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Digital skills for science-based teaching among Jordanian science teachers: evidence from DiKoLAN framework

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ABSTRACT

This study examines the digital competencies of Jordanian science teachers using the DiKoLAN framework, assessing seven key domains: presentation (PRE), documentation (DOC), data processing (DAP), communication and collaboration (COM), information search and evaluation (ISE), data acquisition (DAQ), and simulation and modelling (SIM). Employing a mixed-methods design, it integrates survey data from 164 teachers with interview insights from 14 participants. The findings show high proficiency in PRE (M=4.48) and DOC (M=4.28), but lower scores in SIM (M=3.53), reflecting limited integration of advanced tools like artificial intelligence (AI) simulations. Private school teachers reported greater access to resources and training, while public school counterparts faced infrastructural and developmental barriers. The results highlight the need for targeted, subject-specific training and equitable resource allocation to support digital integration in science education. These insights inform policy and curriculum development aimed at bridging digital competency gaps.

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1. INTRODUCTION

In recent years, the digital landscape of education has significantly transformed, making digital competencies crucial for teachers, particularly in science education [1], [2]. Integrating digital tools in the classroom enhances learning and prepares students for an increasingly technology-driven future [3], [4]. As science becomes more dependent on technology for exploration, analysis, and collaboration, educators must acquire the skills necessary to effectively guide their students in utilizing these tools [5], [6].

The digital transformation of education underscores the need for teachers to develop essential digital competencies that enhance learning outcomes. In science education, digital tools support experimentation, data analysis, and collaborative learning [3]. To meet these demands, frameworks like DiKoLAN have been developed to guide and assess teachers' digital integration skills [7], [8]. However, Jordanian science educators face persistent challenges—most notably the lack of digital infrastructure in public schools—which hinders the adoption of advanced tools [9]. While private schools have advanced through targeted training and investment, public institutions continue to fall behind, deepening the digital competence gap [10].

This study seeks to examine science teachers' digital competencies through the DiKoLAN framework, which focuses on discipline-specific skills essential for science instruction. By mapping areas of strength and deficiency, the research supports targeted strategies to enhance digital preparedness in Jordanian science education. Digital competencies are essential for teachers across disciplines, but especially in science education due to its experimental, data-driven, and technology-oriented nature. Science pedagogy relies on experiential learning and analytical reasoning, both enhanced by digital simulations, computational tools, and visualization software [11], [12]. Integrating digital skills into science instruction is no longer optional—it is critical for preparing students for scientific careers and ensuring engagement with modern scientific practices [13].

Unlike mathematics, where digital tools assist with computation and graphing, science depends on technology for inquiry-based learning [3], [14]. Simulations enable safe investigation of complex or hazardous experiments, while virtual labs and augmented reality (AR) applications offer 3D exploration of biological structures, improving comprehension [7], [14]. Additionally, science instruction demands data acquisition (DAQ), analysis, and visualization, requiring educators to master tools beyond general information and communication technology (ICT) skills, including artificial intelligence (AI)-driven platforms and scientific modelling software [10], [14].

The DiKoLAN framework addresses these needs by identifying competencies such as simulation use, collaborative tools, and digital resource integration in science teaching [7], [14]. The rise of AI in scientific research—spanning environmental monitoring to automated experimentation—further increases the demand for digitally competent science educators [5], [9], [10], [14]. Continuous professional development and peer knowledge-sharing are vital for maintaining relevance. Thus, digital literacy forms a foundational pillar of effective 21st-century science education [7], [14].

AI is increasingly vital in science education. Alshorman [9] found that while Jordanian science teachers recognize AI's educational potential, they face barriers such as limited resources and inadequate training. This highlights the need for targeted professional development to build digital competencies [9]. Emerging technologies like AI, AR, and 3D simulations enhance science learning through immersive, interactive experiences. Educators must understand AI capabilities and align their use with educational standards to address diverse learner needs [10], [15].

Innovative AI applications—such as Harvard's CS50 chatbot—demonstrate how intelligent tools can boost student engagement [16]. Estonia's AI Leap program further shows how national initiatives can improve teacher and student digital readiness [17]. AR and 3D tools also support conceptual understanding by visualizing abstract scientific content [18]. Effective implementation requires strategic investment in infrastructure, specialized training, and curriculum integration, enabling teachers to fully leverage these technologies for improved learning outcomes.

The DiKoLAN framework offers a subject-specific model for building digital competencies in science education, complementing the broader DigCompEdu framework [8], [13]. It defines seven core areas: digital literacy, pedagogical integration, technical proficiency, instructional design, assessment, collaboration, and lifelong learning [7], [15]. Teachers are expected to evaluate and use digital tools confidently, design tech-integrated lessons, troubleshoot software, assess student understanding, and foster collaborative learning.

Continuous professional development is emphasized to keep pace with technological change. Tailored to science education, DiKoLAN supports skills in data analysis, simulations, online research, and digital communication [8], [19]. These competencies form the basis for evaluating Jordanian science teachers' digital readiness, as outlined in Figure 1.

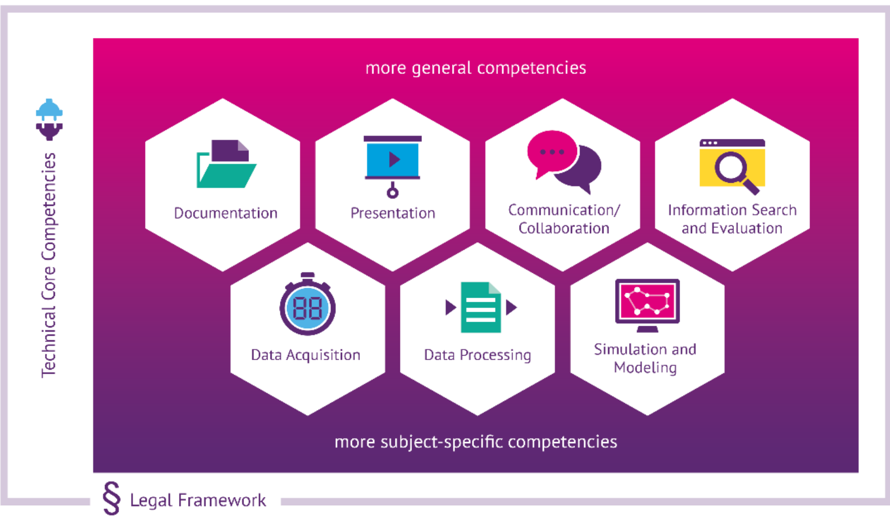

Figure 1. The DiKoLAN framework [7]

Although many science teachers are digital natives, the DiKoLAN framework highlights the need for explicit training to use digital tools effectively in education. It emphasizes developing competencies to select appropriate technologies, integrate them into lessons, and promote digital literacy [7]. The framework also stresses technology's transformative role in fostering engagement, inquiry-based learning, collaboration, and personalized instruction [8].

2. LITERATURE REVIEW

Science educators face unique challenges in integrating advanced technologies such as AI, AR, and data visualization tools [5]. While these tools can enrich instruction, effective use requires specialized training and technical proficiency [6], [8]. Early-career teachers, despite being digitally familiar, often need formalized training to apply educational technologies effectively [20], [21].

Digital competence is essential for preparing students for the 21st century, and science teachers play a central role in this effort [22], [23]. Tools like AI and AR enhance student engagement and promote inquiry-based learning [10], [15]. The DiKoLAN framework supports the integration of such tools, combining technical skills with pedagogical strategies for scientific inquiry [7], [8].

Previous studies show that educators using simulations and AI applications report better student outcomes [13], while frameworks like UNESCO's ICT-competency framework for teachers (CFT) and international society for technology in education (ISTE) standards help define digital literacy profiles for science teachers [7], [11]. However, digital competence is also shaped by context, highlighting the need for subject-specific frameworks and continuous professional development [2], [24]. In Jordan, public school teachers often face barriers such as outdated infrastructure and insufficient training [9]. This study builds on earlier research by identifying these obstacles and offering practical recommendations for improving digital readiness through targeted support and policy reform.

2.1. Theoretical framework

This study is grounded in the technological pedagogical content knowledge (TPACK) framework, which continues to serve as a foundational model in science education for integrating technology, pedagogy, and content knowledge [25]. A recent bibliometric analysis confirms the growing relevance and expansion of TPACK-based approaches, particularly in science teaching, where digital tools must align with both subject content and instructional strategies. This framework remains critical in contexts that demand inquiry-based learning supported by AI simulations and interactive models. Additionally, this study adopts elements of constructivist learning theory, which emphasizes active learning and knowledge construction. Recent research confirms that scaffolding using digital tools (e.g., simulations, AR, and 3D models) supports metacognitive engagement and motivation in learners [26].

2.2. Empirical background and key studies

Empirical research affirms the critical role of digital competencies in science education. Research by Alshorman [9] noted that while Jordanian teachers value AI tools, they face significant barriers such as limited resources and insufficient training, underscoring the need for targeted development. Other researches [27], [28] similarly emphasized the importance of specialized AI training and the urgency of bridging resource gaps in public schools. Estonia's AI Leap initiative [17] illustrates how structured training in AI, data analysis, and simulations enhances digital readiness and student engagement. AI-powered chatbots support personalized learning in complex scientific tasks [16]. These findings collectively highlight that digital competency frameworks must be reinforced with subject-specific training to enable effective integration of AI-based tools in science classrooms.

2.3. Digital competencies in science education

Digital competencies are critical in science education. The DiKoLAN framework [7] underscores the role of digital tools in enhancing instructional effectiveness, student engagement, and inquiry-based learning. Jugembayeva *et al*. [3] found that simulations and virtual labs improve comprehension of complex concepts, aligning with DiKoLAN's emphasis on advanced tools. McDonagh *et al*. [1] highlighted the need for ongoing teacher training in data processing (DAP) and simulation. Similarly, Rudenko *et al*. [13] noted that proficiency with presentation (PRE) tools boosts student engagement, supporting DiKoLAN's PRE and documentation (DOC) competencies.

2.4. Challenges in integrating advanced digital tools

While many educators excel at basic digital skills, they often struggle with advanced tools like simulations and data modelling. Jugembayeva *et al*. [3] noted a significant lack of necessary training and resources. McDonagh *et al*. [1] highlighted that teachers may fail to acquire practical skills for these tools without professional development. Rudenko *et al*. [13] found that motivated and confident teachers are likelier to adopt new technologies, improving student learning. This highlights the need for a supportive environment that fosters ongoing digital skill development among educators.

2.5. Resource disparities between schools

Research highlights notable disparities in digital competencies across schools. Jugembayeva *et al*. [3] found that greater access to digital tools leads to more competent teachers. McDonagh *et al*. [1] noted that private institutions offer more training opportunities, resulting in more proficient educators. This study confirms that private school teachers in Jordan have higher digital competencies than their public counterparts. The importance of these competencies is emphasized in the effective integration of technology in science education, with the DiKoLAN framework serving as a key resource for skill development [7].

2.6. Addressing gaps in existing research

While earlier studies have contributed to digital competency research, key limitations remain. Most rely on general frameworks like DigCompEdu, which overlook subject-specific skills in science education [7], [13]. Self-assessment tools often fail to reflect real classroom practices [3], [5], and differences between public and private school teachers remain underexplored [4].

This study addresses these gaps by: i) applying the science-specific DiKoLAN framework, covering competencies such as simulation, data analysis, and modelling; ii) using a mixed-methods approach that combines surveys with interviews to assess both perceived and actual practices; and iii) comparing public and private school contexts to inform equitable digital policy. This offers a focused, practice-based evaluation of science teachers' digital competencies and the barriers to effective integration.

2.7. Study problem

Effective science education today requires teachers to integrate simulations, virtual labs, and data tools to support inquiry-based learning [7], [11]. Unlike ICT or mathematics, science teaching demands hands-on digital tools for experimentation and DAP [3], [14]. Digital simulations have proven to enhance student understanding, making digital competency vital for science educators [7]. However, few studies explore science teachers' digital readiness in developing countries like Jordan, where public schools face resource and training shortages [5], [9]. This study uses the DiKoLAN framework [7] to assess competencies and guide targeted training policies.

2.8. Research questions

The present study is guided by two primary research questions. The first examines the level of digital competencies possessed by science teachers in teaching science, as defined by the DiKoLAN framework. The second investigates whether significant differences exist in the means of digital competency scores across DiKoLAN dimensions, based on teachers' gender, teaching experience, subject specialization, and type of school. The research questions were formulated as:

i) What is the level of science teachers' digital competencies in teaching science according to the DiKoLAN framework?
ii) What are the differences between the means of science teachers' digital competencies for teaching science and its dimensions according to the DiKoLAN framework based on gender, experience, specialization, and type of school?

2.9. Novelty of the study

This study offers a novel contribution to science education by applying the DiKoLAN framework—tailored to subject-specific digital competencies—to the under-researched context of Jordanian science teachers [7], [8]. Unlike prior studies that adopt broad frameworks like DigCompEdu or rely on self-reported digital literacy [2], [23], this research uses a mixed-methods approach, combining survey data from 164 teachers with qualitative insights from 14 interviews to investigate real-world practices and challenges. It also explores variations in digital competency by school type, gender, experience, and subject specialization—an intersection rarely examined in past work [3], [28]. By revealing disparities in resource access and training, especially in public schools, and underscoring the role of AI and emerging technologies, this study contributes to the global conversation on equitable digital integration and offers actionable insights for policy and reform in developing countries.

3. METHOD
3.1. Research tool
To assess Jordanian science teachers' digital competencies, this study adopted a mixed-methods approach combining quantitative and qualitative data. The quantitative phase involved a 35-item self-administered questionnaire, developed using the DiKoLAN framework to measure seven core competency areas. Content validity was established through expert review in science education and educational technology, and a pilot study with 20 teachers was conducted to refine the instrument.

The qualitative phase comprised 14 semi-structured interviews with teachers selected by gender, school type, and experience. These interviews explored participants' use of digital tools, challenges in technology integration, and professional development needs. Prompts addressed their use of digital tools in science instruction, obstacles to implementing AI-based simulations, and the support required to enhance digital teaching. Interview data were analyzed using reflexive thematic analysis, following Braun and Clarke's 6-phase method as operationalized by Byrne [29]. This approach facilitated the identification of recurring themes related to digital access disparities, training gaps, and the adoption of educational technologies.

3.2. Validity and reliability
To ensure content validity, the questionnaire was reviewed by experts in science education and digital technologies. A pilot study involving 20 science teachers was then conducted to evaluate item clarity, structure, and relevance. Based on the feedback, minor revisions were made, including rewording unclear items and adjusting the question sequence to enhance readability and accuracy. Internal consistency was assessed using Cronbach's alpha, calculated for each of the seven digital competency dimensions using (1):

$$\alpha = k/(k-1) * (1 - \sum\sigma^2{}_i/\sigma^{2t}) \quad (1)$$

where, k=number of items in the scale; $\sigma^2{}_i$=variance of each individual item; and σ^{2t}=total variance of the test (sum of all item variances and their covariances). The instrument showed high reliability, with an overall Cronbach's alpha of 0.843. Dimension-specific alphas were: PRE (0.870), DOC (0.855), DAP (0.852), communication and collaboration (COM) (0.829), information search and evaluation (ISE) (0.838), DAQ (0.824), and simulation and modelling (SIM) (0.800).

3.3. Data collection and analysis
Data were collected from 164 science teachers in 90 public and 74 private schools across Jordan using purposive sampling to capture diversity in school type, teaching experience, and subject specialization (physics, chemistry, and biology). The quantitative phase involved an online questionnaire, followed by 14 semi-structured interviews selected for variation in school type (7 public and 7 private), experience (7 below and 7 above 5 years), gender (6 males and 8 females), and subject (5 physics, 5 chemistry, and 4 biology). Participants also varied in digital proficiency based on survey responses. Descriptive statistical analysis was used to assess digital competencies across the seven DiKoLAN dimensions. Table 1 presents the means and standard deviations for each area, offering an overview of teachers' self-reported proficiency within the framework.

Table 1. Demographic characteristics of respondents

Characteristic	Category	Frequency (n)	Percentage (%)
Gender	Male	62	37.8
	Female	102	62.2
Teaching experience	Less than 5 years	79	48.17
	More than 5 years	83	50.61
School type	Public	90	54.88
	Private	74	45.12

4. RESULTS AND DISCUSSION
4.1. Quantitative survey
To answer the first question means and standard deviations were calculated, followed by a t-test and Cohen's effect size, which was then converted into explained variance. To answer the second question means and standard deviations were calculated, and a 4-way analysis of variance (ANOVA) was performed between the means.

4.1.1. Results related to the first research question
Mean and standard deviations of teachers' questionnaire responses were calculated, followed by a t-test and Cohen's effect size to assess competency levels and practical significance, as shown in Table 2. Results show that Jordanian science teachers exhibit high digital competencies, with an overall mean of 4.05 (SD=1.84) based on the DiKoLAN framework. The highest score was in PRE (M=4.48, SD=0.57), reflecting strong use of digital media in instruction, followed by DOC (M=4.28, SD=0.66). In contrast, SIM scored lowest (M=3.53, SD=0.75), suggesting difficulties with digital simulations due to limited training or access. High competence is linked to teachers' educational background and prior exposure to technology.

Table 2. T-test results for teachers' digital competencies in science teaching, including Cohen's effect size and explained variance

Scale and dimensions with ID	Mean	Std. Dev.	One sample t-test			Cohen's d		
			Value	Rank	Degree	Value	Variance of Value (%)	Cohen's Class
PRE (2)	4.48	0.57	46.61*	1	High	2.59	62.59	High
DOC (1)	4.28	0.66	40.24*	2	High	1.68	41.31	High
DAP (6)	4.23	0.67	27.09*	3	High	1.50	36.12	High
ISE (4)	4.05	0.67	26.18*	4	High	1.45	34.55	High
COM (3)	3.92	0.79	22.20*	5	High	1.23	27.51	High
DAQ (5)	3.86	0.78	22.11*	6	High	1.19	19.74	Medium
SIM (7)	3.53	0.75	17.88	7	Medium	1.05	19.70	Medium
Total	4.05	0.58	33.21*		High	1.84	45.92	High

*The p-value (p) indicates the statistical significance of the t-test results, where p≤0.05 suggests that the observed differences in digital competencies are statistically significant.

4.1.2. Results related to the second research question
To answer the second question, the mean (M) and standard deviation (S) of teachers' digital competencies in teaching science were calculated according to gender, experience, specialization, and school type, as shown in Table 3. The table indicates notable differences in digital competencies by school type, with private school teachers scoring higher (M=4.39, SD=0.66) than their public-school counterparts (M=3.90, SD=0.68). No significant differences emerged based on gender, experience, or specialization. Private school educators also outperformed in PRE (M=4.45, SD=0.64) and DOC (M=4.65, SD=0.69). Targeted training and resource investment are essential to closing this competency gap. Figure 2 presents mean scores across the seven DiKoLAN dimensions, highlighting strengths and areas requiring further support.

Figure 2 illustrates the average digital competency scores across the seven DiKoLAN dimensions, highlighting stronger competencies in "presentation" and "documentation" and lower scores in "assessment" and "research/evaluation". To examine differences in digital competencies based on gender, an independent samples t-test was conducted. Table 4 presents the results of this analysis, indicating whether statistically significant differences exist between male and female science teachers across the DiKoLAN dimensions.

In Table 4, the PRE dimension items indicate strong digital competencies among teachers, with a mean of 4.73 for the statement, "I utilize digital media to enhance the knowledge acquisition process." The variance explained (67.71%) suggests that teachers effectively use digital PRE to engage students in learning. Continued professional development is essential to keep up with evolving PRE tools and techniques in modern science education.

Table 3. Science teachers' digital competencies by gender, experience, specialization, and school type

IVs with levels		Dimensions of scale															
		DOC		PRE		COM		ISE		DAQ		DAP		SIM		Total	
		M	S	M	S	M	S	M	S	M	S	M	S	M	S	M	S
Gender	Male	4.32	0.64	4.45	0.65	3.7	0.76	4.1	0.68	3.87	0.79	4.02	0.56	3.56	0.67	4.00	0.58
	Female	4.23	0.71	4.85	0.67	3.8	0.80	3.97	0.66	3.74	0.80	4.4	0.58	3.3	0.77	4.04	0.59
Experience	5≤	4.33	0.66	4.45	0.66	3.35	0.74	3.89	0.79	3.68	0.64	4.3	0.89	3.45	0.72	3.92	0.61
	5>	4.25	0.62	4.42	0.56	3.91	0.61	3.83	0.48	3.89	0.70	4.03	0.79	3.98	0.55	4.04	0.59
School type	Public	4.22	0.68	4.23	0.65	3.78	0.55	3.87	0.65	3.77	0.68	4.23	0.76	3.23	0.66	3.90	0.68
	Private	4.32	0.66	4.65	0.69	4.48	0.68	4.44	0.67	4.12	0.56	4.33	0.80	4.45	0.62	4.39	0.66
Specialization	Physics	4.34	0.67	4.6	0.57	3.98	0.66	4.13	0.66	4.04	0.58	4.18	0.74	3.24	0.68	4.07	0.79
	Chemistry	4.31	0.71	4.33	0.73	4.21	0.69	4.12	0.56	3.87	0.89	4.28	0.61	3.33	0.66	4.06	0.48
	Biology	4.22	0.64	4.35	0.56	4.12	0.63	4.14	0.65	3.78	0.79	4.32	0.55	3.21	0.67	4.02	0.65
Total		4.28	0.66	4.48	0.57	3.93	0.79	4.05	0.67	3.86	0.78	4.22	0.67	3.53	0.75	4.05	0.85

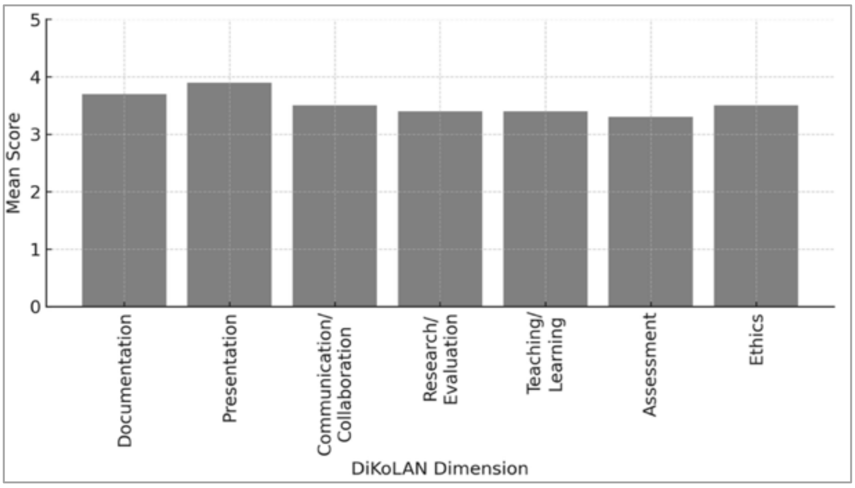

Figure 2. Average digital competency scores by DiKoLAN dimension among science teachers

Table 4. T-test results to measure the teachers' responses to the PRE dimension items, and Cohen's effect size and variance

Scale and dimensions with ID	Mean	Std. Dev.	One sample t-test			Cohen's d		
			Degree	Rank	Value	Value	Variance of Value (%)	Cohen's Class
I utilize digital media to enhance the knowledge acquisition process in a way that is targeted and suitable for my audience. (5)	4.73	0.60	52.18*	1	High	2.90	67.71	High
I am aware of the limits and potentials of various digital PRE media and can choose the most appropriate one for my teaching objectives. (6)	4.61	0.60	51.78*	2	High	2.44	59.78	High
I can create digital PRE that engage and inform my students effectively. (8)	4.23	0.70	40.72*	3	High	2.26	52.12	High
I continuously update my skills in digital PRE tools to improve my teaching practice (7)	3.98	0.78	26.18*	4	High	2.09	47.78	High

*The p-value (p) indicates the statistical significance of the t-test results, where $p \leq 0.05$ suggests that the observed differences in digital competencies are statistically significant.

Figure 3 compares the digital competency levels between public and private school teachers, clearly showing higher scores for private schools across all DiKoLAN dimensions. In order to explore the impact of teaching experience on digital competencies, a one-way ANOVA was conducted across three experience groups. Table 5 reports the results of this analysis, identifying whether significant differences exist in competency levels based on years of teaching experience.

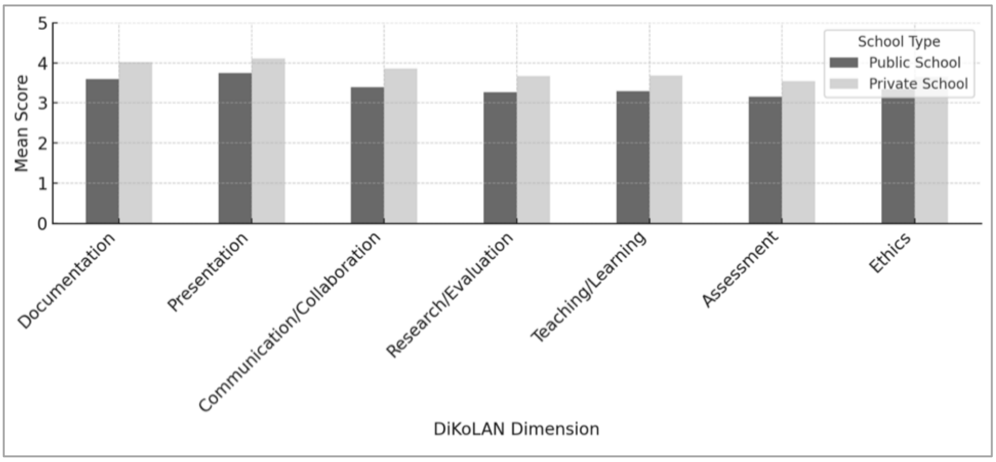

Figure 3. Digital competency scores by school type across DiKoLAN dimensions

Table 5 indicates that educators demonstrate exceptional skills in the DOC dimension, particularly in integrating and preserving various media for instructional purposes (mean=4.35). This competence facilitates effective organization and PRE of scientific content, enhancing student comprehension. Furthermore, a significant variance explained (45.49%) corroborates this assertion. To determine whether specialization affects teachers' digital competencies, a one-way ANOVA was performed among the three specialization groups: biology, chemistry, and physics. Table 6 presents the findings of this analysis, highlighting any significant variations in competency levels by academic specialization.

As presented in Table 6, teachers reported a mean score of 4.08 in using digital tools for ISE, reflecting strong proficiency in guiding students through online research and assessing scientific sources. However, a variance of 26.69% suggests room for improvement in critical digital literacy. A one-way ANOVA examined differences by school type (public, private, and United Nations Relief and Works Agency for Palestine Refugees in the Near East or UNRWA), with results shown in Table 7, indicating whether institutional context affects perceived digital competency.

Table 5. T-test results for DOC dimension scores, including Cohen's d and explained variance

Scale and dimensions with ID	Mean	Std. Dev.	One sample t-test			Cohen's d		
			Value	Rank	Degree	Value	Variance of Value (%)	Cohen's Class
I can combine and save different media types (text, images, video) to create engaging teaching materials. (3)	4.35	0.74	32.91*	1	High	1.83	45.49	High
I am skilled at taking, editing, and integrating photos, images, and videos into my science teaching resources. (2)	4.26	0.81	28.07*	2	High	1.56	37.77	High
I can effectively use digital tools for the systematic organization and permanent storage of teaching-related data and information. (1)	3.98	0.79	26.69*	3	High	1.08	22.41	Medium
I am proficient in structuring and archiving information digitally to enhance the accessibility and PRE of educational content. (4)	3.78	0.86	21.18*	4	High	1.08	18.90	Medium

*The p-value (p) indicates the statistical significance of the t-test results, where p≤0.05 suggests that the observed differences in digital competencies are statistically significant.

Table 6. T-test results for DAP scores, including Cohen's d and explained variance

Scale and dimensions with ID	Mean	Std. Dev.	One sample t-test			Cohen's d		
			Value	Rank	Degree	Value	Variance of Value (%)	Cohen's Class
I am competent in using digital tools for filtering and processing data for use in science education. (21)	4.20	0.80	26.84*	1	High	1.49	35.69	High
I can perform statistical analyses on data sets using digital tools to extract meaningful insights for my students. (22)	4.13	0.83	24.40*	2	High	1.36	31.46	High
I can calculate new quantities and merge data sets to provide a comprehensive view of a scientific concept. (23)	3.92	0.93	19.07*	3	High	1.06	21.41	Medium
I teach students how to process and interpret data using digital resources to enhance their scientific understanding. (24)	3.74	0.91	16.50*	4	High	0.98	18.90	Medium

*The p-value (p) indicates the statistical significance of the t-test results, where p≤0.05 suggests that the observed differences in digital competencies are statistically significant.

Table 7 shows that teachers demonstrate strong competence in facilitating COM using digital tools, with a mean of 3.94 for engaging students in collaborative tasks. Although this is a key skill in scientific inquiry, the explained variance (20.42%) indicates variability in its application. Expanding the use of tools like shared documents and virtual labs may improve consistency. A 4-way ANOVA was conducted to test the significance of these differences, as shown in Table 8.

Table 8 reports the 4-way ANOVA results, indicating a significant effect of school type on digital competencies (p=0.02), with private school teachers scoring higher. This supports previous findings that private institutions have better access to digital tools and training. No significant differences were found by gender, teaching experience, or specialization (p>0.05), suggesting comparable competency levels across these groups. Ensuring equitable access and targeted support for public school teachers is essential to improving digital integration in science education.

Table 7. T-test results for COM scores, including Cohen's d and explained variance

Scale and dimensions with ID	Mean	Std. Dev.	One sample t-test			Cohen's d		
			Value	Rank	Degree	Value	Variance of Value (%)	Cohen's Class
I regularly use digital tools to facilitate synchronous and asynchronous collaborative work among my students. (9)	3.94	0.79	18.42*	1	High	1.01	20.42	High
I am adept at creating and managing shared digital files and data pools for group activities in my classes. (10)	3.81	0.93	15.55*	2	High	0.86	16.68	Medium
I can implement systems for assigning and managing digital rights and responsibilities among my students during group projects. (11)	3.78	1.15	5.44*	3	High	0.30	2.94	Low
I actively use communication platforms to engage with students and support collaborative learning environments. (12)	3.35	1.13	4.74*	4	High	0.26	1.70	Low

*The p-value (p) indicates the statistical significance of the t-test results, where p≤0.05 suggests that the observed differences in digital competencies are statistically significant.

Table 8. The 4-way ANOVA results for science teachers' digital competencies by gender, experience, school type, and specialization

Source of variance	Sum of squares	df	Mean square	F	Sig.
Gender	0.03	1	0.03	0.07	0.78
Experience	0.78	1	0.78	1.81	0.18
School type	2.42	1	2.42	5.70*	0.02
Specialization	0.33	1	0.33	0.8	0.34
Error	79.16	186	0.43		
Total	83.92	191			

*Indicates statistically significant difference at p<0.05.

4.2. Teacher interviews: insights into digital competencies

To complement the quantitative findings, semi-structured interviews were conducted with 14 science teachers. The aim was to gain deeper insights into their digital competencies, the practical challenges they face in integrating technology into science teaching, and their perceived training needs. This qualitative data provided context and depth to the numerical results, helping to interpret patterns observed in the survey responses.

Qualitative interview data were analyzed using reflexive thematic analysis, following Byrne's adaptation of Braun and Clarke's 6-phase framework [29]. Transcripts were reviewed for familiarization, then open-coded to identify patterns related to digital competency, barriers, and training needs. Related codes were grouped into themes such as unequal access to digital resources, gaps in teacher training, and perceptions of AI in science education. Themes were reviewed for coherence, refined, and clearly labelled. Representative quotations were selected, and the final themes were integrated into a narrative aligned with quantitative results and existing literature.

The thematic analysis revealed three core themes. First, public school teachers reported limited access to digital tools and infrastructure, in contrast to better-equipped private schools with more training opportunities. Second, participants cited a lack of structured professional development for integrating digital tools into science teaching. Third, while basic technologies were manageable, advanced tools—particularly simulations and AI—posed challenges due to inadequate training and institutional support. These findings provide qualitative depth to the quantitative results, exposing specific barriers to effective technology use in resource-constrained settings. The data underscore the urgent need for targeted training and policy reforms to enable meaningful digital integration in science education.

4.2.1. Perceptions of digital tools and competencies

Most teachers expressed enthusiasm for using digital tools to enhance science learning and engagement. However, public school teachers cited major resource shortages. One chemistry teacher noted, "*We know digital tools can make science more interactive, but our schools lack the necessary technology*." In contrast, a biology teacher in a private school stated, "*We have smartboards, projectors, and tablets, which help our students understand better*." These contrasting views highlight the resource gap between public and private schools in Jordan.

4.2.2. Barriers to digital competency development

A major theme in the interviews was the stark resource gap between public and private schools. Public school teachers reported limited infrastructure, such as a single shared computer lab and unreliable internet. One rural educator stated that, "*We are trying to teach 21st-century skills with 20th-century tools*." In contrast, a private school teacher explained, "*Our students have personal devices and access to high-speed internet labs*." These disparities highlight the technological divide across school types.

4.2.3. Professional development and training needs

Teachers repeatedly stressed the need for targeted, accessible professional development, especially in under-resourced public schools. One chemistry teacher noted, "*the training is basic and mostly focuses on general computer skills. We need specific training for using digital tools in science*." A teacher outside Amman cited the lack of regular workshops. In contrast, private school educators reported greater support. As one explained that, "*Our school offers workshops on the latest digital tools and trainers to help us implement them*."

4.2.4. Challenges with advanced digital tools

Although basic digital PRE tools are widely used, many educators—particularly in public schools—struggle to adopt advanced technologies such as scientific simulations due to inadequate training and infrastructure. One experienced teacher stated, "*I have tried free simulation programs, but they take too long to learn, and without support, the students lose interest*." A private school physics teacher, despite having access to advanced tools, also described integration as challenging. These findings reveal a digital competency gap, underscoring the need for more user-friendly platforms and practical training.

4.2.5. Institutional and curriculum constraints

Public school teachers frequently encounter institutional barriers that hinder digital integration. One teacher remarked, "*We have to cover so much material quickly, and with large class sizes and limited resources, it is hard to justify using new technologies*." In contrast, private school educators report more curricular flexibility. A teacher from an elite Amman school shared, "*Our curriculum allows for digital tool integration as long as it aligns with learning objectives*." These constraints in public schools contribute to a widening gap in digital competencies between the two sectors.

4.2.6. Support and collaboration among teachers

In under-resourced settings, peer collaboration emerges as a critical coping mechanism. A public-school biology teacher noted, "*We lack formal support for digital tools, but we learn from each other and share ideas*." In contrast, private school educators reported structured peer-learning opportunities. One stated, "*We have regular meetings to exchange ideas on using new digital tools. Public schools could benefit from similar initiatives with better resources*."

4.2.7. Opportunities and optimism for the future

Despite existing challenges, educators across both sectors expressed optimism about the potential of digital tools in transforming science education in Jordan. One teacher observed, "*We see how technology can make learning more interactive and engaging. If public schools had better access to resources and more relevant training, the digital divide could be reduced, allowing all students to benefit*." This shared outlook reflects a belief that, with adequate support, equitable digital integration is achievable.

4.3. Discussion

This study examined the digital competencies of Jordanian science teachers using the DiKoLAN framework, integrating quantitative survey data and qualitative interview insights. The results indicate that while teachers demonstrate strong digital competencies in basic skills, challenges persist in advanced digital tool integration, training availability, and resource disparities between public and private schools.

4.3.1. Digital competencies across DiKoLAN dimensions

The quantitative results showed strong competencies in PRE (M=4.48) and DOC (M=4.28), consistent with several findings [11], [13] on the routine use of digital tools for instruction. In contrast, SIM scored lowest (M=3.53), indicating limited ability to use AI-based tools and virtual labs. This was echoed in interviews, where teachers cited inadequate training and institutional support—findings aligned with prior research calling for science-specific digital training [3], [7]. Broader studies also reveal barriers such as ethical concerns and lack of self-regulation among users, which hinder AI integration [9], [27], [30].

4.3.2. Differences by school type

The digital skills gap between public and private school teachers remains significant, with private educators showing stronger competencies across most areas. This reflects findings that private institutions offer superior access to technology, infrastructure, and professional development [5], [10]. Interviews corroborated that public school teachers face persistent barriers, including outdated equipment, unstable internet, and limited support for digital integration. These inequalities underscore the broader digital divide and the pressing need for equitable investment in resources [3]. Another studies [28], [31] further stressed the training disparities between urban and rural schools and advocate for targeted support to underserved institutions.

4.3.3. Lack of gender, experience, and specialization differences

Both quantitative and qualitative findings confirm that current professional development remains insufficient for science teachers. Many reported that existing programs are overly general and do not address subject-specific digital skills, such as simulation-based instruction, AI integration, and digital assessment tools. Studies show that structured digital training enhances teachers' confidence and effectiveness in using advanced technologies [9], [14]. Interview data further revealed that participants who received targeted training exhibited higher digital readiness.

Research by Alshorman [9] also noted the underutilization of AI in Jordanian classrooms due to training and policy gaps. Moreover, digital readiness appears to be shaped more by continuous training than by gender, experience, or specialization [1]. These results highlight the critical need for ongoing, science-specific training initiatives.

4.3.4. Implications for professional development

The findings indicate that digital competency gaps in Jordanian science education result from both training shortfalls and systemic resource limitations. Schools offering structured digital training show greater teacher proficiency in technology integration. Addressing this issue requires: i) equitable access to digital tools across school types; ii) targeted professional development in subject-specific digital skills; and iii) stronger institutional support for integrating AI, simulations, and advanced technologies into the curriculum. Tackling these areas can narrow the digital divide and empower all science teachers to apply digital tools effectively [7], [30]. Prior studies emphasize the value of continuous professional development [5], the role of mentoring in enhancing teachers' digital competencies [32], and the importance of institutional infrastructure and strategic investment in teacher readiness [33].

5. CONCLUSION

This study assessed the digital competencies of Jordanian science teachers using the DiKoLAN framework, examining differences by gender, specialization, experience, and school type. The results showed moderate overall competency, with strengths in PRE and DOC, and weaknesses in assessment and research/evaluation. Private school teachers scored consistently higher across all dimensions, reflecting inequities in access to digital tools and training. The findings confirm that institutional context and infrastructure significantly influence teachers' ability to integrate technology into science instruction. Experience and specialization also shaped competencies in specific domains.

These findings carry several implications. Integrating the DiKoLAN framework into national teacher training and evaluation systems could establish clear, subject-specific benchmarks for digital instruction. The disparity between public and private schools underscores the urgent need for policies promoting digital equity through improved infrastructure and professional development. Training programs should include modules on practical applications like simulation, modelling, and digital assessment tailored to science education. To support effective digital integration, policymakers must prioritize investment in infrastructure and ensure sustained, targeted training opportunities for all educators. Future research should examine the long-term impact of framework-based training using experimental or longitudinal approaches. While this study provides valuable insights, its reliance on self-reported data and absence of a control group are limitations that future studies should address to validate and expand upon these results.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

INFORMED CONSENT

Informed consent was obtained voluntarily, and participants were made aware of their right to withdraw from the study at any stage without any consequences.

ETHICAL APPROVAL

This study was conducted in accordance with established ethical standards for research involving human participants. All participants were informed of the study's purpose and assured of the confidentiality and anonymity of their responses. No identifying personal information was collected.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author [SMA], upon reasonable request. The data include sensitive information from human participants and are not publicly available due to confidentiality and ethical restrictions.

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