Computer Science for All: Teacher Training for In-Service Teachers

Anika Cichalla[1], Luisa Gebhardt[2(✉)], Tilman Michaeli[2], and Ralf Romeike[1]

[1] Freie Universität Berlin, 14 195 Berlin, Germany
{anika.cichalla,ralf.romeike}@fu-berlin.de
[2] Technische Universität München, 80 333 München, Germany
{luisa.gebhardt,tilman.michaeli}@tum.de

Abstract. The digital transformation in education challenges teacher education. While the use of both subject-specific and generic digital tools for teaching is part of most teacher training in all subjects nowadays, reliable and adaptable computer science (CS) knowledge, which forms the basis for the effective and efficient use of the tools, is not. Also, few training courses cater to the needs of in-service teachers, especially considering their limited resources and lack of basic knowledge of computer science. In this paper, we present a literature review identifying the fundamental computer science skills required for teaching. We also address the challenge of limited resources for the professional development of in-service teachers and propose design principles for effective teacher training courses in this field. As a result, we developed a competency grid with competencies of seven basic CS topics together with four design principles for corresponding teacher training courses.

Keywords: In-service training · Teacher Education · CS competencies

1 Introduction

As the digital transformation progresses, so does its impact on K-12 education. Therefore, the so-called "digital skills" are being discussed in pre-service and in-service teacher education. While the term "digital skills" is often associated with the ability to use digital media, the competencies needed for a digitized world go far beyond this: In scientific disciplines, especially in the natural sciences, digital transformation has opened up new opportunities, fields of research [20] and methods, like data analysis. To also introduce these innovations to the corresponding subjects at school, teachers need the necessary CS competencies to understand these innovations and integrate them into their teaching. Therefore, it is not sufficient for pre-service teachers to be educated in these competencies, in-service teachers must also receive appropriate training. Even though there are materials and courses available for developing CS competencies in pre-service teachers, there are currently few training courses for in-service teachers to develop these competencies.

Published by Springer Nature Switzerland AG 2025
M. Leahy and C. Reffay (Eds.): OCCE 2024, IFIP AICT 734, pp. 179–188, 2025.
https://doi.org/10.1007/978-3-031-88744-4_17

Hence, this paper aims to elaborate on key aspects of in-service teacher training regarding basic CS competencies by (1) identifying intended learning outcomes focusing on basic CS skills and competencies for in-service teachers of all subjects and (2) deriving design principles for teacher training courses concerning limited resources. To this end, various individual research results are outlined and intertwined.

2 Related Work

To identify basic CS competencies for in-service teachers, we first summarize the existing frameworks that focus on competencies for teaching in the digital world. Then, we outline existing approaches, which set requirements for in-service training for teachers.

2.1 Competencies for Teaching in the Digital World

Competence Frameworks. Looking at competencies for teaching in the digital world, we can identify several competence frameworks. The most often referenced competency framework for teachers, both at school as well as university, was proposed by the European Union [18] (DigCompEdu). This framework includes six competence areas and levels, e.g., professional engagement and digital resources. It lists 22 different competencies, focusing on pedagogical competencies.

To clarify what education in a digitized world should look like to educate students to use digital media competently, a group of representatives from media education, computing education, school practice, and business proposed a framework [4]. To achieve this competent handling of digital media, phenomena, objects, or situations in the digitally networked world are to be viewed from three perspectives: (1) the technological perspective, which questions how things work and explains the principles of action, conveying problem-solving strategies, (2) the socio-cultural perspective, which considers interactions with individuals and society, while (3) the application perspective focuses on effective and efficient use. These perspectives justify several essential CS competencies and are captured in the so-called "Dagstuhl Triangle".

The DPACK model builds upon the TPACK model and demonstrates that the required digitization skills go beyond the mere use of media [9]. DPACK does this by extending the TPACK model to include the perspectives of the Dagstuhl Triangle. The original TPACK model proposes that teachers need networked competencies of digital, pedagogical, and content competence, indicating an initial need for basic CS knowledge. Instead of demanding only digital competence to use digital tools, DPACK demands that digital competence also includes understanding how these tools work and how they interact with society. Therefore, according to DPACK, teachers also need basic CS competencies to achieve digital competence. However, DPACK does not specify the competencies that are needed.

Based on the TPACK and DigCompEdu frameworks, the Digital Core Competencies Working Group has developed the competency grid "DiKoLAN", which aims at STEM teachers in the first phase of training [23]. DiKoLan describes that teachers need digital competence in seven areas: documentation, presentation, communication/collaboration, inquiry and evaluation, measurement and data collection, data processing, and simulation and modeling. Similar to TPACK, each area has been divided into sub-competencies of digital, pedagogical, and content competence. In addition, legal principles are listed and linked across all seven topics. Alongside the technological, more user-centered competencies listed in TPACK, CS topics such as data literacy, programming and simulation, and AI are also addressed by DiKoLan.

In order to determine in which CS fundamentals teachers need to acquire competencies, Seegerer [20] developed a synthesis of expert interviews and a literature review with a focus on the fundamental ideas of CS. In the content-related competencies of CS, he distinguishes between basic and advanced topics. As basic topics, he lists algorithms, programming, representation of data, computer organization, social implications, handling data, and networks.

For German-speaking countries, the "Gesellschaft für Informatik e.V." (GI) has developed a competence grid for teachers of all subjects and all phases [1]. The competencies listed are assigned to the topics of information and data, algorithms, languages, computer systems, as well as social aspects and are based on the competency framework for pupils in German-speaking areas. However, the changes in the individual subjects due to the digital transformation are not taken into account. Hence, competencies in topics such as artificial intelligence and simulation are hardly listed at all.

Existing Training Courses. In the German-speaking area, there are already eight training courses summarized by the "Gesellschaft für Informatik e.V." (GI) in which pre-service teachers acquire basic CS competencies. The courses "CS Education as a Perspective in the Teaching of Science" (InfBiSa) and "Media and CS" (MedInfP) are aimed at pre-service teachers at the primary level. Two additional courses are mandatory for pre-service teachers of all school types: "Media Education and Digitization" (MedDig),and "Media and CS" (MedInf). The courses "CS in Everyday Life" (InfLi), "IT4all", "Digi4all" [21] and "Pixel, Byte & Co" (PiBy) are offered as electives for students of all school types. Thematically, the modules deal with CS concepts such as data literacy, algorithms and programming, encryption, the structure of a computer, legal fundamentals and artificial intelligence. They differ in their thematic focus and their design. Most courses are offered as face-to-face courses, but there is also an online module (digi4all). The scope of the courses ranges from 60 h (IT4all) to 210 h (MedInf). The courses focus on different topics. While all courses teach the topics of programming and algorithms, InfLi, IT4all, and PiBy also deal with current topics such as AI, and legal fundamentals are only taught in half of the courses.

In summary, it can be seen that more advanced competencies have been required for teachers in recent years. What was initially described as digital

competence has been continuously refined, and the relevance of basic CS competencies emphasized. However, there is little to no discussion on which CS topics and competencies are essential for all teachers once they are in service. However, these courses have so far been aimed only at pre-service teachers.

2.2 Teacher Training for In-Service Teachers

Initial courses on basic CS skills for teachers of all subjects already exist but are currently only aimed at pre-service teachers. They are not directly transferable to in-service teachers, as the target group differs in several aspects: Their time available for further training, their previous experience, motivation, and their teaching experience.

Hence, to provide high-quality professional development, one needs to understand the challenges and conditions for success. Effective teacher training is based on the latest teaching research: It supports self-directed learning, focuses on central teaching requirements, deepens content knowledge, and strengthens self-efficacy [14]. Collegial cooperation, linking of input, testing and reflection phases, feedback and coaching, a high practical relevance, as well as an appropriate duration are effective methodical measures [22]. Furthermore, coaching and expert scaffolding support teacher participants' implementation of new curricula, tools, and instructional approaches [8].

Regarding the motivation of in-service teachers to participate in training courses, Richter et al. [19] identified that teachers' personal interest in a topic and their desire to develop their professional skills were the main reasons for participating in the courses. Career advancement appears to be the least important reason for the majority of teachers. Furthermore, teachers have not just one motivation for attending training courses, but several. The strongest associations were found between practice expansion, social contacts, and personal interest.

When training is conducted online, teachers find a strong practical focus, multimedia information, interaction, and collaboration with other participants helpful and favor asynchronous offers [6]. Burns [5] points out that distance learning models for teacher education and training must follow the same best practices as face-to-face professional development: successful distance learning programs must pay particular attention to the appropriateness, quality, accessibility, and relevance of digital content; focus on building a strong teacher community; provide learners with ongoing support in their distance courses and workplaces; use a range of formative and summative assessments to improve instruction; and accurately measure teachers' knowledge, skills, competencies, and attitudes. Mayer et al. [15] support these recommendations. They also determined that cognitive presence, social presence, and teaching presence are important for teachers in online learning scenarios, emphasizing the importance of social presence aspects in teachers' online learning (e.g., teacher discussions and collective reflection). They found that cognitive activation, collaboration, clarity, and structure of online professional development were related to teachers' satisfaction with online professional development.

Considering CS, existing online training courses, such as Digi4all [21], draw on similar principles for their design: For example, the ten golden rules for designing e-learning offerings according to Balzert et al. [3] are often used and referenced. In terms of higher education, the "Playful Pedagogy" [16] approach and the design principles of the "Beauty and Joy of Computing" [10] course have become established. Concerning the education of prospective teachers, Gerner [11] has drafted recommendations that relate to the teaching of digital skills.

3 Deriving CS Competencies for Teacher Education

As already established, basic CS competencies are of importance for in-service teachers. However, it has not yet been specified which CS competencies are needed for in-service teachers to achieve comprehensive digital competence. Although there are initial modules that teach the basics of CS, the target group for these modules is pre-service teachers who receive credit for these modules in their studies. There are no training opportunities for in-service teachers, who have limited resources and specific requirements, especially in Germany. To face this challenge and identify general basic CS competencies as well as requirements for appropriate continuing education, we drew on several sources, as this section outlines.

3.1 Relevant CS Topics

First, we need to identify relevant CS topics that professional development courses should cover. To this end, we took the basic categories from Seegerer [20], and compared them with existing training offers. To the Seegerer's topics, we added the topics of simulation, legal fundamentals, and AI, as these are also covered by the existing courses. The topic of social implication has not been listed explicitly here, as this is targeted across topics. Table 1 gives an overview of which of these basic topics are covered by which existing courses.

Table 1. CS topics in existing training courses.

Topic	InfBiSa	MedInfP	MedDig	MedInf	InfLi	IT4all	Digi4all	PiBy
Programming & Algorithm	x	x	x	-	x	x	x	x
Data Literacy	x	x	x	x	-	x	x	x
Cryptography	x	-	x	x	x	-	x	x
Simulation	-	-	-	-	-	-	x	-
Networks	-	x	-	-	x	x	x	x
Legal Fundamentals	-	-	x	x	x	-	-	x
AI	-	-	-	-	x	x	-	x

We observe, that all topics from Seegerer [20] were also targeted by at least one existing offer. Hence we conclude that the topics of programming and algorithms, and data literacy can be regarded as fundamental. In many of the existing courses, additional relevance is given to the topics of cryptography, simulation, networks, AI, and legal basics. These seven topics thus form the basis for further training of teachers with regard to basic CS competencies.

3.2 Deriving Fundamental CS Competencies

Based on our findings from Sect. 3.1, we conclude that teachers need competencies in the CS topics of programming and algorithms (P&A), data literacy (DL), cryptography (C), simulation (S), networks (N), AI and legal bases (LB) in order to develop a comprehensive digital competence. Therefore, we now need to determine which competencies teachers should acquire for each CS topic. When developing these competencies, we need to keep the limited resources of the participating teachers.

For the purpose of deriving a list of necessary competencies for teachers from the identified CS topics, we looked first at the learning objectives of the existing courses. Secondly, we took a closer look at the competency grids of the frameworks DigComp [17], DigCompEdu [18], and DiKoLan [23] and adjusted them to fit the tight time schedule of the target group. To this end, we change the level of required understanding of the competence: For example, instead of aiming for teachers to *implement a software solution to a problem using basing algorithm structure*, we adjust the goal to *understand a software solution which uses basic algorithmic structure*.

Table 2 provides an overview of the resulting CS basic competencies. Looking at this overview, we can observe that most of the derived competencies are assigned to the topics of programming and algorithms as well as data literacy. Comparing these competencies to those mentioned in Table 1, we see that these topics are taught in seven out of the eight courses. This observation supports the importance of programming and algorithms, as well as data literacy, as fundamental topics in computer science. Therefore, to acquire a comprehensive digital competence according to DPACK, the technological competencies listed in Table 2 are of significant importance. We recognize that the derived list lacks depth in some fields, as we needed to reduce them to make them achievable by in-service teachers in a limited timeframe.

4 Design Principles for Teacher Training

The aspects of time available for further training, previous experience, motivation, and teaching experience should be seen as challenges when designing further training for in-service teachers compared to students.

Teachers often take part in in-service training to develop their professional skills [19]. For this reason, the problem of making in-service training as attractive and competence-enhancing as possible must be addressed. In addition, the

Table 2. Fundamental Competencies for the derived CS Topics.

ID	Competency
P&A 1	Identify and apply properties of algorithms
P&A 2	Understand software solution which uses basic algorithmic structures
P&A 3	Interpret and evaluate algorithms with respect to given objectives
P&A 4	Identify social implications of the usage of algorithmic solutions
DL 1	Explain the basic structure of a computer and how it encodes and stores data
DL 2	Explain the differences between digital and analog data
DL 3	Distinguish data, information, and knowledge
DL 4	Recognize the importance of data or data analysis to their subjects
C 1	Distinguish encoding and encryption
C 2	Describe basic methods of encryption
S 1	Model and simulate scenarios from their subjects using digital tools
S 2	Describe and apply features of a model
N 1	Assess the technical development of computer systems
N 2	Describe how the Internet works
AI 1	Identify and explain basic AI technologies
AI 2	Use common AI technologies responsibly
LB 1	Purposefully use data protection measures
LB 2	Deal with ethical, legal, and organizational aspects of digitization and school development

limited opportunities available to in-service teachers for further training must be taken into account.

The wealth of experience of the participating teachers can be used for the training by always embedding the CS skills in a topic that focuses on digitalization. In this way, the relevance for the teachers is continuously demonstrated and, in addition, a reference to the teaching experience and the teachers' subjects is clarified and incorporated. Online courses are one way of dealing with time constraints and, at the same time, enabling self-directed and practical learning. Based on Seegerer's [21] positive experiences with the online Digi4all course and the framework presented concerning the design principles, we have compiled four basic design principles:

Teaching CS Based on the Dagstuhl-Triangle. The digital transformation also leads to new topics becoming relevant for discussion in the classroom [4]. Teachers, accordingly, need an adequate foundation in CS. According to the Dagstuhl Triangle, consistent teaching of content ensures that teachers are continuously shown the relevance of basic computer literacy. Additionally, teachers learn, guided by their own learning experiences, how to teach the self-learned competencies in their own classes. According to the Dagstuhl-Triangle, a connection to media education and the subjects of the teachers must be created during a CS in-service training. At this point, the teaching experience of the participants becomes a supporting foundation of the in-service training [14].

Demonstrate Importance for Teachers of All Disciplines. In Germany, pre-service teachers usually study two or more subjects, which they will also teach later. The digital transformation leads to new topics, methods, and tools in these individual subject disciplines. Experience shows that participants attend training courses on the acquisition of CS competencies not so much out of professional interest but because they see it as important for teaching in the digital world [10,16,20]. It is, therefore, vital to ensure the transferability of what has been learned to the individual subjects. For this reason, references to other subjects should continuously be emphasized or elaborated by the participants. This can be realized, for example, by providing a list of ideas for application in individual subjects on our part or by prompting specific research by the course.This method reveals shared connection points among different subjects to the participants, laying the groundwork for the collegial exchange that Lipowski [14] considers important.

Scaffolding. In competence acquisition, scaffolding can be a supportive measure by assisting the learning process and initially limiting the degree of freedom in performing a task [13]. Beginning programming, in particular, can present problems. In their Playful Pedagogy, Petre and Richards [16] suggest, in the spirit of scaffolding, on the one hand, to give precise, narrowly defined instructions to build confidence in the learners. On the other hand, learners should also be encouraged to break away from the approach. Differentiated support options allow learners to access assistance based on their level of learning. Following Seegerer [20], the Use-Modify-Create approach [12] in particular is used for this purpose in the course. Explanatory videos should be used, and practical tasks should be initially instructed in small steps in order to pick up on the divergent previous experiences of the participants. All three, input, testing, and reflection phases are combined [14].

Low-Threshold Access and Motivation Constructive approaches to teaching competencies are also emphasized for online training [2]. At the same time, the thematic approaches must be kept as low as possible to motivate teachers to deal with CS topics. This motivation must be continuously maintained to give teachers confidence in their competencies because, with high self-efficacy expectations, they are more open to new approaches and ideas for teaching [7]. To achieve this, low-threshold approaches should be provided through active engagement and playful experimentation.

5 Conclusion and Future Work

In the current discourse, the importance of basic computer science competencies is emphasized strongly, but these competencies have not yet been formulated in solidified terms for in-service teachers, and a corresponding competency framework that fits the needs and limitations of the target group has not yet been developed. Despite that, training courses for teachers on the acquisition of

digitization-related skills already exist. These existing training courses are, however, not designed to suit the practical needs of in-service teachers and do not include CS competencies.

Aiming to formulate a CS competency framework from existing courses and literature, we have identified the computer science topics of programming and algorithms, as well as data literacy, as fundamental. Additionally, we found that teachers need basic competencies in cryptography, simulation, networks, AI, and legal fundamentals. From these findings, we developed a reduced framework of competencies suitable for in-service teacher training and the limited resources of in-service teachers.

To make teaching courses for the chosen CS competencies as attractive as possible for in-service teachers, we derived design principles for such courses, taking related work and the limited resources of the target group into account. We found that successful in-service teacher training should embed the Dagstuhl-Triangle, demonstrate the relevance of the taught CS competencies for teachers of all subjects, have low-threshold access and motivation, and use scaffolding.

In future work, we will examine the feasibility of such training. Under the critical aspects of motivation and time, we will implement teacher training for the chosen competencies and determine whether and how teachers can implement the learned competencies in their teaching. The resulting PD offer will then be evaluated using Design-based research.

References

1. Arbeitskreis Lehrkräftebildung der Gesellschaft für Informatik e.V.: Informatikkompetenzen für alle Lehrkräfte [Computing competencies for all teachers]. Gesellschaft für Informatik e.V. (2023)
2. Arnold, P.: Einsatz digitaler Medien in der Hochschullehre aus lerntheoretischer Sicht [Use of digital media in university teaching from the perspective of learning theory]. e-teaching.org (01 2005)
3. Balzert, H., Balzert, H., Zwintzscher, O.: Die E-Learning-Plattform W3L [The E-learning platform W3L]. Wirtschaftsinformatik **46**, 129–138 (04 2004)
4. Brinda, T., Diethelm, I., Gemulla, R., Romeike, R., Schöning, J., Schulte, C.: Dagstuhl-Erklärung: Bildung in der digitalen vernetzten Welt [Dagstuhl declaration: wducation in the digital networked world] (03 2016)
5. Burns, M.: Distance education for teacher training: Modes, models, and methods (2023)
6. Capparozza, M., Fröhlich, N., Dehmel, A., Fauth, B.: Gestaltung und Evaluation von webbasierten Lehrkräftefortbildungen: Ein Systematic Review [Design and evaluation of web-based teacher training: a systematic review]. In: Scheiter, K., Gogolin, I. (eds.) Bildung für eine digitale Zukunft [Education for a digital future], vol. 15, pp. 363–397. Springer Fachmedien Wiesbaden, Wiesbaden (2023)
7. Cousins, J.B., Walker, C.: Predictors of educators' valuing of systemic inquiry in schools. Canadian J. Progr. Eval. **15**, 25–53 (2000)
8. Darling-Hammond, L., Hyler, M.E., Gardner, M.: Effective Teacher Professional Development. Learning Policy Institute (2017)

9. Döbeli Honneger, B.: Deutsch und Digitalisierung: Ein Vortrag mit Venn & Aber. Vortrag auf der 33. Jahrestagung der AG Medien [German and digitization: a lecture with venn & but. lecture at the 33rd annual conference of the AG medien] im Symposion Deutschdidaktik, LMU München. https://beat.doebe.li/talks/muenchen18/
10. Garcia, D., Harvey, B., Barnes, T.: The beauty and joy of computing. ACM Inroads **6**(4), 71–79 (2015). https://doi.org/10.1145/2835184
11. Gerner, V.: Digitale Kompetenz bei Pädagogischen Professionals fördern [Encouraging digital competence among pedagogical professionals]. Ph.D. thesis, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) (2019)
12. Lee, I., et al.: Computational thinking for youth in practice. ACM Inroads **2**, 32–37 (2011)
13. Lin, T.C., Hsu, Y.S., Lin, S.S., Changlai, M.L., Yang, K.Y., Lai, T.L.: A review of empirical evidence on scaffolding for science education. Int. J. Sci. Math. Educ. **10** (04 2011)
14. Lipowsky, F., Rzejak, D.: Fortbildungen für Lehrpersonen wirksam gestalten. Ein praxisorientierter und forschungsgestützter Leitfaden [Designing effective training for teachers. A practice-oriented and research-based guide] (02 2021)
15. Meyer, A., Kleinknecht, M., Richter, D.: What makes online professional development effective? The effect of quality characteristics on teachers' satisfaction and changes in their professional practices. Computers & education 200, 104805 (2023). https://www.sciencedirect.com/science/article/pii/S0360131523000829
16. Petre, M., Richards, M.: Playful pedagogy: empowering students to do, design, and build. In: Leicht-Scholten, C., Schroeder, U. (eds.) Informatikkultur neu denken - Konzepte für Studium und Lehre, pp. 41–54. Springer, Wiesbaden (2014). https://doi.org/10.1007/978-3-658-06022-0_3
17. R, V., S, K., Y, P.: Digcomp 2.2: The digital competence framework for citizens - with new examples of knowledge, skills and attitudes. Scientific analysis or review KJ-NA-31006-EN-N (online), KJ-NA-31006-EN-C (print), Luxembourg (Luxembourg) (2022)
18. Redecker, C.: European Framework for the Digital Competence of Educators: DigCompEdu (11 2017)
19. Richter, D., Kleinknecht, M., Gröschner, A.: What motivates teachers to participate in professional development? An empirical investigation of motivational orientations and the uptake of formal learning opportunities. Teaching and teacher education 86, 102929 (2019). https://www.sciencedirect.com/science/article/pii/S0742051X18314112
20. Seegerer, S.: Informatik für alle – Beitrag und exemplarische Ausgestaltung informatischer Bildung als Grundlage für Bildung in der digitalen Transformation [Computer science for all: contribution and exemplary design of computer science education as foundation for education in the digital transformation]. Ph.D. thesis, Freie Universität Berlin (2021)
21. Seegerer, S., Michaeli, T., Romeike, R.: Informatische Grundlagen in der allgemeinen Lehrkräftebildung [Computing basics as part of general teacher education]. INFOS 2021 - 19. GI-Fachtagung Informatik und Schule (2021)
22. Tondeur, J., Van Braak, J., Sang, G., Voogt, J., Fisser, P., Ottenbreit-Leftwich, A.: Preparing pre-service teachers to integrate technology in education: a synthesis of qualitative evidence. Comput. Educ. **59**(1), 134–144 (2012)
23. Von Kotzebue, L., et al.: The framework DiKoLAN (Digital Competencies for Teaching in Science Education) as basis for the self-assessment tool DiKoLAN-Grid. Educ. Sci. **11**, 775 (2021)