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Fostering Secondary School Chemistry Teachers' Digital Competences in Accordance with the Digital Competence Framework for Educators

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Abstract

This paper presents the results of research aimed at identifying and assessing the impact of the innovative educational program "Teaching Chemistry in Secondary Schools: Fostering Digital and Scientific Literacy." The programme aimed to help chemistry teachers develop digital competence in accordance with the European Framework for the Digital Competence of Educators (DigCompEdu) requirements. The research sample consisted of secondary school chemistry teachers combined (N=15) from three Slovak regions. The research was conducted during the first term of the 2024/2025 school year. The innovative educational programme consisted of 6 modules, covering a total of 50 hours. This innovative educational programme aimed to provide teachers with access to knowledge on teaching chemistry, with a focus on fostering digital competence through activating methods such as inquiry-based teaching, digital technology-supported teaching, and the use of digital summative and formative assessment tools. The research instrument was the DigCompEdu Check-in Questionnaire, completed by the teachers before and after finishing the educational programme. A comparison of the pre-test and post-test results indicated an overall improvement in teachers' digital competence, moving from explorers to integrators. The analysis of their results in the area of Teaching and Learning indicated an increased frequency of teachers using digital tools to implement various teaching methods focused on developing students' independent learning and group cooperation. The analysis of their results in the Assessment area indicated an increase in teachers' monitoring of students' progress and their analysis of information and feedback gathered about students. However, teachers still opted to use digital assessment tools less frequently. Therefore, it is necessary to make various digital assessment tools, addressing specific chemistry topics, accessible to teachers.

Keywords: assessment, DigCompEdu, questionnaire, teacher, teaching and learning

1. Introduction

The digital transformation of schools and education is linked to the integration of digital technology into the teaching process. With the growing importance of digital technologies, the

need for digitally competent teachers, who can effectively use these technologies in the teaching process and enhance students' digital skills, is also increasing (Instefjord & Munthe, 2017; Ng, 2012; Redecker, 2017). Teachers' digital competences determine their ability to effectively use digital technology, tools, and resources to enhance both teaching and learning. These competences include not only technical knowledge but also the skills and attitudes necessary to integrate technology into teaching (Kiryakova & Kozhuharova, 2024).

There are several teachers' digital competence development frameworks such as European Framework for the Digital Competence of Educators: DigCompEdu (Redecker, 2017), UNESCO ICT Competency Framework for Teachers (UNESCO, 2018), or Educators' Digital Competence Framework (UNICEF, 2022), which offer a structured approach to defining and understanding the digital competences needed by current teachers. The presented research specifically focused on DigCompEdu.

DigCompEdu was designed by the European Commission in accordance with the institutional and contextual requirements of different countries, and it is open to updates (Caena & Redecker, 2019). This framework defines six digital competence areas for educators (Redecker, 2017):

Area 1 Professional Engagement

The teacher uses digital tools for effective communication, professional collaboration with colleagues, the application of digital technologies in practice, and continuous professional development.

Area 2 Digital Sources

The teacher selects appropriate digital resources for teaching, creates new learning materials, and develops digital content. He or she integrates modern digital devices and tools into the teaching process to enhance the effectiveness of teaching methods and promote collaboration and independent learning among students.

Area 3 Teaching and Learning

The teacher effectively implements learning activities with the support of digital technologies, focusing on developing students' independent learning as well as promoting teamwork. These activities stimulate interactive learning and encourage the involvement of all students in the learning process.

Area 4 Assessment

The teacher uses digitally supported formative and summative assessment. He or she analyses the data collected on students' progress and provides feedback.

Area 5 Empowering Learners

Through digital technology, teachers support active and differentiated student learning. It enables students to progress at their own pace while emphasising the importance of developing both digital and civic mindsets, thereby contributing to their digital literacy.

Area 6 Facilitating Learners' Digital Competence

The teacher integrates activities, assignments, and assessment procedures into instruction to support students' ability to find, analyse, and interpret information. Thus, the teacher fosters students' critical thinking, along with their responsible and ethical use of technology.

According to Cattaneo et al. (2022), the main determinants of teachers' digital competence include their attitude towards technology and the frequency with which they use digital tools.

Teachers face several challenges in integrating digital technologies into their teaching practice. Although subject-specific digital tools are highly valued by teachers, the findings reveal multiple barriers to their strategic use, including time constraints, high workloads, failing infrastructure, lack of technical support, and a fear of change (Althubyani, 2024; Vieira et al., 2023; Wohlfart et al., 2023).

The insufficient use of digital technology in Slovak schools is primarily attributed to challenging preparation for teaching with digital tools (51.5%), inadequate technical equipment (22%), and a lack of ability to use such tools (20%) (Increasing Digital Competences – The Growth of Education in Society, 2022; press release).

The acquisition of these digital competences is essential for teachers to effectively integrate new technologies into the ever-evolving educational environment of the 21st century (Schleicher, 2024).

2. Methods

2.1 Research Aims and Questions

The research aimed to identify and assess the impact of the innovative educational programme "Teaching Chemistry in Secondary Schools: Fostering Digital and Scientific Literacy" on the development of digital competence among secondary school chemistry teachers in accordance with DigCompEdu requirements.

Based on this goal, the main research question and the related sub-questions were formulated as follows:

- RQ: Is the proposed innovative training effective in developing selected digital competences in accordance with the DigCompEdu framework?
- RQ1: What are the differences in teachers' digital competences in the *Teaching and Learning* domain before and after completing the innovative training?
- RQ2: What are the differences in teachers' digital competences in the *Assessment* domain before and after completing the innovative training?

A quasi-experimental, one-group pre-test – post-test research design was used in this research. The research was conducted during the first term of the 2024/2025 school year.

2.2 Research Sample

The selection of schools and teachers was deliberate and followed the following criteria. Schools whose teachers actively participated in the national project Digital Transformation of Education and School (DiTEdu) (https://www.ncdtv.sk/) and expressed their interest in undertaking the innovative educational programme "Teaching Chemistry in Secondary Schools: Fostering Digital and Scientific Literacy" were included in the study. Based on these criteria, the research sample consisted of secondary school chemistry teachers (combined) (N=15; 2 men and 13 women) from three Slovak regions. These teachers were from three Slovak regions: Banská Bystrica, Prešov, and Košice. Their teaching experience fell into the following ranges: 6–10 years (1 teacher), 16–20 years (4 teachers), and more than 21 years (10 teachers).

2.3 Research Instrument

The DigCompEdu Check-in Questionnaire, based on the DigCompEdu framework (Caena & Redecker, 2019; Redecker, 2017), was used as the research instrument . It is designed for self-assessment of teachers' and educators' digital competences, determining their level of digital skills, identifying strengths and weaknesses in the use of digital technologies in education, and

providing recommendations for improvement and further professional development. The DigCompEdu Check-in Questionnaire consists of 22 items that represent the 22 digital competences across six areas in DigCompEdu. 1) Professional Engagement (4 items), 2) Digital Resources (3 items), 3) Teaching and Learning (4 items), 4) Assessment (3 items), Empowering Learners (3 items), and Facilitating Learners' Digital Competence (5 items).

For each of these items, the teacher responds by selecting one answer from a list of seven options. These response options are arranged sequentially from the lowest to the highest level (Below A1 – No engagement, A1 – Newcomer, A2 – Explorer, B1 – Integrator, B2 – Expert, C1 – Leader, C2 – Pioneer), reflecting the gradual development of digital competencies according to the DigCompEdu framework (see Table 1). At these levels, A1 represents the lowest level, and C2 represents the highest level (Cabero-Almenara & Palacios-Rodríguez, 2020).

Table 1. Different DigCompEdu competence levels

Level	Score	Description
*Below A1**	0 – No engagement	I do not use digital technology or have not yet integrated it into teaching.
A1 Newcomer	1 – Partial adoption	I do not have much experience with digital technology in teaching.
A2 Explorer	2 – Occasional use	I do not use digital technology often, but I am aware of its potential in teaching and am interested in further exploration.
B1 Integrator	3 – Increasing diversity/intensity	I experiment with various digital technologies in teaching, but I still need to expand their selection.
B2 Expert	4 – Systematic/complex use	I use digital technologies in teaching confidently and strive to understand the advantages and disadvantages of different digital strategies for specific pedagogical situations.
C1 Leader	5 – Strategic/effective use	I approach the use of digital technologies strategically and consistently, and I know how to select the appropriate digital strategy for a particular pedagogical situation.
C2 Pioneer	6 – Innovative and advanced use	I am continually experimenting with advanced digital technologies and developing new pedagogical approaches that can serve as models for other educators.

Source: Based on Cabero-Almenara & Palacios-Rodríguez (2020), Ghomi & Redecker (2019).

At the beginning, a series of demographic questions were included in the questionnaire: gender, years of teaching experience, and the region in which the school where the teacher works is located.

2.4 Research Procedure

In the preparatory phase of the research, the content of an innovative training programme, "Teaching Chemistry in Secondary Schools: Fostering Digital and Scientific Literacy (TCDCL)", was designed in line with the requirements for the development of digital competences embedded in DigCompEdu (see Table 2). The content focus of the training programme has been designed in accordance with the State Educational Programme for Secondary Schools, the subject of chemistry (SEM, 2014), and educational strategies.

The aim of the innovative training was to make knowledge about chemistry education available to secondary school teachers, focusing on the development of digital and scientific competences as well as skills for learning, through methods and concepts of active inquiry, such as inquiry-based teaching, teaching chemistry with the support of digital technologies,

and the use of digital tools for summative and formative assessment. Teachers' digital skills and competencies for the 21st century were developed in line with DigCompEdu.

Table 2. Compliance of the "Teaching Chemistry in Secondary Schools: Fostering Digital and Scientific Literacy" training programme topics, focused on the development of digital competences, with the DigCompEdu framework

Module topics and their aims **50 hours** **present (25h), online (15h) and distance (10h) form of education**	**Area of digital competence development according to DigCompEdu**
Topic 1: An introduction to education for the 21st century	**Teaching and Learning**
• Providing knowledge on activating methods of chemistry teaching, with a focus on active inquiry and the use of digital technologies for chemistry education in the 21st century. • Making knowledge of the European Digital Competence Framework for Educators (DigCompEdu) document/standard available.	
Topic 2: Models and modelling in chemistry teaching	**Teaching and Learning**
• The use of chemical modelling programs ChemDraw, Chemix, and ACD/ChemSketch in chemistry teachers' preparation. • The use of LaTeX editors.	
Topic 3: The inquiry-based method in chemistry teaching	**Teaching and Learning**
• Making knowledge about inquiry-based teaching available, creating inquiry-based activities for each level to explore specific topics in secondary school chemistry.	
Topic 4: Computer-aided experiments	**Teaching and Learning**
• Development of skills in collecting, storing, processing, and evaluating experimental data, as well as drawing conclusions. • Measuring using selected sensors (temperature, pH, gas pressure, voltage), ion-selective electrodes, and a colorimeter.	
Topic 5: Assessment in the 21st century with digital technologies – summative assessment and formative assessment	**Assessment**
• **Summative assessment** • Creation of tasks and interactive tests using digital tools for summative assessment (Google Forms, Kahoot). • **Formative assessment** • The use of digital tools in formative assessment (Kahoot!, Google Forms, Slido, Mentimeter, PollEverywhere). • **Didactic games in chemistry teaching**	
Topic 6: Artificial Intelligence in Chemistry Teaching	**Teaching and Learning**
• **AI in the teacher's work** Presentation of various possibilities for using AI in a teacher's work (in lesson preparation and the creation of teaching materials). Different ideas on how to integrate AI into learning tasks for students.	

Source: Own processing

The educational materials designed for individual topics can also be used for self-study, through which the teacher gains greater independence and an opportunity to gain experience outside the programme.

The contents of the TCDSL programme including the educational materials designed were transferred into the MS Teams environment. For four months (September – December) of the 2024/2025 school year, the TCDSL programme was taught using the MS Teams e-course support. The scope of teaching was 6 or 7 lessons every two weeks in 6 modules for a total of 50 hours. A combined present (25h), online (15h) and distance (10h) form of instruction was applied. The lecturers of the innovative training were experts in the field of chemistry didactics from three Slovak universities: the Faculty of Science at P. J. Šafárik University in Košice, the

Faculty of Education at Trnava University in Trnava, and the Faculty of Science at Comenius University in Bratislava.

The chemistry teachers (N=15) filled in the same DigCompEdu Check-in Questionnaire before (September 2024) and after (December 2024) completing the educational programme TCDSL.

3. Results

Descriptive statistics and graphical comparisons were used to provide an initial insight into changes in teachers' digital competences over the course of the programme. Given the small research sample, qualitative feedback – such as open-ended responses and interviews – was also included to add further depth and context to the findings. The integration of both quantitative and qualitative approaches supports a more comprehensive understanding of the impact of the programme. We will discuss the analysis of this qualitative data in a separate article.

Teachers' responses (N=15) to the DigCompEdu Check-in Questionnaire were evaluated in terms of their overall level of digital competence as well as selected competences from two areas: Teaching and Learning (Area 3) and Assessment (Area 4). Fig. 1 presents how teachers rated their overall level of digital competence before (pre-test) and after (post-test) TCDCL training on a scale from A1 (Newcomer) to C2 (Pioneer).

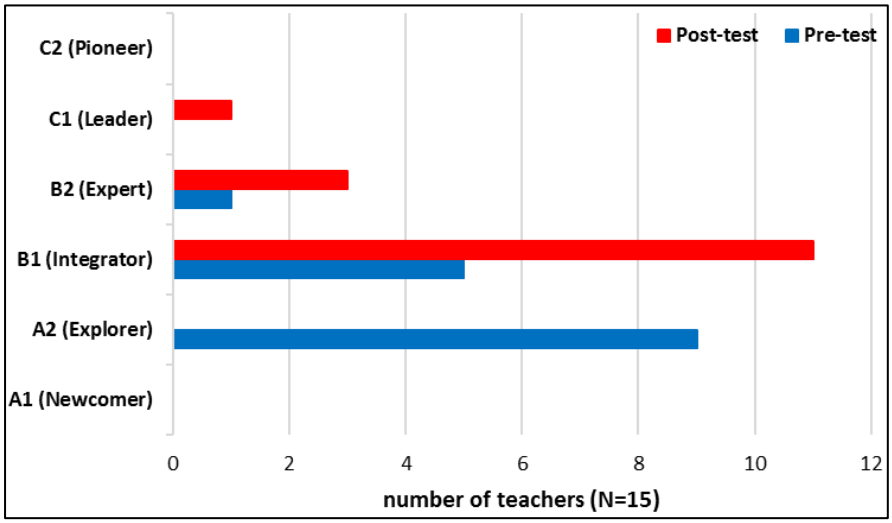

Figure 1. The results of the overall level of teachers' digital competence (pre-test vs. post-test)
Source: Own Processing

Teaching and Learning (Area 3)

Figures 2 and 3 present the results of teachers' digital competence in *"Teaching"* and *"Independent Learning"*.

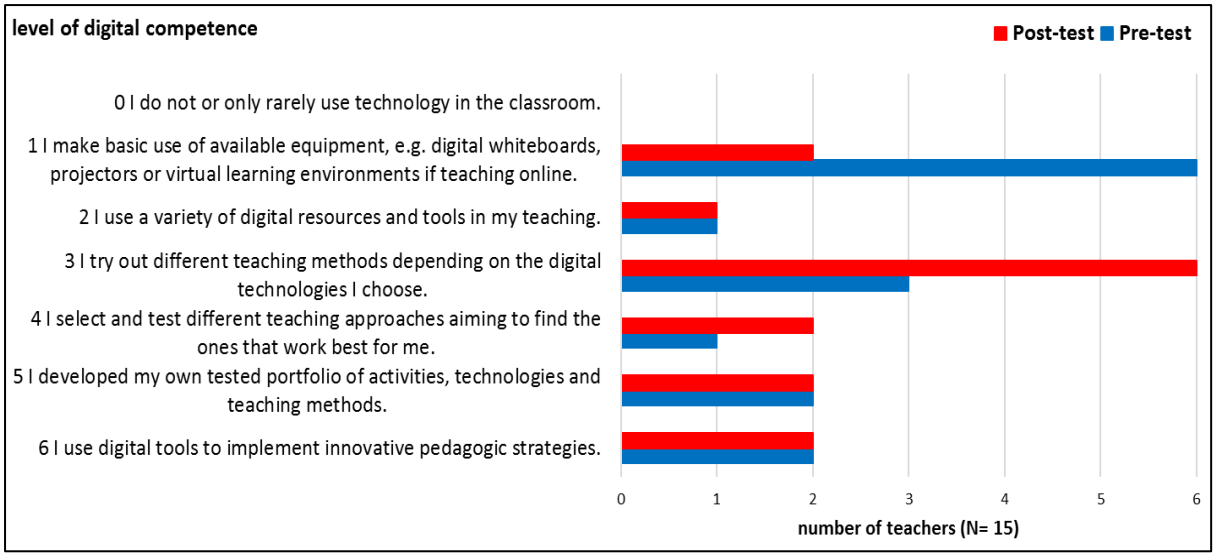

Figure 2. The results of the level of teachers' digital competence "Teaching" (pre-test vs. post-test)
[I carefully consider how, when, and why to use digital technologies in classroom with my learners, so that they are used with added value]
Source: Own Processing

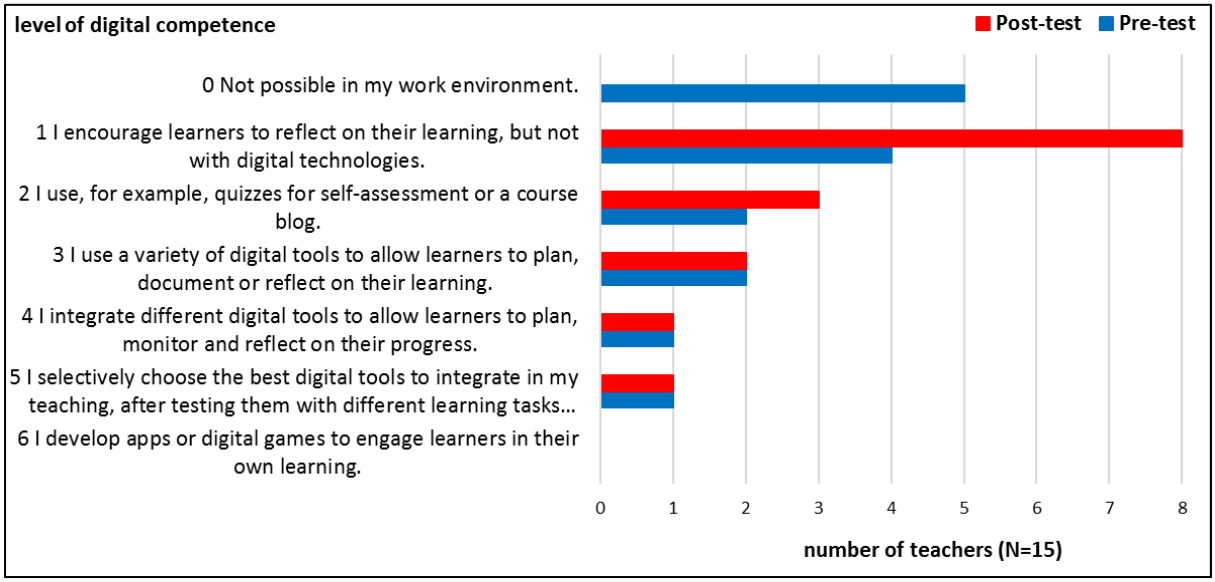

Figure 3. The results of the level of teachers' digital competence "Independent Learning" (pre-test vs. post-test)
[I use digital technologies to allow learners to plan, document, and monitor their learning themselves, e.g., quizzes for self-assessment, ePortfolios for documentation and showcasing, online diaries/blogs for reflection...].
Source: Own Processing

Assessment (Area 4)

Figures 4 and 5 present the results of teachers' digital competence in *"Assessment Strategies"* and *"Feedback and Planning"*.

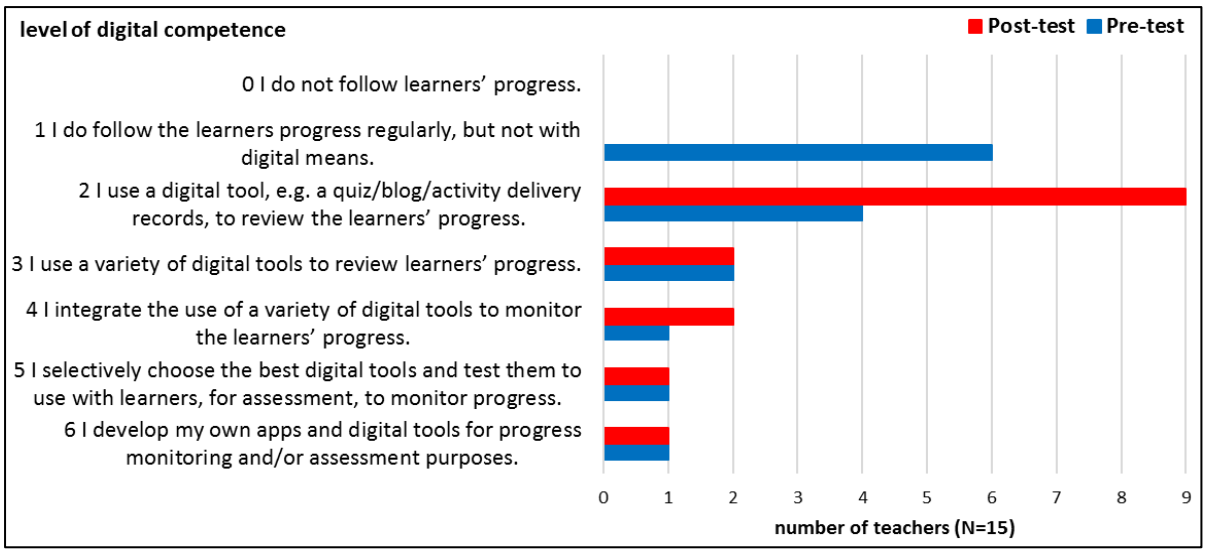

Figure 4. The results of the level of teachers' digital competence "Assessment Strategies" (pre-test vs. post-test) [I use digital assessment tools to monitor student progress].

Source: Own Processing

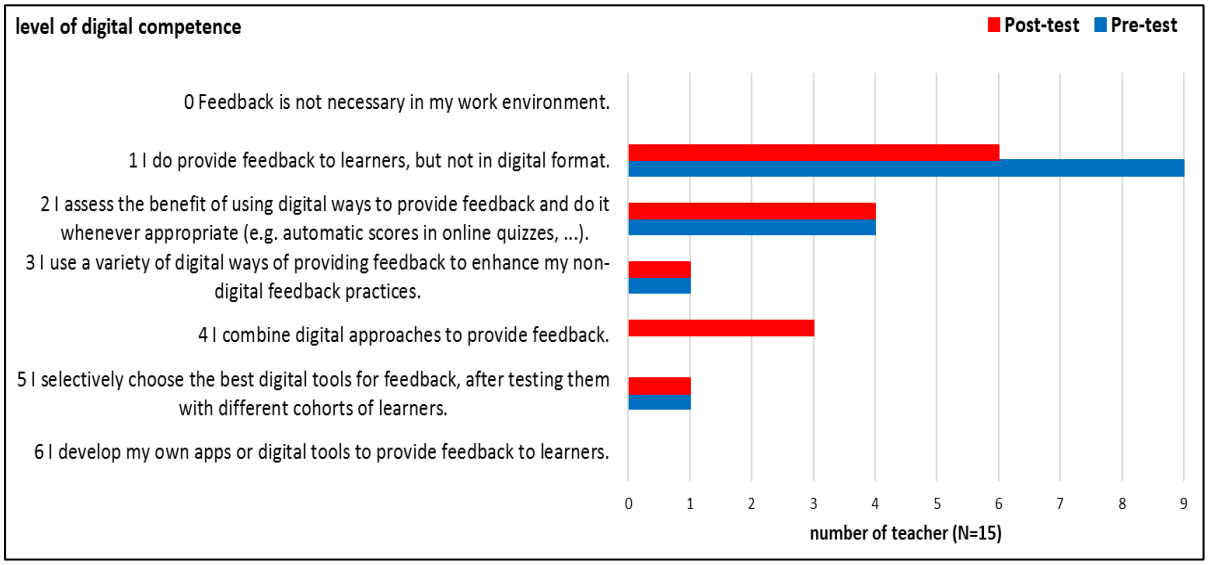

Figure 5. The results of the overall level of teachers' digital competence ***"Feedback and Planning"*** *(pre-test vs. post-test)*
[I use digital technologies to provide effective feedback]
Source: Own Processing

4. Discussion and Conclusion

This study investigates the impact of the innovative educational programme *Teaching Chemistry in Secondary Schools: Fostering Digital and Scientific Literacy (TCDSL)* on the development of chemistry teachers' digital competences, aligning with the DigCompEdu framework. The evaluation results from the DigCompEdu Check-in questionnaire indicate a positive impact of the training programme on teachers' overall level of digital competences. According to these results (see Fig. 1), the number of teachers at the B1 (Integrator) and B2 (Expert) levels increased following the training. The content, formats, and methods employed in the TCDSL training programme may have contributed to this positive change (see Table 2). Although both levels generally represent medium-level competences, this shift indicates an improvement in teachers' ability to regularly and effectively use digital technologies in

teaching, integrate them into the teaching process, and adapt them to various educational goals and needs (Redecker, 2017).

The positive impact of the TCDSL training programme on the development of teachers' digital competences was also evident in two specific areas of the DigCompEdu framework: *Teaching and Learning*, and *Assessment*. The analysis of the *Teaching and Learning* results revealed that teachers are more inclined to experiment with different teaching methods based on the digital technologies they select (see Fig. 2). As part of the TCDSL training programme, teachers were introduced to and actively engaged with methodologies that incorporate activating methods for teaching chemistry in secondary schools (Ganajová et al., 2021), such as inquiry-based teaching and instruction supported by digital technologies (e.g., computer-assisted experiments, the use of modelling programmes). This result also reflects teachers' increasing confidence in integrating digital tools and their openness to innovation, including the adoption of new teaching methods (Ghomi & Redecker, 2019). However, while teachers encourage students to reflect on their learning, they do not actively promote the use of digital technology for this purpose (see Fig. 3). This may be due to the challenges teachers face in providing technical resources, such as a stable internet connection, tablets, or other digital devices, for every student. In addition, the availability of appropriate software, technical support, and sufficient digital competences among students to use these technologies effectively in teaching can also present challenges. The analysis of results in the *Assessment* domain revealed that teachers use digital tools (e.g., quizzes, blogs, activity logs) to monitor student progress (see Fig. 4) and are increasingly likely to combine digital approaches to provide feedback (see Fig. 5). As part of the TCDSL training programme, teachers acquired knowledge of both summative and formative assessment strategies, along with digital tools (e.g., Google Forms, Kahoot!) that can be used to facilitate student assessments. However, some teachers still do not utilise digital assessment tools to monitor student progress. Therefore, it is essential to provide teachers with access to a variety of digital assessment tools tailored to specific topics in secondary school chemistry and to support them in effectively integrating these tools into their teaching. This can be incorporated into the optimisation of the content and scope of the *TCDSL* training programme.

Teachers should be supported in acquiring and developing digital competences, which encompass not only the use of digital technologies but also the application of pedagogical approaches and guidance from other educators. This will ensure their readiness to effectively integrate digital technologies as tools for enhancing learning outcomes and supporting student development. In addition, a digitally competent teacher plays a key role in encouraging pre-service teachers to use digital technologies as pedagogical tools, integrating them into their professional teaching skills, and supporting their teaching practices (Ghomi & Redecker, 2019; Instefjord, 2014; Napal Fraile et al., 2018; Røkenes & Krumsvik, 2014).

To expand the use of digital tools in education, professional development workshops and peer-to-peer learning opportunities can help teachers become familiar with these tools. Ensuring user-friendly platforms, seamless integration with existing systems, and ongoing support will encourage adoption, while offering automated feedback and data analysis tools can improve student learning outcomes. Gradual implementation through pilot programs and the sharing of successful examples will help ease teachers into broader use of these tools.

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