

Digital Competence for Science Teaching

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Abstract. *The digital competence of science teachers can be described at the basic (teachers as citizens); general professional; and special professional levels. At the basic level typical competences include use of e-mail, Internet browsers, Word processors, home multimedia; the general-professional level includes ICT usages common to all teachers, such as interactive boards At the special-professional levels subject-specific ICT applications are added, such as the use of data loggers, digital microscopy, subject specific software and virtual laboratory. Three levels of mastery of digital competence are proposed, at the basic (Remembering, Understanding), medium (Applying, Analyzing, Synthesizing) and expert (Evaluating, Creating).*

Keywords. Computers, Digital competence, ICT, Science teachers, Teacher education

1 Introduction

With the exponential growth of knowledge and the emergence of cutting-edge technologies, the basic question becomes how to educate students to perform appropriately in situations that were unknown when they were being educated (Illeris, 2008, p. 2). This refers to all educational levels before the end of formal education. As a consequence of changing demands, the attention of educators has to be reoriented from content towards competences. The European Parliament published a framework of eight key competences for lifelong learning (Recommendation of the European Parliament and of the Council, of 18 December 2006, on key competences for lifelong learning [Official Journal L 394 of 30.12.2006].) as “a combination of knowledge, skills and attitudes appropriate to the context”. The proposed list of competences is as follows: Communication in the mother tongue; Communication in the foreign languages; Mathematical competence and basic competences in

science and technology; Digital competence; Learning to learn; Interpersonal, intercultural and social competences and civic competence; Entrepreneurship; and Cultural expression. In daily educational practice, this list can be regarded as wishful thinking. The reason is that the competences in the document are not presented in operational form, an omission that places a heavy load on educators who try to implement these guidelines in practice. They need not only to possess these competences but also to be able to prepare instructions and teaching activities in such a way as to enhance their development in students. The problem of operationalizing Digital competence was recently addressed by the Digital Competence Framework for Citizens (DigComp 2.1), with the aim of providing a general frame of reference and self-evaluation tools. Recognition of the need to change teaching strategies toward active, student-centered methods, where students construct knowledge in a safe and socially-rich environment, is insufficient by itself. The question to be answered is, are teachers prepared for this task? The second question is, will they welcome changes to teaching strategies mastered over years of practice? For teachers, there are always two possible ways of including something new into their routines. The first one is to quietly wait for someone else to change their curriculum, a process which, in a semi-rigid system, where decisions are prepared at the state level, can take years. The second one is to take destiny into their own hands and use their right to autonomously choose a teaching method to be used in the classroom. And the third question is, how do we train pre-service teachers for their new role in the classroom?

In recent decades, information and communication technologies (ICT) have become a part of everyday experience for a large number of people, with the potential to change virtually every aspect of human lives. Moreover, “Information and communication technology (ICT) has become, within a very short time, one of the basic building blocks of modern society” (UNESCO, 2002). With innovations emerging on a daily basis, the skills needed to survive in an ICT-rich

world are increasing daily, and the gap between those who possess knowledge and technology and those who do not, is becoming wider and wider (Mariscal, 2005). Terms like (e)competence, digital literacy or digital competence (Mallan and Yarger, 1975; Recommendation of the European Parliament and of the Council, 2006; Bjekić, Krneta and Milosevic, 2010) have been introduced to address the importance of computer-based technologies, both in society in general and in education as one of the most important processes within it. In practice, the use of ICT in education always lags far behind its use in science, industry or communication. For example, the usage of ICT in Slovenian schools outside of specialized subjects like Computer Science or Informatics is encouraged but not obligatory for teachers. As a consequence, in Science education there exists an asymmetry with the expectations of students, who expect the teaching of science to involve a mixture of interesting, multimedia-supported lectures, with frequent laboratory and field work. In reality, they most often get direct instruction intended to cover the textbook content in detail, with success on final examinations as the ultimate goal of education (Krečič, Grmek and Perše, 2008; Šorgo and Špernjak, 2007; Špernjak and Šorgo, 2009). However, in Denmark preservice teachers have to pass a license qualification exam that verifies their digital competency, to ensure quality information and communications technology (ICT) usage (Maderick, Zhang, Hartley, and Marchand, 2016). These expectations have advanced to the point where institutionally this integration has become a requirement for the accreditation of higher education and teacher education programs in the United States (Council for the Accreditation of Educator Preparation, 2014; National Council for Accreditation of Teacher Education, 2011). The key role in ICT education has been assigned to schools, and the heaviest load has been confidently delegated to teachers. The role of ICT usage in schools for learning purposes is twofold. The first one is to serve societal expectations, and the second is to raise the quality of education. In attempts towards better education, it is often forgotten that the presence of ICT cannot raise the quality of education by itself, because ICT is only a prerequisite and a tool for improving the quality of teaching and learning as dominant school activities (Mooji and Smeets, 2001; Tearle, 2003); buying school equipment is the easy part of the job (Hawkins, 2002; Hepp, Hinostrroza, Laval and Rehbein 2004; Resnick, 2002).

The implementation of ICT in schools is not – either logistically or materially – a simple task and generally can follow two tracks. One is through specialized subjects like Computer Science or Informatics, while the second is the currently prevailing idea that ICT must be incorporated into the teaching of every subject by all teachers. As a consequence, teachers have to possess, in addition to subject-specific competences, the knowledge, skills,

and flexibility to incorporate ICT into their teaching practice, a requirement that can be accompanied by many practical problems in implementation (Selwyn, 2000; Tondeur, van Braak and Valcke, 2007).

If we recognize the demand for flexible and better educated digitally competent citizens as one of the main goals of educational systems, then teachers have to be one step beyond their students. Teachers not only need to possess the appropriate knowledge, skills and attitudes toward the proposed competences, but also need to be additionally competent in the pedagogy of its successful implementation in teaching to enhance learning. As a suitable theoretical framework toward the development of teacher competences, we can use Shulman's (1986) model of Pedagogical Content Knowledge (PCK), extended where technology is used, to Technological Pedagogical Content Knowledge (Mishra and Koehler, 2006; Koehler, Mishra, and Yahya, 2007).

2 Digital competence in science teaching

One of the basic competences is digital competence, which “involves the confident and critical use of information society technology (IST) and thus basic skills in information and communication technology (ICT)”. Explanations about digital competence given in the Recommendations can be regarded only as a framework and are not sufficiently operational to be used directly in the case of science teachers, where the introduction of ICT into regular instruction is accompanied by many challenges (Špernjak and Šorgo, 2009; Šorgo et al., 2010). According to Maderick et al. (2016), the term digital competence herein shall be construed and limited to meaning, having the skill, ability, and knowledge to successfully use computers, their related applications and software in the practice of teaching and education.

In the case of teachers, we can recognize the double role of ICT in their lives. The first role is to fulfil their personal needs as digital citizens, possessing the skills with and knowledge of computers in the role of clerical, informational and multimedia tool. On the professional level, their role does not end with the use of ICT to improve their content teaching, maintain school e-administration and function as a desktop library. Teachers must additionally be prepared to cooperate with other educators in the effort to educate digitally competent students. According to Kör, Erbay, Engin and Dunder (2017), individuals with positive attitudes towards technology are more likely to use technological devices.

As science educators, we can easily recognize that general definitions and frameworks concerning digital competence (digital literacy, ICT-competence, etc.) in school work are too narrow because science teaching, especially in practical, laboratory and field work, goes

beyond the common teaching practices used in most other subjects (Moradi, Fallah and Ahmadi, 2009). In practical and laboratory work, ICT is regularly used in the form of data-loggers, digital microscopy, controllers, etc., comprising instructional practices rarely or never used in other subjects. For a complete development of digital competence in science teaching, the teacher must be keen on the basic acquisition, classification, analysis, assessment and presentation of primary data, while also being competent in the sound use of the technology connected with computer interfaces. In such cases we can recognize digital competence as being closely connected to the description of technological competence within the theoretical framework of Technological Pedagogical Content Knowledge (Mishra and Koehler, 2006). In their words (p. 1028), “Teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology ..., and knowing how teaching might change as the result of using particular technologies.”

There are many possibilities for using ICT in biology (science) instruction. Besides creating documents, collecting information, communication and the use of multimedia, the most important element involves virtual and real computer-supported biological laboratory (CSL) exercises (Rogers and Wild, 1994; Strømme, 1998). CSL offers many advances in biology (science) teaching. Students like to work with ICT to perform experiments (Šorgo and Špernjak, 2007; Špernjak and Šorgo, 2017) in what they consider an interesting way, and this activity results in skills and knowledge of high quality (Pickering, 1980; Beatty and Woolnough, 1982; Kirschner and Meester, 1988; Špernjak, Puhek and Šorgo, 2010), especially when inquiry and problem-based approaches are used (Domin, 1999). By using such techniques, they are developing a wide set of generic and key competences (Michael, 2006). Yet, these promises are fulfilled only for those with access to and competence to use these new technologies (Mariscal, 2005).

On the other hand, demand for using digital technologies in the school laboratory, in field-work, or in the classroom places additional responsibility on science teachers. Students can use computers as sophisticated typewriters, as desktop libraries or communication tools and for multimedia in literally every subject, while the use of ICT units as processors, controllers and data-loggers can be introduced in only a limited set of school subjects or activities (Haydn and Barton, 2007). In this case, if, for example, one teacher at a school does not promote the use of computers in the classroom as a tool for finding information, the loss for students is minor, because with equivalent work in other subjects they can fill the gap. If, on the other hand, science teachers do not use data-loggers in the school laboratory, there is nobody at school to cover the missing knowledge (Špernjak and Šorgo, 2009).

3 Levels of Digital Science Competence

Russell, Bebell, O’Dwyer, and O’Connor (2003) identified six categories of ICT use by teachers: use of ICTs for lesson preparation, material production, student guidance, special education, email, and also for recordings and registers. Braak, Tondeur and Valcke (2004) identified two types of strategies for or patterns of use of ICTs in schools: mere support of the teaching process, and effective use of those resources in teaching development.

As a framework for setting competence levels for digital Science competence, in a range from pre-competence to expert level, we have used and modified levels from a revised Bloom’s Taxonomy (Krathwohl, 2002) and combined these with the framework of ICT literacy in the 21st century (Moradi et al. 2009). As a theoretical framework, we produced the 3x3 matrix presented in Tables 1 and 2. First, we can recognize the three levels of digital competence (Table 1). At the first level are competences defined in the Framework as key digital competence that are common to all citizens. At the second level are general professional competences, which are common to all teachers but not to other professions. At the third level are the special-professional digital competences of Science teachers. An example of such a competence is the usage of data-loggers in the school laboratory.

The second divide is at the level of mastery of digital applications, along with the competence to use them correctly in the classroom (Table 2).

Table 1. Levels of digital competence among science teachers

Horizontal circles of digital competence	Descriptions	Examples
1. Basic	Teachers as citizens	e-mail, Internet browsers, Word processors, home multimedia, etc.
2. General - professional	ICT usages common to all teachers	Interactive boards blackboards, school e-administration, Moodle, etc.
3. Special - professional	Subject-specific usage of ICT	data loggers, digital microscopy, special subject-specific software, virtual laboratory, etc.

We cannot recognize expertise simply by counting the applications that are used by a teacher. A teacher could be at the expert level in using some applications,

while ignoring other applications. On the first, basic level, teachers are able to use ICT in limited ways; on the second level, they can use applications within the common practice proposed by the manufacturer, and on the third 'expert' level, they can make substantial changes to applications or create new content. We believe that reaching the expert level for digital competence in Science teaching is an onerous task because of the need for mastery of a wider list of digital equipment and software than in most other subjects.

Area-Moreira, Hernandez-Rivero and Sosa-Alonso (2016) affirmed a direct relationship between a teacher's competence as a digital citizen and professional behaviour with ICT in the classroom. The higher the level of competence and digital citizen participation exhibited by the teacher, the higher will be the educational use of technology in the classroom.

Table 2. Levels of mastery of digital competence to be used in the classroom

Levels of DC*	Description	Examples
1. Basic	Knowledge / Remembering and Comprehension/ Understanding	Applications are mostly used for teacher preparation or production of materials not used in digital form (tests, work-sheets, etc.). In the classroom they can run applications or show pre-prepared presentations.
2. Medium	Application/ Applying Analysis/ Analysing	Teachers can use ICT within the common practice proposed by the manufacturer, can perform minor adaptations and evaluate ICT and its usage in the classroom
3. Expert	Evaluation/ Evaluating Synthesis/ Creating	Teachers are able to pedagogically optimize use of ICT, are able to change software, create new content, merge applications, combine hardware in novel ways, perform inquiry/research concerning ICT use, etc.

*DC = digital competence

4 Teacher education for digital competence

Science teachers' education for the integration and full exploitation of available digital technology cannot stop at the level of courses where they are only taught how to use equipment or software, but must include pedagogy and explore the context where and when such technology can be used. According to Guzman and Nussbaum (2009), teacher education should consist of several domains:

1. **instrumental/technological:** Many wrongly believe that adding a course for pre-service teachers or sending a teacher to an expository course to get basic information about an application or test equipment is sufficient for successful implementation of ICT in teaching practice. An even worse practice is to buy or give them educational ICT without appropriate training. The problem arises whenever they return to school to find such equipment, for which they regularly cannot find support or help when they get into difficulty. In cases where an application can be used exclusively in school, it is less likely to be accepted and used than in cases where an application can be used at home (Šorgo, Verčkovnik, and Kocijančič, 2010; Špernjak and Šorgo, 2009), where teachers can find support from the family.
2. **Pedagogical/curricular:** Buying equipment or preparing a course is meaningless if the teacher cannot recognize how to include ICT in existing teaching practice in a pedagogically sound manner. Most often teachers can only with difficulty recognize how to combine new technologies with their syllabi and external assessment of knowledge. So, teachers tend to prefer technologies that fit into existing pedagogical-curricular structures.
3. **Didactic/methodological:** When one medium replaces another without significantly changing the didactic-methodological structures of teaching, it can readily be accepted. We can recognize this pattern in the usage of computers for word processing and as desktop libraries, or in the switch from transparencies and an overhead projector, to multimedia presentations (Šorgo, Verčkovnik, and Kocijančič, 2010).
4. **Evaluative/investigative:** every technology is successful only within a pedagogical-curricular context; teachers should thus possess the knowledge and skills to evaluate their own work and its impact on students. The assessment should not be on the cognitive level alone but must include assessment of skills and attitudes-values, which implies an additional work-load.
5. **Communicational/relational:** the potential for ICT to be used as a communication tool is one of its

strongest personal features, besides interactivity. Yet we can recognize from the frequency of usage of different applications among teachers (Špernjak and Šorgo, 2009) that they easily accepted information searches on the internet and e-mail use, but that they did not maintain their own web pages, or use the internet to build online communities. In addition, even tools that allow interactivity, like Moodle, are mostly used as places to deposit papers or presentations.

6. Personal/attitudinal: A system of personal values and attitudes is an important enhancer or blocker of the inclusion of ICT in practical activities. The mere addition of new knowledge will not by itself change attitudes toward technology, so education concerning ICT usage should not be value-free.

One challenge to be overcome at many universities offering teacher education is that existing courses concerning ICT and multimedia are headed by ICT experts, who are rarely experts in, say, Science or Science Didactics. As a result, any connections between domains have to be made by students, which can be a difficult task--at least at the pre-service level. Maderick et al. (2016) believe "that without accurately knowing preservice teachers' digital competence as Technological Pedagogical Content Knowledge (TPACK), teacher educators may not be able to provide appropriate opportunities for them to learn to integrate technology into teacher learning experiences" (p. 3). An additional trap is accepting the myth that prospective teachers, as part of the generation of digital natives, are already proficient in the use of digital technology in the classroom (Kirschner & De Bruyckere, 2017).

Our proposal is a concept best described as "learning by doing," where prospective teachers build their digital competence from basic to expert levels. They should be trained in the competent use of technologies in a wide array of teaching contexts, not only in general but in professional contexts, as well.

On the other hand, experienced teachers have already built their personal pedagogical content knowledge, which, if successful, cannot easily be changed. If teachers change such material, there is no assurance that student outcomes will be methodologically or pedagogically better (Špernjak and Šorgo, 2017).

5 Conclusions

We can conclude that digital competence for science teaching goes beyond the general use of ICT in education. Science teachers can at least potentially use applications and equipment not used by teachers of other subjects, which burdens them with greater responsibility to achieve such competence levels. They need to test and practice ICT applications not only as

courses or laboratory exercises, but as part of their compulsory and reflective school practice. Simply sending them on a course or including such courses in pre-service training will probably fail if they do not find support when they return to school or begin teaching.

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