description in the second tier does not confirm that level. For students who claim foundation level, all responses are confirmed. This level indicates that the student can carry out the right competencies if given guidance from other people (lecturers/friends/experts).

Skills in Operating Digital Devices and Applications

Digitally literate individuals should be able to perform basic operations on computers and other digital devices as part of daily life (Ng, 2012), even in learning activities. In this study, students' skills related to digital devices and applications were identified through students' ability to choose appropriate digital devices and applications to find information about the dilemma of using hydrogen fuel. Meanwhile, skills in operating it can only be measured accurately through performance tests.

Based on self-assessment by students in the first tier, "knowing and using appropriate digital devices and applications to find information about the dilemma of using hydrogen fuel," many students claim that they have skills in determining and operating digital devices and applications on level 2 (intermediate) and 3 (advanced). However, after confirming it with the second tier, "writing as many digital devices and applications as possible to find information about the dilemma of using hydrogen fuel," most responses were declared unconfirmed. An example of an unconfirmed response is when students claim to have intermediate to highly specialized skills, but they only write "laptop," "PC," "mobile phone," general browser such as "Google," and general terms such as "internet" as verification. Information literate students are expected to use digital browsing applications that are indeed credible sources of information, such as "Google Scholar," "Eric Document," "journal websites from reputable publishers," "university websites," and "national library websites."

> (Confirmed) R-38: Level advanced: "Google Search, Google Scholar, university websites, journal websites."

> (Confirmed) R-52: Level foundation: "Device: mobile phone and laptop; application: Google, social media, YouTube."

> (Unconfirmed) R-04: Level intermediate: "Device: mobile phone; application: Google Search."

Interesting findings were obtained from the response by R-07, who wrote "internet" as a digital application to get information. However, after being interviewed more deeply, R-07 explained that the Internet he meant was Google, especially Google Scholar. Participants obtained information about Google Scholar through the TikTok application, which indicated that students could obtain information from anywhere. "TikTok is a place where young people can find like-minded individuals, work through the coming-of-age experience, and cultivate a sense of generational culture." Therefore, the younger generation is interested in and comfortable using it. TikTok can also be used for learning purposes (Khlaif & Salha, 2021), for example, as learning media and resources.

> R-07: "I usually use Google, mostly Google Scholar."

> I: "Oh, you have been using Google Scholar to find info on college assignments?"

> R-07: "Yes because Google Scholar is more reliable. I got information from TikTok that while studying in college, students are no longer allowed to use the general Google like Brainly. We have to find a more trusted one like Google Scholar."

This finding is similar to Weber et al. (2018), which shows that students tend not to use Google Search, advanced search, and bibliometric search prior to digital literacy workshops. This area of competence in digital devices and applications is essential to master before students begin searching and sorting information from hypermedia or the Internet. Information provided by specific websites, such as Google Scholar and reputable journal websites, has higher reliability than general browsers, such as Google.

Skills in Accessing and Evaluating Information from Digital Media

Digitally literate students must know how to assess information, verify the credibility of information, distinguish between opinion and fact, and determine the information required (Alt & Raichel, 2020). These skills are essential for students because they allow them to optimally filter the information they use to build knowledge. These skills can be called data literacy, information literacy, and media literacy (Park et al., 2021). Several things indicate the limitations of students' skills in implementing information literacy, for example, the lack of variety and accuracy of keywords entered in search engines. Students usually only see and select the first result that appears without regard to the credibility or relevance of the source of information and conclude that they are finished obtaining data with only that first result (Van de Vord, 2010).

Students' skills in accessing and evaluating information from digital media in this survey were determined through several indicators. Students can "know the keywords to obtain information related to the dilemma of using hydrogen fuel," "use information from reliable information sources only," "not find it difficult in selecting information on digital platforms (the Internet)," and "assess or evaluate the usefulness of the information." All of these skills significantly affect the process of students building perceptions and knowledge, so it is crucial to identify student interactions with digital platforms when looking for information to solve problems (Weber et al., 2018).

In the skill "knowing keywords to obtain information related to the dilemma of using hydrogen fuel," most of the student responses were confirmed. It shows that students can assess their information literacy skills. The survey results show that most students reach the intermediate level, where they can determine keywords independently without needing help from others. Some of the important keywords that the students successfully wrote were "the advantages and disadvantages of hydrogen fuel," "is hydrogen fuel effective," "the definition of hydrogen fuel," and "hydrogen fuel vs fossil fuels." Students with a high level of information literacy skills tend to enter several keywords simultaneously to obtain more specific results.

> (Confirmed) R-44: Level intermediate: "Hydrogen, hydrogen fuel, environmentally friendly, the disadvantages of hydrogen fuel, the advantages of hydrogen fuel, efficiency, how it works (typed together)."

> (Unconfirmed) R-39: Level Intermediate: "Switch to hydrogen."

After successfully typing a few keywords and obtaining a list of information on the search page, the students were tested on their skills in choosing a title and whether to "only use information from trusted sources of information." In this section, the effect of the blog "*BERALIH KE HIDROGEN: BENARKAH SOLUSI?*" seems enough to make students confused and difficult to evaluate the credibility of the source of information. As previously explained, the blogspot-based information that the researcher integrates into the survey contains misinformation that serves as a benchmark for students' information literacy skills. The survey results show that most students still use the blog as a source of information, including 11 out of 19 advanced-level students and three out of 13 highly-specialized level students. This finding is fascinating because some students are still wrong in evaluating the credibility of a source of information. If students in learning activities apply similar skills, they will be very vulnerable to being exposed to misinformation and even hoax (information containing false news intended to harm readers, divide, and cause conflict).

> (Unconfirmed) R-06: Intermediate level: "https://greenhydrogenforlife.blogspot.com/2022/04/bahan-bakar-hidrogen.html & https://www.esdm.go.id/assets/media/content/content-apa-itu-teknologi-hydrogen-fuel.pdf"

> (Unconfirmed) R-16: Advanced level: "https://greenhydrogenforlife.blogspot.com/2022/04/bahan-bakar-hidrogen.html?sc=1661836792610#c6740250539831088525 & https://id.wikipedia.org/wiki/Bahan_bakar_hidrogen"

Answers from R-06 and R-16 in the second tier indicate that the two students still use blog information. Although both wrote other credible sources in the form of uploads from the Ministry of Energy and Resources of the Republic of Indonesia and Wikipedia, both responses were considered unconfirmed because they used information from reliable sources and unreliable ones. This finding was re-confirmed by using interviews to explore why students used the blog. Some students (R-07 and R-14) did not notice that the blog did not include a clear source of information and the author's name.

> I: "From your point of view, does the blog post (BERALIH KE HIDROGEN: BENARKAH SOLUSI?) contain reliable information?"

> R-07: "I think it is reliable because of the link provided. There are also words like "ministry," so it is reliable."

> R-14: "I think it is reliable. The post listed takes data from the Ministry of Energy and Resources of the Republic of Indonesia and lists large companies like Tesla. I think it is credible."

> R-48: "I think Blogspot is the place for reliable information."

Based on the survey results and structured interviews, some students are fooled by mentioning institutions or significant trademarks in the articles. From there, they assume that the post can be trusted and do not crosscheck with information from other sources.

The following information literacy skills, "not find it difficult in selecting information on digital platforms (internet)" and "assess or evaluate the usefulness of the information," are still interrelated with each other. In the second tier, students were asked to identify information to provide opinions regarding the dilemma of using hydrogen fuel and assess the usefulness of the information on the blog post "*BERALIH KE HIDROGEN: BENARKAH SOLUSI?*" The survey results show that most students' responses are confirmed according to the selected level. However, some student responses were inconsistent with the level selection, for example, claiming a highly-specialized level but only focusing on information about the hydrogen gas production process (R-11) without including more specific information, such as hydrogen gas as a fuel and the effectiveness of the hydrogen fuel in terms of chemistry and other aspects.

In addition, R-41 students only focused on the effects of hydrogen gas on the environment and living things. The general statement refers to hydrogen gas in nature and does not indicate hydrogen gas as a fuel.

> (Unconfirmed): R-11: Highly-specialized level: "Hydrogen gas production process, hydrogen gas production method."

> (Unconfirmed): R-41: Intermediate level: "Effects of hydrogen gas for the environment and living things."

> (Confirmed): R-22: Advanced level: "Definition of hydrogen gas, hydrogen gas manufacturing process, advantages of hydrogen fuel, disadvantages of hydrogen fuel, the impact of hydrogen fuel on the environment, how to use hydrogen fuel, hydrogen fuel for two-wheeled vehicles."

After students were asked to list information to answer dilemmas about hydrogen fuel, students assessed the usefulness of the information provided by the blog "*BERALIH KE HIDROGEN: BENARKAH SOLUSI?*" by answering the question in the second tier: "The information in '*BERALIH KE HIDROGEN: BENARKAH SOLUSI?*' fulfilled all my needs". The survey results show that most students answered "yes," the information on the blog has fulfilled all students' information needs in answering questions about the dilemma of using hydrogen fuel. This finding was then re-confirmed using interviews, where several respondents who chose the answer "yes" stated that the post contained the advantages and disadvantages of hydrogen as a fuel and concluded that the information in the blog post was complete and precise.

Assessing the usefulness of information is closely related to the cognitive aspects of digital literacy because students need critical thinking to determine whether the information obtained so far has answered their problems (Katz et al., 2008). Based on the results of surveys and interviews, some students do not seem to fully understand what information they should look for regarding the dilemma of using hydrogen fuel, so they only rely on blog posts included in the survey.

Skills in Communicating and Collaborating Through Digital Devices

Communication and collaboration skills in this study include students' skills in determining digital platforms to collaborate and communicate with others and in writing comments on digital platforms by following the etiquette on the Internet. When asked to write down digital platforms commonly used to communicate and collaborate with others, most students wrote Zoom, Google Meet, and WhatsApp. A small number of students wrote Google Docs, Instagram, and Telegram. The survey results show that most students can communicate and collaborate online at intermediate and advanced levels. The responses of students who were classified as unconfirmed mainly were because they could not name a digital platform or claim an intermediate to highly-specialized level but only mentioned one type of digital platform.

> (Confirmed) R-22: Advanced level: "WhatsApp, Google Slides, or Google Docs (via chat), Zoom or Google Meet."

> (Unconfirmed) R-28: Advanced level: "WhatsApp."

> (Unconfirmed) R-66: Advanced level: none.

Furthermore, regarding communication skills according to etiquette, all comments from students meet the rules of netiquette in terms of language. The response stated as unconfirmed was because the student had claimed the intermediate to highly specialized level but chose the "I cannot or do not want to comment" so that his level of proficiency could not be confirmed. In addition, the confirmed criteria for this skill are only based on netiquette rules and not assessing content. Thus, if students do not write inappropriate words (hate speech, racism, discrimination, swearing, and swearing), they are declared to understand how to communicate well through digital platforms.

> (Confirmed) R-06: Intermediate level (username: kharinaan): "According to the article, hydrogen fuel has more negative sides or disadvantages, so it is less effective. However, efforts must still be made to make the earth greener with renewable fuels. As a chemistry student, I agree with the idea of using hydrogen to replace gasoline."

> (Unconfirmed) R-14: Highly specialized level: none.

One participant who did not write a comment was then interviewed regarding his knowledge of netiquette and the reason for not writing a comment. Students understand the essential things to be considered when communicating through digital platforms.

> R-14: "I have read the comments on the blog, and for the most part, I agree with them (so I am not commenting)."

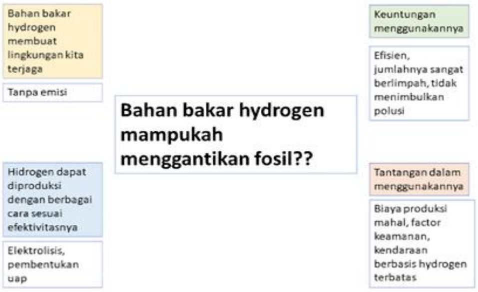
> "I always pay attention to the important thing not to contain discrimination, hate speech, like that."

Skills in Creating Digital Learning Content

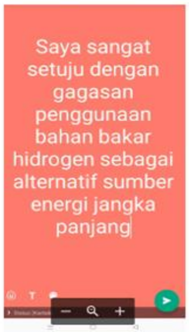
Digitally literate individuals use and create digital content responsibly. Digital content creation is nothing new, but it requires thinking skills and adequate

(Confirmed) R-34: Intermediate level

(Confirmed) R-15: Intermediate level



(Confirmed) R-04: Intermediate level



(Unconfirmed) R-51: Advanced level

Figure 1. Students' digital content of the dilemma of using hydrogen fuel (Source: Students' work derived from Canva (R-34), Instagram story (R-15), Microsoft Power Point slide (R-04), and WhatsApp story (R-51))

technical skills to make it meaningful. The term digital content creation has a strong relationship with digital productivity, where students must present information in digital format, and digital creativity, which refers to students' creativity in creating digital content (even multimedia) following the goals and target audience (Essential Skills Wales Suite, 2016).

Linking the skills of creating digital content as part of digital literacy with chemistry can be done by asking students to solve problems in the blog post "*BERALIH KE HIDROGEN: BENARKAH SOLUSI?*" and present it in the form of digital content. Students can freely present it in any digital media (social media stories, posters, slides, flyers, infographics, etc.) and use any application (PowerPoint, Adobe Photoshop, Canvas, etc.). Based on the survey results on the first tier, most of the students claimed that their skills were at level 2 (intermediate) and level 1 (foundation).

Furthermore, in the second tier, students are asked to create and upload digital content related to questions on the blog. The analysis of the results showed that most students were at level 1 (foundation) because many could not show their digital works or only upload simple full-text content (R-51). In general, there are three kinds of digital content from students: posters (R-34), PowerPoint slides (R-04), and social media stories (R-15) (**Figure 1**).

Furthermore, interviews were conducted with several students who did not create or upload digital content to explore their reasons for not doing so. All interviewed students stated that they were more familiar with digital content for social and entertainment and had never created digital content containing information related to learning.

Safety Skills

Students' skills in maintaining safety on digital platforms in this survey (items 9 and 10) are still an inseparable part of digital content creation skills (item 8). After creating and uploading digital content, students are asked to share the link and set the privacy of the content so that anyone with the link can access it. Based on the survey results in the first tier, most of the students rated their skills at level 2 (intermediate). However, through confirmation with the second tier, most students reached level 1 (foundation). Further interviews with students with "unconfirmed" responses showed that students understood how to set privacy but did not reach the stage of regulating privacy because they only uploaded content in the form of files (not links) from the start.

> R-07: "I usually upload content on TikTok. It has content privacy options for yourself, your friends, or everyone else. I can also set it on Google Drive for anyone with links or certain shares only."

> R-14: "Usually, I use Google Drive. If I have something I want to share, I decide whom I want to share it with, for example, my friends in the class. If I want to share it with the public, I click on the access option for everyone."

This finding shows that it is necessary to emphasize to students that sharing information or files through digital platforms is very important, especially to work together in learning. Therefore, students must master the skills to share information through Google Drive and others. Maintaining safety in digital environments requires managing personal information, paying attention to etiquette, and being aware of rights and responsibilities for oneself and others (Kaeophanuek et al., 2018).

Skills in Solving Technical Problems

Carrying out chemistry learning using digital technology is often unavoidable due to technical constraints hindering the learning process and harming students. The skills to overcome common technical problems, such as not responding or lagging document files or projects and management of corrupted files, must at least be mastered by students. Likewise, technical obstacles when conducting synchronous online learning with conference call-type digital platforms (e.g., Zoom Meetings, Google Meetings), such as failing to share the screen, failing to connect audio or microphone, and turning video or camera on and off, must be able to be overcome by students so as not to limit the benefits of digital technology.

Students' skills in solving technical problems are ideally tested with performance tests. However, at least this skill can be identified by describing the steps. If students do not write down the stages of problem-solving, then their skills cannot be identified. The first-tier survey showed that most students rated their technical problem-solving skills at level 2 (intermediate). However, with the second tier selection, the highest student skill achievement is at the foundation level, and all students are only in the foundation and intermediate categories. In the second tier, students are asked to write down the technical problems they overcame and the steps to solve them. An invalid or unconfirmed answer is when students only write down the type of technical problem without explaining the steps they took to solve it or write a description that does not match the selected level criteria. Student R-38 claimed that his skills reached level 3 (advanced), where he could independently solve technical problems and provide information assistance to friends who faced similar problems. However, student R-38 said he asked for expert help, which did not meet the advanced-level criteria.

> (Unconfirmed) R-38: Level advanced: Yes, there is. Technical problems when trying to operate the application (resolved by restarting or refreshing), unable to upload digital content (ask for expert help).

> (Confirmed) R-51: Level foundation: The problem I have ever faced was the computer suddenly got an error while I was taking an exam. Then I immediately called the computer lab operator to check the computer.

Specific Skills in Chemistry and Its Learning

Specific competency areas related to careers or skills are the last aspects added to DLGF compared to the previous version of the framework, DigComp 2.0. This aspect is crucial because the Internet entry into almost all fields, including chemistry and chemistry learning, requires the chemistry community to understand and use this digital technology development best. In this study, the familiarity of chemistry students with specific digital applications in the field of chemistry and its learning was identified with two question items: "knowing technology or digital applications related to expertise (chemistry or chemistry learning)" and "operating technology or digital applications related to skills (chemistry or chemistry learning) well."

The survey results show that there are quite many variations of chemistry-specific digital applications written by students. These applications are categorized into digital applications for chemistry or science and general digital applications that can be used in chemistry and other learning. The digital applications for chemistry or science mentioned by the students are PhET simulation (https://phet.colorado.edu/), Chemlab (https://www.chem-lab.be/), Chemdraw (https://chemdrawdirect.perkinelmer.cloud/js/sample/index.html), Chemix (https://chemix.org/), Kingdraw (http://www.kingdraw.cn/en/index.html), and Periodic Table 2022 (https://www.periodictable.co.za/). In addition, some students mentioned the second group of chemistry applications, for example, Olabs (https://www.olabs.edu.in/?pg=topMenu&id=41), Google Classroom, Google Meet, Zoom, and LMS.

Based on the survey results in the first tier regarding knowledge about specific digital applications of chemistry and learning, most students claimed that their proficiency level was at level 2 (intermediate). However, after going through the second tier, most student responses were declared unconfirmed, so the highest number of confirmed responses became level 1 (foundation). The response of students who were declared unconfirmed was if they only mentioned learning applications that were too general, such as Google Meet, Zoom, and LMS. In addition, based on the survey results, students with responses classified as confirmed as intermediate level and above are in the second to the fourth year of study.

> (Unconfirmed) R-15: Intermediate level: "Zoom, Google Meet: for online discussions."

> (Confirmed) R-18: Foundation level: "I do not know, maybe an LMS like Sipejar (LMS at Universitas Negeri Malang). However, the application for chemical reactions has not been studied."

> (Confirmed) R-34: Intermediate level: "ChemDraw: for drawing 3D chemical molecules; PPT: for making moving images for learning with transitions and others; Sipejar: for learning chemistry."

Then, interviews were conducted with students who only mentioned the application of chemistry learning, which is too general to dig up more information. The interviews with four students showed that most students (primarily first-year students) did not know about digital applications specifically for chemistry. However, one student stated that he could independently operate an application about chemistry if he read the instructions in the manual or guide on YouTube.

> I: "What specific chemical applications do you know and can operate?"

> R-45: "I do not know. Usually Google Classroom."

> I: "Ever heard of an app for drawing chemical molecules?"

> R-45: "Not yet."

> I: "But here you are stating level 2, which means you can do it independently. Why did you choose that level?"

> R-45: "Because I know how to operate it if there are instructions."

Item number 13, discussing students' skills in operating chemistry-specific digital applications and their learning, can only be confirmed through performance tests, and cannot be done with a knowledge-based assessment like other items. However, if the students' responses are unconfirmed on item 12, then automatically, item 13 is also unconfirmed. The logic underlying this decision-making is that if students cannot name the related digital application and explain its function, it cannot be confirmed that students can operate it.

Advantages of Two-Tier Digital Literacy Instruments

Different research objectives and conditions cause variations in the design of digital literacy assessment instruments. Literature review shows that although self-assessment is the most practical and cost-effective and reaches many participants, it limits the level of trustworthiness, including the credibility of test results and their interpretation (Siddiq et al., 2017). The findings of this study using a two-tier instrument showed that 48.54% of the total respondents were declared "unconfirmed" after being verified using the second tier. If this digital literacy skills survey uses only the first tier (self-assessment), the survey results do not show the actual digital literacy proficiency level profile of chemistry students, and it will not be easy to make the correct interpretation.

The second tier, in the form of knowledge-based assessment, helps to increase the accuracy of the self-assessment results with students' actual skills. Although not as accurate as performance-based assessments, this two-tier instrument is more practical for large-scale research samples and more accurate than self-assessment alone. Performance-based tests to observe every step taken by test participants in interacting with digital platforms require enormous energy in their implementation and are challenging to carry out on a large scale, for example, the PIAAC PS-TRE test (van Deursen & van Diepen, 2013) and performance tests with Think Aloud Protocol method (Greene et al., 2014).

CONCLUSION

Referring to the DLGF framework (Law et al., 2018) and DigComp 2.1 proficiency level (Carretero et al., 2017), the researcher developed a chemistry-specific digital literacy skills assessment instrument in a two-tier format (r=0.947) consisting of 13 question items. The survey results show that most students' skills belong to the foundation and intermediate levels. In more detail, the achievement of students' digital literacy skills after confirmation using the second tier and interviews are, as follows:

1. Most chemistry students have level 1 (foundation) skills in information and data literacy–sub-competence evaluating the credibility of information sources; digital content creation; safety–sub-competence governing the privacy/accessibility of digital content; problem-solving; and career-related competencies.
2. Most chemistry students have level 2 (intermediate) skills in devices and software operations; information and data literacy–sub-competences in determining keywords, selecting information, and assessing the usefulness of

information from a source; and communication and collaboration–sub-competencies have the etiquette of communicating on digital platforms and communicate and collaborate online through digital platforms.

3. No chemistry student has level 3 (advanced) or level 4 (highly specialized) skills in any digital literacy competence.

Previous studies that measured digital literacy skills were often limited to examining the definition of digital literacy or survey research where digital literacy skills were measured through self-assessment (van Deursen & van Diepen, 2013). The two-tier digital literacy assessment instrument developed has the advantage that it can confirm students' actual digital literacy skills with the level chosen by the students themselves. It can also be used for surveys with large-scale samples. This instrument has a higher level of trustworthiness than self-assessment because it not only depends on the participants' perceptions but is also proven by follow-up questions to confirm the truth of the perception. Qualitative data from interviews also complemented the information on the digital literacy skills of chemistry students.

Limitations of the Study

The first limitation of this study is that, even though it is designed with self-assessment and continued with knowledge-based assessment, the two-tier instrument cannot measure students' digital literacy skills in the sub-competence of "operating chemical-specific digital applications" optimally. It also does not explain how students interact with digital platforms when looking for information about the dilemma of using hydrogen fuel. These competencies can be measured maximally by using performance tests so that, in the future, other researchers can consider designing and using performance-based digital literacy tests.

The second limitation is the number of participants. It is not easy to generalize the digital literacy proficiency level of chemistry students to the chemistry student population in Indonesia. Other researchers must focus on enriching and strengthening research results with various methods. The third limitation is that a small part of the participant's responses, which were initially "unconfirmed", turned out to be "confirmed" after interviews. These findings suggest that other researchers also collect additional data to increase the validity of the survey results using a two-tier instrument.

Implication

After successfully identifying that only a small proportion of students have a high proficiency level in digital literacy, it is necessary to apply appropriate learning strategies, accompanied by explicit instructions to train students' digital literacy skills on an ongoing basis (Le et al., 2022). Students with low digital literacy skills, especially in information and data literacy competencies, will find it difficult to take advantage of advances in information technology for their own development (Somerville et al., 2008). The collection, evaluation, and assimilation of information with existing knowledge are one of the most important competencies in digital literacy for higher education, so students must be explicitly trained on the right way to do it (Weber et al., 2018). In particular, it is important to show students the role of scientific journals in academia and how to find journal articles using advanced tools such as Google Scholar, Web of Science, and higher education/national library catalogs.

The next implication is that skills in creating digital content can be trained by integrating them with various fields of science because digital content plays a role as a learning medium, positioned as a medium to assist learning and as learning output. Based on the goal to continuously practice digital content creation skills, this goal can be combined with cognitive goals, such as measuring understanding by writing digital essays, as well as other skills such as argumentation skills by presenting arguments in an attractive and persuasive form through posters, infographics, and so on. In addition, disseminating informative digital content needs to pay attention to platforms for sharing information, for example through Google Drive or social media. In addition, because of the many cyber hazards, such as theft of work or plagiarism, it is also important for students to be able to manage the status of their file sharing. The findings in this study increasingly emphasize the importance of designing chemistry learning to improve the skills of chemistry students in digital literacy in the process of building knowledge.

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APPENDIX A: DIGITAL LITERACY PROFICIENCY LEVEL BASED ON DIGCOMP 2.1

Table A1. Digital literacy proficiency level

Competency	Level of digital literacy proficiency			
	Foundation	Intermediate	Advanced	Highly specialized
0. Operation of digital devices & applications	With the help of others (teachers or friends), I can define & operate digital devices & applications.	Independently, I can define & operate digital devices & applications.	Independently, I can define & operate digital devices & applications & provide information assistance to others (friends).	Independently, I can define & operate digital devices & applications & give good guidance to others (friends).
1. Data & information literacy	With the help of others (teachers or friends), I can identify, find, & filter data/information from digital media, identify the credibility & relevance of digital information sources, & group data/information.	Independently, I can identify, find, & filter data/information from digital media, identify the credibility & relevance of digital information sources, & group data/information.	Independently, I can identify, find, & filter data/information from digital media & provide information assistance to other people (friends), identify the credibility & relevance of digital information sources & provide information assistance to other people (friends), & group data/information & provide information assistance to others people (friends).	Independently, I can identify, find, & filter data/information from digital media & give good guidance to others (friends), identify the credibility & relevance of digital information sources & give good guidance to others (friends), & group data/information & give good guidance to others (friends).
2. Communication & collaboration	With the help of others (teachers or friends), I can select & identify digital applications to communicate & collaborate with others (WhatsApp & others), identify & define digital applications to share data/information with others (Google Drive & others), & understand & implement netiquette (communication etiquette on the Internet) such as using good & correct language, not supporting discrimination, & not being biased.	Independently, I can select & identify digital applications to communicate & collaborate with others (WhatsApp & others), identify & define digital applications to share data/information with others (Google Drive & others), understand & implement netiquette (communication etiquette on the Internet) such as using good & correct language, not supporting discrimination, & not being biased.	Independently, I can select & identify digital applications to communicate & collaborate with others (WhatsApp & others) & provide information assistance to other people (friends), identify & define digital applications to share data/information with others (Google Drive & others) & provide information assistance to other people (friends), understand & implement netiquette (communication etiquette on the Internet) such as using good & correct language, not supporting discrimination, not being biased, & providing information assistance to other people (friends).	Independently, I can select & identify digital applications to communicate & collaborate with others (WhatsApp & others), provide information assistance to other people (friends), & give good guidance to others (friends), identify & define digital applications to share data/information with others (Google Drive & others) & provide information assistance to other people (friends), & give good guidance to others (friends), understand & implement netiquette (communication etiquette on the Internet) such as using good & correct language, not supporting discrimination, & not being biased, providing information assistance to other people (friends), & giving good guidance to others (friends).

Table A1 (Continued). Digital literacy proficiency level

Competency	Level of digital literacy proficiency			
	Foundation	Intermediate	Advanced	Highly specialized
3. Digital content creation	With the help of others (teachers or friends), I can create digital content, develop or modify existing digital content, & understand & implement copyright rules for digital information & content	Independently, I can create digital content, develop or modify existing digital content, & understand & implement copyright rules for digital information & content	Independently, I can create digital content & provide information assistance to other people (friends), develop or modify existing digital content & provide information assistance to other people (friends), & understand & implement copyright rules for digital information & content and provide information assistance to other people (friends).	Independently, I can create digital content & give good guidance to others (friends), develop or modify existing digital content & give good guidance to others (friends), & understand & implement copyright rules for digital information & content & give good guidance to others (friends).
4. Device safety	With the help of others (teachers or friends), I can understand & manage the privacy of data or information from digital content (privacy, accessibility, & the like).	Independently, I can understand & manage the privacy of data or information from digital content (privacy, accessibility, & the like).	Independently, I can understand & manage the privacy of data or information from digital content (privacy, accessibility, & the like) & provide information assistance to other people (friends).	Independently, I can understand & manage the privacy of data or information from digital content (privacy, accessibility, & the like) & give good guidance to others (friends).
5. Technical problem-solving	With the help of others (teachers or friends), I can identify, search, & solve technical problems.	Independently, I can identify, search, & solve technical problems.	Independently, I can identify, search, & solve technical problems & provide information assistance to other people (friends).	Independently, I can identify, search, & solve technical problems & give good guidance to others (friends).
6. Career-related competence	With the help of others (teachers or friends), I can identify & operate applications related to chemistry & its learning (Chemdraw & the like).	Independently, I can identify & operate applications related to chemistry & its learning (Chemdraw & the like).	Independently, I can identify & operate applications related to chemistry &its learning (Chemdraw & the like) & provide information assistance to other people (friends).	Independently, I can identify & operate applications related to chemistry & its learning (Chemdraw & the like) & give good guidance to others (friends).