Digitalkunde

Report on the 1st Digitalkunde Workshop, October 2022

Special thanks to everyone who made the 1st Digitalkunde Workshop possible!

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The Workshop "From Rechnerkunde to Digitalkunde – Talks on K-12 Computing Education Philosophy" took place from October 5 to 7, 2022 at the Heinz Nixdorf MuseumsForum, Paderborn, Germany

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... what a peculiar term for a new international field of research. It presents a challenge for translation into English due to the meaning conveyed by its suffix '-kunde'. [This applies similarly to the term 'Bildung.'] While the prefix 'digital' refers to the process of digitization or the state of digitality, 'kunde' is a quite common ending used to label school subjects or learning areas in Germany. For example, there is a subject called Erdkunde (Erd(e) = Earth), in which children and young people are provided with basic information about the Earth without necessarily engaging in (delving into) geography in the scientific sense. In primary school, there is a learning area called Sachkunde (Sach(e) = subject matter or object), which covers a plethora of topics including natural sciences and technology. While Sachkunde tends to focus more on a phenomenological level, there is also room for scientific thinking, albeit with little emphasis on mathematics and formalisms.

'Kunde,' hence refers to something that relates to science(s) without necessarily having a scientific claim associated to it. The suffix '-kunde' can be traced back to the Old High German word 'kundja,' which means knowledge or recognition. However, in the context of digitalkunde, it is important to note that it does not necessarily imply a lack of scientific rigor, but rather refers to a broader approach that encompasses both theoretical and practical knowledge in the field of digital artifacts.

Accordingly, Digitalkunde aims to convey knowledge about digitization and ultimately thinking beyond mere computer science. Its focus is on the educational goals of schools. It is about educating people about digital technologies and promoting an emancipatory approach to them. Computer science education may contribute to this, but perhaps is isn't. Complementary educational approaches and contents may be necessary.

We have at least one reason and two motives for proposing the idea of "Digitalkunde" in a workshop at Paderborn University in 2022. The reason is a workshop that marked the beginning of computer science as a school subject in Germany exactly 50 years ago. The workshop aimed to explore the contents and goals (using the terminology of that time) of "data processing" as a subject. At that time, a proposal was also made to add a subject called "Rechnerkunde" (Rechner being the German word for computer) to secondary school curricula.

One of our motives behind Digitalkunde is that certain competencies related to the critical reflection of digital technologies in their sociocultural context or interaction with these systems have been marginalized in the learning area that is conceived and realized as computer science education in Germany. Another motive is that existing German educational programmes, focusing on such goals, are not sufficient because they largely disregard the fundamental aspects of computer science as they are usually conceived as media education or usage training. Our goal is to find out whether it is possible to combine the three perspectives of computer science, critical reflection, and use so that children and young people become digitally kundig (digitally literate, an adjective derived from '-kunde').

These three perspectives were, for example, mentioned in the "Dagstuhl Declaration" in 2016 and hence depicted in the "Dagstuhl Triangle" , which is well known and often referred to in the German educational context. This graphical representation is frequently the matter of intense discussions. While some express satisfaction with this approach and agree with it, others are in clear disagreement with it.

This being so, the Dagstuhl Declaration was not first in identifying these three perspectives. They have rather been part of educational policy papers or justification contexts for some time already. This can be taken as an indication that it is indeed important to combine these three perspectives in some way.

However, it can also be taken as an indication that such an integration has not yet been accomplished yet. But why is this so? Are there approaches in which the connection of the perspectives has been more successful? Have similar approaches been developed in other areas? What can we learn from them? Is there research on such approaches? In our workshop in 2022, we want to discuss these and other questions with researchers from other countries under the common title of 'Digitalkunde'. The intended goal is to deepen our discussions in concrete cooperative research projects. To this end, we bring media educators and scientists as well as computer scientists together (in one room). Let's go!

About this Report

This report collects invited and submitted abstracts and short papers to the workshop. They present the author's ideas, proposals and suggestions for the workshop conducted in the autumn of 2022. They were written before the discussions at the workshop, and were the subjects of discussion during the workshop.

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Identifying the Systems in Systems Change: Building Equitable and Sustainable CS Education at Scale

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1. Introduction

As the world becomes more technologically powered, the discussion of computer science (CS) education has moved from the domain of a career orientation or specialist degree to a fundamental skill required to navigate the modern world safely, and contribute to the solution of humanities problems. Non-profits and corporations alike have created campaigns, sought to influence policy makers, raised and provided funds, and implemented programs to provide learning to educators and students. Although a large amount of the public messaging around the need for CS education has focused on workforce development (Code.org, 2018b, 2018a; Smith, 2016), the advocates who are focused on equity also call for computing as a fundamental literacy - a gatekeeper to fully realizing an engaged and empowered citizenry and and important component of primary and secondary education.

The tension between workforce development and fundamental literacies for citizens is most keenly felt in secondary education. The curriculum, tools, and learning outcomes needed to accelerate youth's trajectories into employment are not the same as what is designed to promote early introduction to the subject and fundamental computational literacy. Additionally, many nations are working to ensure youth with historically marginalized or excluded identities find computing to be a welcoming discipline in order to create workforces that are more representative of the gender, socioeconomic, and ethnic/racial makeup of overall populations.

No matter what the end goal, workforce preparation or general citizen literacy, systemic change and equity cannot happen through only through the professional development of teachers, without intervening in the systems where those teachers educate. (Elmore, 2004; Cohen, Peurach, Glazer, Gates, & Goldin, 2013) Most teachers have significant control over the environment within their classrooms, making minute changes during a lesson, adapting to formative assessment, and building the day to day learning environment and progression of instruction. Yet, the scheduling of the course, the policy requiring the course for graduation, the recommendations of guidance counselors, the allocation of computer lab time to CS in addition to basic keyboarding or computer literacy, and the choice in primary grades to provide systemic PD for all teachers for integration of computing into other disciplines are outside the scope of power of teachers.

In our work at CSforALL, we have endeavored to empower local leaders with frameworks for identifying clarity in computing education visions, to create rich and rigorous alignment between visions, policy, and enactment, and partner with researchers to understand the impact and outcomes of their efforts. (Santo et al., 2019; DeLyser & Wright, 2019) In this paper we will detail the frameworks we are using to approach systems change for computing education, share some findings from 5 years of research, and make recommendations for multi-level systems approaches to create environments empowering educators to provide high quality instruction and pathways to both fundamental literacy and workforce development.

2. Systems are Multi-Level

Education is inherently local and, especially to a student or family, the sum total of an educational pathway is made up of multiple institutions and experiences over time. In a recent National Academies report, they state "Many learners will need multiple experiences with computing to develop enduring interest in and competencies for computing. These experiences will likely need to include both in-school and out-of-school opportunities". (National Academies of Sciences, Medicine, et al., 2021) CSforALL focuses explicitly on the institutions, and their support structures, who implement education, specifically CS education, locally. These institutions are supported by a national network of curriculum and tool providers, and informed by promising practices studied by researchers.

CSforALL's members are the actors on the ground, providing the direct interventions, teacher professional development, curriculum, research, and policies supporting implementation of CS. Members may have CS experts, curriculum or pedagogy specialists, or professionals focused on equity and inclusion, but few have all of those capacities, and school districts especially need to learn in a community of practice to center equity goals in CS education initiatives. CSforALL powers those capacity-building efforts through strategic planning (DeLyser & Wright, 2019; DeLyser, Wright, Wortel-London, & Bora, 2020), community learning, and annual prompts to move the work forward through commitments (DeLyser, 2018). CSforALL's efforts compliment those of our membership, providing receptive environments for teachers who attend PD to implement within their buildings.

In the international context, the CS education community has long recognized the need to perceive the multi-leveled decision makers who influence educational outcomes. (Hubwieser, 2013) The Darmstadt model highlighted the division of knowledge, action, and consequences across multiple dimensions, and has been used multiple times since to analyze CS education approaches (Hubwieser et al., 2015; Raman, Venkatasubramanian, Achuthan, & Nedungadi, 2015). In this position paper we explore the work of CSforALL which connects the various levels and creates a shared understanding of equity goals amongst its members.

2.1. Identifying Needs and Selecting Focus

In 2016 the United States was responding to increased awareness of the need for computing education, prompted in large part by city and state level initiatives (Fancsali, Tigani, Toro Isaza, & Cole, 2018; Dettori, Greenberg, McGee, & Reed, 2016; Xavier et al., 2019) and advocacy from national non-profits such as Code.org and ACM. The NYC Foundation for CS Education, also known as CSNYC, was at the heart of the initiative in New York City. Because of the size and scale of NY (1.1M students enrolled in over 1,500 schools), CSNYC adopted an approach welcoming multiple implementations of curriculum allowing teachers and schools to tailor implementation to school goals, culture, and resources. With a call for a national hub for computing education, CSNYC applied for a small grant through the National Science Foundation in order to create a broad home for CS education within the US that was not tied to a particular curricular intervention or approach and brought together actors with multiple perspectives. This hub was called the CSforALL Consortium and was launched in the fall of 2016 with 188 members. (DeLyser & Preston, 2015)

At the launch of the CSforALL Consortium, we conducted a needs assessment in order to identify early activities and set a strategic agenda for community participation. The needs assessment was conducted in two ways, first a question on the membership application form asked "What would you like from an organization like the consortium?" 220 responses from members were read and coded with categories related to CS Education. The categories were then used to create a structured interview approach used in focus groups of members. The members participated in focus groups based upon their member type (Education Association, Content Provider, Funder, or Program Provider). CSforALL staff interviewed 150 members over a 4 month period from October 2016 - January 2017. Recordings of the focus groups were transcribed, and CSforALL staff again engaged in a categorization task of member responses.

The most frequently expressed need was for connections to other organizations (116 members), followed closely by funding opportunities (102 members). Identifying Resources for In-School Implementation was an important theme. Members asked for curriculum resources (60 members), information about best practices (35 members), information about national initiatives(32 members), and defining a K-12 scope and sequence (28 members). CSforALL built on these results and focused on (1) Community Building - creating communities of practice to connect and convene the community and convening an annual support for stakeholders to celebrate progress and announce new commitments; (2) Implementation

Guidance - sharing case studies and models of successful implementation; and (3) Dissemination of Resources - facilitate the dissemination of resources and relevant research.

In addition to the membership activities, CSforALL also launched programs focused on specific sub-groups within membership. While teachers often were supported by the professional development provider supplying their curriculum, unless the school or district had chosen a curriculum that spanned K-12, there was little support for connecting isolated learning experiences for students, at the time resulting in students getting multiple years of "first courses". Building on other national curriculum reform and roll out initiatives and research (Grossman, Reyna, & Shipton, 2011), CSforALL designed the SCRIPT program to engage district leaders in planning workshops to create sustainable CS education initiatives within their schools. Early SCRIPT work was studied with the support of NSF (1738675) and yielded findings regarding routines around equity, challenges of implementation, and system wide implementation practices (Santo et al., 2019, 2019; Santo, DeLyser, & Ahn, 2020). Since its launch, the SCRIPT program has served over 700 districts, private, and charter schools impacting over 5.5 million students. In the second half of 2022, the CSforALL technological infrastructure is being updated to enroll these districts in CSforALL membership, and they and future districts will be an increasingly larger part of the membership of CSforALL, and the proposed alliance.

2.2. Research and Practice

Another constituency supported through individual programs is researchers. In the fall of 2017, CSforALL partnered with SageFox Consulting Group and CSEDResearch.org in order to launch RPPforCS, a connected community of practice (CCOP) for researchers and practitioners who were awarded grants through NSF's CS for ALL RPP funding solicitation. Over four years of community supports and encouragement, researchers and practitioners in this (CCOP) have shared their research with the broader national CSforALL Community through webinars, the CSforALL Summit, and a whitepaper compendium, as well as providing exemplars and best practices to the next generation of aspiring CSEd researchers who desire to engage in RPP approaches through research-practice briefs, project spotlights, and theme studies. (McGill, Peterfreund, Sexton, Zarch, & Kargarmoakhar, 2021; Esiason, Zarch, Sexton, & Peterfreund, 2020)

Research Practice Partnerships (RPP) are built on a value system where the day to day experience of practitioners, often educators, provides an important expertise that is critical in designing, implementing, and improving interventions.(Fishman, Penuel, Allen, Cheng, & Sabelli, 2013; Penuel, Allen, Coburn, & Farrell, 2015; Coburn & Penuel, 2016) The National Science Foundation in the US has invested heavily in this model of research, funding over 150 projects over the last 5 years.(Foundation, 2018) nation These projects, both small and large, have endeavored to use this methodology and many have produced significant findings for the CS education communtiy through publications. A picture of the full scope of projects can be found at www.sagefox.com/rppforcs.

Research Practice Partnerships are an important component of the next generation of CS education implementation. The creative implementation of CS education, especially in K-12 environments, is outpacing researcher's ability to document promising practice, and in many cases standard practice, in classrooms. Teachers are daily building pedagogical content knowledge /citegudmundsdottir1987pedagogical, and many pedagogical environments are being used by teachers in new and creative ways as they adapt them to global classrooms and informal learning environments.

2.3. Distributed Decision Making

Education pathways are composed of a series of experiences, both in and out of school, where students experience opportunities to engage with, build interest in, and develop skills and competencies for particular subjects. Those experiences are contained within a distributed system of institutions, led by professionals and volunteers who make daily implementation decisions that impact student and system outcomes. To make it more complex, each individual community, and sometimes even schools within communities, have local values surrounding the purpose of education as well as culturally responsive student needs in order for education goals to be met with student engagement and a sense of belonging. Decades of research in implementation science has shown that implementing at scale requires local adaptation and feedback loops to ensure program outcomes, not just implementation ideas, come to pass. (Aarons, Hurlburt, & Horwitz, 2011; Metz & Bartley, 2012; Meyers, Durlak, & Wandersman, 2012)

CSforALL uses frameworks and guided strategic planning in its SCRIPT program to create local ownership of CS education initiatives (Coburn, 2003), create opportunities for school leaders to engage in culturally responsive school leadership practices (Khalifa, Gooden, & Davis, 2016), and create coherence in implementation strategies (Cobb, Jackson, Smith, & Henrick, 2017). In the original design of the CSforALL consortium, and continued design of SCRIPT and other programs, CSforALL sees institutions as a unit of change necessary to implement equitable CS education at scale. Although educators are a necessary component of institutional capacity, alone they lack the power and sustainability to make permanent, equitable change for students. By reforming the curricular systems and the institutions that employ the educators, and raising awareness of high quality research and practice, we empower the educators to focus on creating high quality educational environments that drive student outcomes.

Research practice partnerships also fall under the umbrella of CSforALL values, creating close connection between local actors, parents, teachers, and researchers in order to create culturally responsive and sustaining research and implementation.

3. Recommendations

All CS education implementation is not the same, and researchers as well as implementors should be clear on the specific goals they are trying to achieve. These goals MUST be co-created and built upon the hyper local values, expertise, and knowledge of community and educators. We make these recommendations to global CS education researchers, and policy makers, in order to construct a more just and equitable implementation of CS education with the potential to inspire and engage generations to come.

Recommendations:

- Use an asset based mentality when engaging with schools, educators and community. They each have expertise regarding children and learning spaces that will benefit research and outcomes.
- Adopt a philosophy of true partnership in research, empowering practitioners to not only be subjects, but co-creators and co-designers of interventions and measurement.
- Use formative assessment to monitor and tweak over summative assessment to measure. CS Education research is still a relatively new field and requires incremental approaches to improvement.
- Build frameworks not absolutes. Fidelity of implementation at scale is a known problem, and is almost impossible.

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Phenomena of the Digital World as a Basis for Authentic Digital Education Curricula

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1. Introduction

The digital world, with its phenomena, artifacts, systems, and situations, influences the students' everyday lives and, directly or indirectly, the classroom. When including these into educational settings, it is possible to take on different perspectives: A technological perspectives focuses on the "look under the hood" of technology, investigating the question "How does it work?". A user-oriented perspective asks "How do I use it?" from a practical perspective, investigating the possibilities and common uses of technology to facilitate our lives. In a third perspective, the socio-cultural perspective, questions on the effects of technology, ethical issues, and cultural connections can be asked (Brinda et al., 2016).

In this contribution, I want to discuss what some of these phenomena could be based on existing research. Further, this article elaborates how school subjects can address these phenomena through different "lenses" addressing the three perspectives. The findings could be of interest for designing a phenomena-based curriculum, as some countries and states are currently doing.

2. Phenomena of the Digital World

Phenomenon-Based Learning is concerned with "studying a real-world phenomenon in a holistic manner by covering every entity related to that phenomena by passing through the outlines between subjects" (Wakil, Rahman, Hasan, Mahmood, & Jalal, 2019). Originality and authenticity are important demands of the learning process. Students play an active role in the comprehension by actively constructing their knowledge about the phenomenon. It can be argued that phenomenon-based learning offers natural ways to learn, to address and to produce information in pedagogical environments. The teacher can provide help, similar to a construction worker who helps building the bridges between learning at school school and other environments (Meriläinen & Piispanen, 2012). To gather phenomena related to the digital world occuring in the everday lives of students, it is important to know about the prevalence of certain digital artifacts and activities. Moreover, for an authentic, student-oriented curriculum, it is important to investigate how the presence of these artifacts and activities changes at different ages.

The KIM study of 2020 (Südwest, 2020) shows that almost all children (>=95%) from the age of six to 13 have access to the internet, smartphones, and computers/laptops as digital artifacts via their parents. Less than half have access to tablets, smart TVs, or digital assistants. Almost half of them (42%) have their own smartphones. Half of the boys (49%) own some sort of game console (girls: 33%). 18% of the children have an own computer/laptop and only 9% have an own tablet. Important smartphone activities (at least once a week for more than 50%) are getting and sending messages, getting called by parents or friends, using apps, using the internet, playing games, getting and sending voice texts as well as taking and looking at pictures. Moreover, the children listed smartphone gaming, tablet gaming, surfing in the internet, and watching TV as activities that they do rather alone than with friends, siblings, or parents.

Regarding twelve to 19 year-olds, the annual JIM study (Südwest, 2022) shows that almost all of them (95%) own a smartphone. 75% have their own computer/laptop and around half of them have their own TV (58%), game console (51%), and/or tablet (51%). The possession of digital artifacts increases drastically after the age of twelve. The media-related activities of most teens (more than 50%, at least once a week) comprise using the Internet, listening to music, watching TV, Internet videos, digital games, streaming, and listening to the radio.

In a study of Borowski et al., more than 600 students were asked to gather questions that they would pose to an expert who could answer all of their questions on digital artifacts such as computers, mobile phones, robots, the Internet etc. Using the qualitative content analysis method, a two-dimensional category system was formed: Perceivable artifacts comprised *the Internet*, *computers*, *robots*, *mobile phones*, *sound and pictures*, *game consoles*, and *games*; perspectives on these artifacts comprised *history and future*, *operation*, *potential*, *development and production*, and *safety and durability*. Moreover, the children also asked a number of general ICT questions.

With these results in mind, the most popular phenomenon, both in the lives of children and teens, seems to be the smartphone and its functions. Browsing the World Wide Web or using other services of the Internet seems, including different types of messaging (text/pictures/voice/videos) seems to be something that is already an important part of childrens' and teenagers' everyday lives. In addition, gaming also seems to be a part of the occuring phenomena in most students' digital environments. Borowski et al. could show that these phenomena are not just prevalent in the students' lives, but that they also have questions about how they work, how they can be used, and how the affect us and our environment.

3. Teaching a Phenomena-Based Curriculum in Digital Education

To investigate different views on certain phenomena of the digital world, an interdisciplinary approach is needed. The Dagstuhl Triangle offers three possible perspectives on phenomena, artifacts, systems, and situations of the digital networked world:

- **Technological Perspective:** The technological perspective is concerned with the functioning of the artifacts of digital world. It provides answers to questions regarding the operating principles as well as possibilities for expansion and design of different systems. In addition, the technological perspective is concerned with basic problem-solving strategies and methods.

- **Socio-cultural Perspective:** The socio-cultural perspective examines interactions between individuals, society, and the digital networked world. It explores questions such as: How do digital media affect individuals and society? How can we assess information and, doing that, develop our own points of view? How can we influence social and technological developments? How can society and individuals shape digital culture and cultivation?

- **User-oriented Perspective:** The user-oriented perspective focuses on questions on how to select systems and how they can be used effectively and efficiently. This requires an orientation regarding existing possibilities and functional scopes of common tools, together with their safe handling.

In an extension of the Dagstuhl Triangle, the Frankfurt Triangle offers similar perspectives: *technological and media structures and functions*, *social and cultural interactions*, and *interaction (use, action, subjectification)*. All perspectives are related to the analysis, reflection, and design of a specific object of interest, which could be a phenomenon or an artifact of the digital world. The Frankfurt Triangle suggests to develop educational concepts that address digital media and systems, including the phenomena associated with them and their foundations (Brinda et al., 2020). Both the medias' technological and medial structures, the social-cultural interactions as well as the uses, actions and subjectivations must be included. The overall objective is to analyze, reflect, and shape digital artifacts and the phenomena associated with them throughout these three perspectives in order to be able to explain and assess them.

New school subjects in German-speaking countries, such as "Medien und Informatik" (Switzerland), "Digitale Grundbildung" (Austria), or "Digitale Welt" (Hesse, Germany) integrate all three of these perspectives in one way or another into their curricula. These approaches try to create a holistic and interdisciplinary understanding of the digital world.

4. The Role of Phenomenon-Based Learning in Digitalkunde

Though newer pedagogical approaches in Computer Science Education focus on more than just the technological side of digital artifacts, such as *Informatik im Kontext* (Diethelm, Koubek, & Witten, 2011), their overarching characteristic still lies in understanding the phenomenon's structure and function, and designing them in order to learn about them (Harel & Papert, 1991). Researchers in Computer Science Education have found several ways to summarize the central learning objectives of their subjects, for example the Fundamental Ideas (Schwill, 1997), Big Ideas (Bell, Tymann, Yehudai, et al., 2018), or Great Principles (Denning, 2003) of Computer Science (Education). These collections build a solid foundation for all questions related to the structure and the functioning of phenomena of the digital world.

But when establishing a subject such as Digitalkunde, there might be more to it. Digitalkunde, in the understanding of this contribution, means the ability to be "kundig" in the digital world (German for "knowing your way around"). But this ability also includes the often neglected user-oriented perspective of the Dagstuhl Triangle as well as the socio-cultural perspective. Aspects such as critical information and media literacy combined with Computer Science Education (Dengel & Heuer, 2018), learning objectives deriving from the Sustainability Development Goals (Rieckmann, 2017), and application skills, (e.g. suggested in DigiComp Edu (Tretinjak & Anđelić, 2016)), need to be added to classrooms and Teacher Education alike. This is where a phenomenon-based learning approach can help Digitalkunde to include all of these aspects in an appropriate way: While Digitalkunde cannot cover all aspects, it can give students insights into the ideas behind digital phenomena, while also teaching how to apply their knowledge in their everyday life, and reflecting their own role in these phenomena of the digital world.

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The Purpose of Computer Science Education in the Context of Fachdidaktik (Subject Matter Didactics)

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1. Introduction

The compulsory subject "Informatik" (informatics, computer science) exists in Austria's comprehensive schools since 1985 and has already allowed entire generations of students to experience computer science education. Despite being a pioneering subject at the forefront of computer science education in the 1980s, informatics education in Austria has not been able to expand beyond two, roughly 50-minute units of compulsory instruction per week in the 9th grade ever since.

This niche existence of informatics education in Austrian curriculums may finally have come to an end, as a completely new subject has been introduced to Austria's curriculum in 2022, labeled "Digitale Grundbildung" (Digital Basic Education) – at least that's how it looks at first glance. This new subject will feature twice as many lessons in total compared to the current compulsory subject of informatics. Although the subject was welcomed in principle by the majority of the community of informatics educationalists, clear criticism has also been voiced in public statements regarding the (draft) curriculum of Digitale Grundbildung.

2. Digitale Grundbildung

The name of the subject has been attacked for not including informatics, and the overall design of the curriculum has been criticized for being inconveniently derived from the "Frankfurt Triangle," a set of analytical categories that may not be suited for creating a curriculum (OCG, 2022). In addition, the intention to introduce a separate teacher training program has raised serious concerns (Kappel, 2022). If the current official guidelines were to be implemented, this would result in informatics teachers and teachers of Digitale Grundbildung teaching different subjects at school at the same time. Considering the content of the curriculum, informatics educationalists view most of it as devoted to media education topics and concerns, although this has been disputed by media educators (Kainz et al., 2022). Yet, at the same time, one comment from outside the educational sector has characterized it as a more or less convenient, but at least unfavorable compromise between the disciplines of media pedagogy and informatics. Interestingly, the very same authors go so far as to hint at a perceptible skepticism towards digital transformation (Friesl et al., 2022).

All of these statements point towards disciplinary differences between media pedagogy and informatics education. But when taking a look at further statements in the Austrian press, or at the recent book of the head of the working group responsible for preliminary work on the curriculum, one might get the impression that there are actually deeper ideological trenches (APA, 2022; Missomelius, 2021). These have been known for quite a while in the academic discourse, not only in Austria, but also in Germany as well as in German-speaking Switzerland, and have been repeatedly expressed from both sides. (Hermida & Schmid, 2019, pp. 1–2; Herzig, 2016; Seegerer et al., 2019)

3. Informatics and Media Education

To some degree, the notable differences not only result from rivaling domains of subject matter, but rather from specific points of view on schooling. As has been pointed out by Terhart (2013) for STEM subjects in general and by Witten (2003) and Koubek (2005) for informatics education in particular, there is a tendency to misunderstand or even neglect the ideal of Bildung and Allgmeinbildung especially in those sections of "Fachdidkaktik". Terhart ascribes this tendency, among other things, to a close proximity to educational psychology, selective funding and promotion through large-scale standardized testing in education (e.g., PISA), while Koubek tried to argue that it is caused by the "layered models" in which computer scientists tend to think (Koubek, 2005, pp. 59–61; Terhart, 2013, pp. 149–152). However, in many concepts of media education and also the one present within the curriculum of Digitale Grundbildung, Bildung plays a vital role (Swertz, 2019).

The University of Vienna has now responded to the novel "two-track" approach to informatics education and media education. A new curriculum for teacher training of informatics teachers is currently being conceptualized that integrates teacher training for Digitale Grundbildung. This will inevitably lead to some topics related to media education being included into the new curriculum and a few courses of computer science being cut. But what looks like a loss initially can also be a great opportunity to advance the scope of informatics education.

According to current literature defining the characteristics and nature of the institution of Fachdidaktik in German-speaking countries, Fachdidaktik is usually[1] attributed at least two main functions: (empirical) research and teacher training. But Fachdidaktik performs these functions by constituting its own domain specific knowledge/field through "mediating" between and drawing from (foremost) related scientific disciplines (eg. Mathematics), general pedagogy, educational psychology and practical contexts as well as societal or political demands (Abraham & Rothgangel, 2017; Vollmer, 2021, pp. 144–147**.** The scope of a Fachdidaktik is therefore not limited to a single scientific discipline, nor to teacher training, the analysis and optimization of subject matter or the investigation of subject principles, but extends beyond these spheres.

As the Fachdidaktik of informatics in Austria is confronted with new ideological and practical implications through media education, it might be appropriate to reconsider approaches of informatics education and Bildung that explicitly deal with both content-specific and non-content-specific goals [Klafki]. Not to repeat the mistake of the 1990s and move computer science didactics closer to the humanities, but to embrace certain pedagogical tasks that are expressed as media pedagogical competencies in the curriculum of Digitale Grundbildung (Koubek, 2005, p. 58).

We think a stronger commitment to Allgmeinbildung and Didaktik might be a reasonable approach given the current situation, since its core concept of "meaning" emerging through situated "matter" (Hopmann, 2007, pp. 115–117) would be able to combine Bildung-oriented media education and more content focused informatics. We are interested in opinions on how to push research or teacher training in this sense, and would like to share our experiences with other people facing similar issues.

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It’s (still) complicated. General digital educational goals in shared responsibilities. Balancing traditions, expectations, and potentials from a mathematics education perspective

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1. Introduction

General secondary education in Germany is mainly structured along subjects, reflecting a particular tradition of what constitutes the foundation of the overarching aim of Allgemeinbildung (general education, see, e.g., Biehler, 2019 for the historical genesis of this term) and, at the same time, mirroring disciplinary structures. For example, mathematics education in German secondary education aims first and foremost at the acquisition of mathematical competence with the goals of providing the students three fundamental experiences, namely experience mathematics (1) as useful to understand the world, (2) as a deductive discipline, and (3) as a field of problem-solving (Winter, 1996; Biehler, 2019). Whereas the first and third goals can be seen in line with conceptions of *literacy*, the second goal refers to the specific nature of mathematics as a scientific discipline. The German national educational standards for mathematics can be read as the current consensus regarding which mathematical topics and mathematical practices should contribute to these overarching goals (KMK, 2022).

The observed digitalization and the associated public discourse recently led to action in German educational policy, so educational aims related to digitalization have been put on the national agenda as shared responsibilities. Calls for reviewing the education within the subjects and their educational value in this regard have been heard but a common discourse regarding general educational goals is not observed. As a precaution, the preamble of the central policy document states that these "new" educational goals should be subordinate to the current educational policies (KMK, 2016). Accordingly, the related policy papers argue that the inclusion of digital educational aims does not represent a fundamental re-orientation of goals of secondary general education.

So far, questions of educational goals related to digitization and possible implications for the goals of mathematics education only play a subordinate role in the disciplinary discourses. For example, although the national educational standards for mathematics do address a need to use digital mathematics tools in instruction and establish related practices, they have ostensibly emphasized their potential for supporting the acquisition of mathematical competences (KMK, 2022). Contrasted with a broader perspective on digitization, it is an open question whether mathematics education, its goals, contents, or practices should be recalibrated in the light of an increasing emphasis on digital educational aims. However, the hesitations may also be because what general digital educational goals may be is still a question with many different answers in the educational discourse in Germany.

To set the grounds, this paper first addresses the question of how educational goals for secondary education related to digitization might be thought of. Reviewing three major traditions in the German educational discourse regarding digital educational goals, the paper proposes a synthesized framework as a working model that allows better locating the responsibilities for the overarching digital educational goals through delineating different areas, for instance, a subject-specific and cross-disciplinary one. In a second step, and following the author’s particular interest in mathematics education, it addresses the question of what contributions mathematics education can make to digital educational goals in general secondary education.

Although recent developments may fuel such reflections, they have been sparked already by the first advents of technology decades ago. This contribution offers a perspective from within the discipline of mathematics education research in Germany on traditions, past and current expectations, and potentials of mathematics education regarding digital educational goals. The considerations may interest readers outside the specific field of mathematics education for several reasons: First, the contribution provides a synthesized framework on digital educational goals that – in contrast to others – highlights the possible contributions of the subjects (and especially computer science education). Second, the question of what contributions education within a subject can make to digital educational goals in general secondary education is certainly relevant for all subjects, so the contribution might be a model of how to work towards answers within a subject. Third, the contribution may also help persons from fields adjacent to mathematics (e.g., natural sciences, computer science) think about possible overlap, mutual responsibilities, or at least interdisciplinary research desiderata.

2. Educational aims related to digitization in general secondary education in Germany

2.1. Traditional perspectives on educational goals related to digitization

Three lines of educational discourses can be identified with relevance regarding digital educational aims and their understanding in Germany today. Looking back at discourses over several decades, some of which are highly controversial, it may not be possible to do full justice to the historical development of the traditional perspectives. Still, the essential lines of arguments should be introduced in this overview.

First, we can delineate a line of discourse with a **strong pragmatic orientation** rooted in the 1980s and the concept of “informationstechnische Grundbildung” (short ITG; BLK, 1987). It is based on a dominant view of digital technologies as tools, focusing on them as (universal or area-specific) aids for solving problems. Educational goals can be described as skills and abilities for the targeted use of digital tools, media, or systems, which should be rooted in basic information technology knowledge. From the beginning, this line of discourse has been strongly interwoven with the development of computer science as an independent academic discipline. Today, focusing on computer and communications technologies (ITC), the ICT-literacy framework of the ICILS study series (Senkbeil et al., 2019), as well as the European Digital Competence Framework for Citizens (DigComp) stands in the tradition of this discourse line (Vuorikari et al., 2022). ICT literacy may hence be read as a modern interpretation of ITG. For delineating the range of skills and abilities, areas with varying delineations are used, spanning roughly (1) basic competencies to operate the technologies, (2) competencies for collecting, processing, and storing data, (3) competencies for digitally supported communication and collaboration, (4) digital problem-solving and production. In addition, in some cases, (5) general educational aspects of computer science education are located as a supporting structure in this line of discourse.

The ITC-discourse line is sometimes said to have a one-sided, technical-mathematical character, although there is, in principle, an openness regarding tools, media, or systems. In addition, the functional-pragmatic orientation is criticized (Tulodziecki, 2016), and the latter is sometimes even seen as incompatible with the concept of “Bildung” in Humboldt’s sense (Wiater, 2018). Despite the simplified presentation of this line of discourse within this contribution, it should not be overlooked that the 1987 ITG concept already includes aspects of critical media education (e.g., showing the opportunities and risks of information technologies and building a rational relationship to them, BLK, 1987, p. 12). The newer frameworks, as used in ICILS or DigComp, also include that being able to critically reflect on the use of digital tools, media, or systems is an important aspect of being digitally competent. However, the references to a functional-pragmatic view, motivated by the desire to cope with requirements in the future world of work and life, are always clear points of reference in this line of discourse. Moreover, in retrospect, it cannot be denied that early efforts for implementing the targeted goals in the classrooms may have shown an unbalanced focus favoring the inclusion of new tools (Mandl et al., 2003, p. 291) above its critical reflection, so that first-hand experiences may have shaped the perception of the discourse line accordingly.

Second, a **media-pedagogical line of discourse** takes as a starting point that media are constitutive for society. Reflecting on them is central to becoming an autonomous, educated, socially responsible person. Even if there are sometimes controversial discussions within media education about the differences and commonalities of various approaches, which cannot always be understood in detail from the outside, Herzig (2021) summarizes the current understanding of education in the media education line of discourse generally under the objective of enabling "appropriate, self-determined, creative and socially responsible action regarding media" (Herzig, 2021, p. 5, own translation). If objectives are specified in media education – which is sometimes decidedly refused (e.g., Jörissen, 2011) –critically reflecting on media enters the center of interest (Tulodziecki, 2016). However, objectives often remain vague if elaborated at all in this line of discourse.

Approaches from the line of discourse on media education have further in common that they refer to a communicative concept of media, which can appear restrictive from other perspectives. Roughly speaking, media education approaches are often still characterized by the driving question of how newspapers, television, and the internet as sources of information, which in principle can also be instruments of power, are handled in a society. Although new forms of communicating in social networks have also been discussed as relevant, at its core, the concept of *media* remains tied to communication and communication intentions (see, e.g., Tulodziecki, 2016, for a proposal to update the concept of media). This makes it difficult to link media education concepts to disciplines where digital literacy concepts are more oriented toward using digital tools to solve problems. Nevertheless, the media-pedagogical line of discourse also resonates with some researchers in subject-specific educational research (for mathematics, e.g., Hischer, 2016).

The media-pedagogical line of discourse has strongly influenced educational policy in Germany. For instance, media education, as coined by this discourse line, was included as a general educational goal (KMK, 2012). As media-pedagogical conceptions are, if at all, only to a small extent functionally pragmatic, they are partly positioned (or read) as a counter-draft to contributions from the first line of discourse. In part, certain sub-discourses, such as educational theoretical discourses on media education in the narrower sense, even explicitly distance themselves from any pragmatic perspective (see for a discussion of this aspect, e.g., Barberi, 2017; Jörissen, 2011). However, integrative efforts can also be identified, for example, when researchers from the media-pedagogical and ICT lines of discourse work towards an interdisciplinary understanding of digital educational goals (Dagstuhl Triangle, GI, 2016).

The **third** line of discourse focuses on **competencies for learning** under the conditions of digitality and hence has a different starting point again: In contrast to the other two lines of discourse, digital tools, media, or systems appear here from an instrumental perspective, i.e., as (auxiliary) means for achieving (subject-specific or other) learning goals (Scheiter, 2021). This raises the question of what someone needs to master digital learning processes. Thereby, the range of learning scenarios may span from autodidactic processes, such as in online courses, to supervised learning processes, such as when specific visualizations are introduced by a teacher as part of instruction, to social learning processes, such as when an interest group collaboratively builds a knowledge base in an online forum.

A related question with particular relevance for general education is what someone needs for *future* learning. Any answer to this question is naturally subject to high uncertainty due to its reference to the future. However, it is assumed that technological developments will continue to impose high volatility on societies, so learning across the lifespan will be a central condition for successful participation in society. Learning is assumed to take place in informal contexts increasingly and increasingly rely on digital technology. In addition, it is expected that future learning (e.g., on the job) may be more closely linked to emerging problems and hence be more problem-based. Regarding the social setting, on the one hand, highly individualized learning opportunities have to be considered; on the other hand, cooperative settings are expected to increase due to the division of labor in highly specialized fields.

Answers to the question of what is likely to be particularly relevant for learning under such conditions are being addressed, for example, in the context of 21st Century Skills concepts[1]. The KSAVE model (Binkley et al., 2012), which represents a synthesis of various approaches, can be used as an example. It comprises ten components in four areas, whereby overlaps occur with competencies that have already been dealt with here under the other two lines of discourse (see also van Laar et al., 2017 on overlaps of constructs of digital literacy and 21st Century Skills).

However, complementing the other lines of discourse portrayed in this section, the synthesis of 21st Century Skills frameworks highlights the special role of certain personal and motivational aspects for digitally supported learning processes. In line with research findings on learning with digital media, self-regulation skills (e.g., regarding learning or information processing), motivational aspects such as digitization-related self-efficacy expectations (i.e., self-perception as a digitally competent person), or

[1] 21st Century Skills frameworks aim to comprehensively display what is needed for successful participation in future societies. The frameworks have been developed with economic interests in mind and partly in cooperation with U.S. companies (e.g., Trilling & Fadel, 2009). Only the part related to learning processes will be discussed here.

positive digitization-related attitudes such as openness to innovations are listed. It should be noted that such personal and motivational aspects, which can only be touched upon here, are relevant for learning processes in general. However, their importance has also been demonstrated in the context of digitally supported learning processes.

The observation that personal and motivational aspects are consistently crucial in various learning contexts does not imply that they are regarded as stable characteristics of a person. Instead, it is assumed that they are socially shaped and are acquired when interacting in corresponding contexts (for an overview, see, e.g., Zimmerman, 2000). For example, self-efficacy expectations regarding digitally supported learning processes would be expected to be shaped by corresponding experiences and may differ from self-efficacy expectations regarding other learning conditions.

In summary and under the assumptions outlined for future learning, an independent contribution to the problem of determining a possible target dimension concerning digitization can be identified from this line of discourse. This line of discourse emphasizes, in particular, but not exclusively, personal and motivational aspects of competence as a prerequisite for successful future learning processes, which, according to the argumentation, would also have to be consistently trained. This, in turn, would require relevant experiences with digital learning processes. What remains unsolved in this argumentation is the problem that assumptions have to be made about the nature of future learning, which remains a factor inflicted with high uncertainty.

2.2. Synthesis of a framework for educational goals related to digitization

Recent German policy documents regarding digital educational goals for general secondary education clearly show references to the discourse lines presented above, although with varying intensity. A first attempt to conceptualize a framework for digital competence (KMK, 2016) raised critical concerns from different perspectives, as it was seen to neglect, for instance, the possible contributions of subject-specific education in general (GFD, 2018) and those of computer science education in special (Brinda, 2016). Although certain interdisciplinary initiatives, like the Dagstuhl triangle as the result of a cooperation of computer science and media educators, are used in sub-discourses (e.g., GI, 2016), to date, a common consensus model for digital competence is still lacking. Especially, frameworks that allow us to reflect on the possible contribution of different subjects to general digital educational goals are missing. This paper proposes a framework (Figure 1) as a working model synthesizing digital educational goals from the different discourse lines as well as recommendations issued as reactions to the recent national policy actions into one framework (KMK, 2021; SWK, 2021).

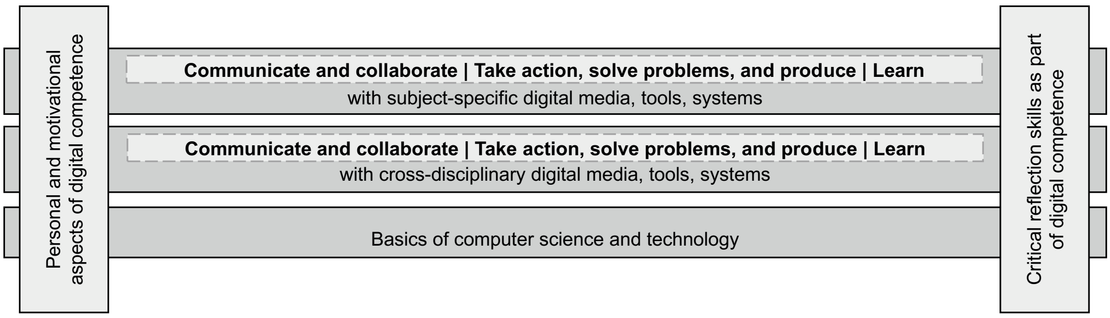

Figure 1 – Framework of digital competence as a working model for digital educational goals

The framework first differentiates three competence areas (Figure 1, horizontal boxes): The *Basics of computer science and technology* area is intended to cover aspects that, from a general educational perspective, provide answers to the question "How does it work?". These basics are certainly related to what computer science as a school subject may contribute to general education, but must not be equated with it (Schulte & Scheel, 2001). Two areas related to *cross-disciplinary* and *subject-specific digital media, tools, and systems* take up pragmatic perspectives. The splitting into two areas emphasizes that specific digital media, tools, and systems may become relevant by discipline, as represented by school subjects, as part of their contribution to general education. Although the term *technologies* might be suitable as an umbrella term, the framework explicitly mentions *digital media, tools, and systems* to avoid potential misunderstandings arising from using single terms (e.g., *media* as sometimes exclusively associated with communicative functions). It is important to consider that special educational goals of the subjects, like those of specialist courses at the upper secondary level (as opposed to general education goals within the subjects), are meant to be outside the framework. At the same time, cross-disciplinary educational goals may be considered a shared responsibility of all subjects.

The subject-specific and cross-disciplinary areas of digital competence should each be based on knowledge of its central concepts (not shown in Figure 1, e.g., cross-disciplinary: What is a blog?; subject-specific for mathematics: What is a computer algebra system (CAS)?). From a pragmatic point of view, it must be ensured that basic skills to operate a technology (not shown in Figure 1) and associated practices are acquired. To emphasize the latter, modes of use spanning a range of possible practices are shown in the model: (1) communication and collaboration, (2) taking action, solving problems, and producing, and (3) learning. The modes of use reflect areas that recur in the ICT line of discourse but also focus on future learning originating from the third line of discourse portrayed above. The modes are not to be understood as a complete list of practices or without overlaps, which becomes apparent when thinking of complex practices as needed, for example, for digitally supported, collaborative learning within a subject.

Finally, *personal and motivational aspects* and *critical reflection skills as parts of digital competence* are outlined as cross-cutting areas (Figure 1, vertical boxes). This reflects that their acquisition requires manifold experiences of engaging in practices using digital media, tools, or systems. It should be emphasized that these aspects of digital competence are not understood as goals that are subordinate, optional, or exclusively relevant for particular groups of students. They are rather seen as an integral part of digital educational goals. One could even discuss – following the discourse originating in media education – that the general educational value of digital competence manifests itself only through the development of personal-motivational aspects and critical reflection skills.

According to the synthesized framework, being digitally competent as a goal of general education means being able to master relevant challenges that relate, for example, to questions of communication, problem-solving, or learning in a self-determined and socially responsible way so that it satisfies the criteria of the reference field (subject-specific or cross-disciplinary).

The synthesized framework is one potential answer to the question of how educational goals for general secondary education related to digitization might be thought of. It differs from other frameworks in several aspects: First, it distinguishes between a subject-specific and a cross-disciplinary area, allowing for closer investigations of the possible mutual contributions and responsibilities. Second, it suggests that being digitally competent also comprises being basically literate in computer science and technology (which may not be undebated outside of computer science education). Third, the framework emphasizes that general education should cultivate personal digital maturity despite its various contributions and shared responsibilities.

3. Possible contributions of mathematics education to digital educational goals in general secondary school

Based on the framework of potential goals related to digitization for general education (Figure 1), we will now explore what possible contributions mathematics education at general schools in Germany could provide. Mathematics is set according to the expertise and interest of the author. The analysis can be read as an example. It would be necessary to compare and integrate similar analyses regarding other subjects to see to which extent goals related to digitization for general education may be met or missed in a disciplinarily structured organization of general schools in Germany. The analysis further focuses on the areas *basics of computer-science and technology,* and *subject-specific aspects* (Figure 1) as prior work in mathematics education research in Germany is more informative for these areas than the others.

3.1. Mathematics as a foundation of digitization: Possible indirect contributions

This section will elaborate on whether mathematics education may indirectly contribute to *basics of computer science and technology*. We use the notion of a possible “indirect” contribution since it is not to be expected that learning mathematics directly leads to a growth of understanding in the focal area but may instead support its understanding. For example, this would be the case when a learner understands a concept better because s/he knows underlying mathematical concepts.

It should be noted that parts of computer science, which originally emerged from mathematics, still see themselves as strongly influenced by mathematics (especially theoretical computer science, e.g., Knuth, 1974). However, this only applies to part of the discipline, which also has strong roots in engineering, is mainly interdisciplinary and even has relations to social sciences. When looking at secondary mathematics, various potential reference points can be identified. Calculation procedures, for instance, could be a well-familiar starting point for a basic understanding of the concept of algorithms from a computer science point of view. As another example, the concept of prime numbers is crucial for RSA encryption. Likewise, statistical concepts could be the foundation for getting insights into emerging data-based technologies. In general, it is argued that the techniques of abstraction and modeling, which are practiced in mathematics, are important basic principles for computer science, and the formulation of facts in the formal language of mathematics is a precursor for programming skills.

However, given empirical findings on the transferability of skills between domains, indirect contributions to modeling and abstraction skills in computer science by means of transferring similarly situated skills from mathematics should not be overestimated. Skepticism about the potential indirect contributions of mathematics as a foundation of digital technologies is warranted for further reasons: First, there is often a considerable gap between the basic mathematical concepts taught at school and their use in computer science. For example, RSA encryption uses prime numbers, but knowledge of the concept of prime numbers (potentially together with a basic understanding of encryption) does not yet explain RSA encryption. As another example, if mathematics education is expected to lay a foundation for advanced data-based methods, it would be necessary to aim at a basic understanding of multiple regression, which would require the use of tools to analyze larger datasets (e.g., Borovcnik, 1988). But, with reason, neither regression nor the analysis of larger datasets is currently part of school mathematics. Remarkably, a suggestion of how certain machine learning methods may be introduced at secondary school proved quite ambitious with respect to mathematical prerequisites and yet had to remain in essential parts intransparent for the learners (Mariescu-Istodor & Jormanainen, 2019).

Consequently, views that assume that mathematics instruction generally contributes to digital literacy because of the foundational nature of mathematics are to be challenged (see also Vohns, 2021). Moreover, such views systematically underestimate that concepts may be understood essentially differently in different disciplines. Mathematical concepts may even conflict with related concepts from computer science (Knuth, 1974; for the example of the concept of algorithm, Mühling et al., 2021). It should also be noted that there are approaches within computer science education to teach central concepts without programming and/or a mathematical formulation (e.g., computer science unplugged, Bell & Vahrenhold, 2018). There are even preliminary empirical findings that certain computer science skills may be more strongly related to skills in languages than mathematical skills (Prat et al., 2020), which may be surprising to a mathematician at first sight.

To sum up, it seems there is currently limited potential for the subject of mathematics to make an (indirect) contribution to the competence area *basics of computer science and technology*, although systematic empirical evidence is still largely missing. To work on this gap, it would be first necessary to have a clearer picture of possible educational expectations regarding the focal area, which in this contribution would be regarded as the realm of computer science education. Second, it would be necessary to investigate in more detail whether and how mathematics and computer science topics could and should be connected. It should be noted that even if points of reference are mutually known, indirect contributions of the subject of mathematics to the digital basics, as discussed in this section, may only be expected if the curricular organization allows that topics are picked up and deepened from the perspective of the subject of computer science.

3.2. Mathematics as part of digitization: Possible direct contributions

For the possible direct contributions of mathematics education to general digital educational goals, we focus on the subject-specific area given in the synthesized model and only briefly visit the cross-cutting areas. This leads us to first focus on mathematics-specific tools for problem-solving in a *tool-oriented analysis*. These tools typically include various types of calculators, computer algebra systems (CAS), dynamic geometry systems (DGS), spreadsheet applications (possibly also more specific data analysis programs), and systems that combine corresponding functions. Different solutions are used in German mathematics education, typically explicitly developed for instructional purposes. However, their main functionalities often resemble corresponding expert systems that are, for example, used in fields that apply algebraic, geometric, or statistical modeling (Greefrath & Siller, 2018).

According to the general goals of mathematics education in Germany (see section 1, Winter, 1996), a digital mathematics tool would have to be part of instruction if it is widely used and powerful for solving mathematical problems (see goals (1) and (3)), which is, for instance, clearly the case for spreadsheet applications. In addition, and in line with goal (2), it might be argued that a mathematical tool should be part of instruction if it represents a unique achievement of mathematics as a world of its own. The latter can be argued for CAS as a modern algebraic and DGS as a modern geometric materialization of mathematics (e.g., Fischer, 2012). At the same time, it can be argued that mathematics instruction that supports students to experience mathematics as a deductive science might also profit from traditional, tool-free practices of working mathematically (e.g., reasoning and proof). This brief insight into the discourses within mathematics education research substantiates that concerning general educational goals of mathematics education, there are sound arguments for (and partly against) the inclusion of (most of the) digital mathematics tools mentioned in general mathematics instruction.

Accordingly, a broad range of digital mathematical tools is anchored in the German national educational standards. However, in practice, the use of digital mathematics tools in secondary education currently varies widely. For example, CAS are currently compulsory in the upper grades in some Länder (e.g., Thüringen) and optional (e.g., Schleswig-Holstein) or even prohibited for certain uses (e.g., Baden-Württemberg) in others. Systematic surveys on the de facto implementation of digital mathematics tools are rare. However, in a non-representative survey in the school year 2017/18 with 163 secondary mathematics teachers from different federal states, 25% (DGS) and 50% (CAS) of the teachers reported that they do basically not use such tools (Ostermann et al., 2021).

From the perspective of mathematics education research, this lack of adoption of digital mathematics tools is often considered to result in severe difficulties for students using the tools to solve problems. According to the theory of instrumental genesis (Rabardel, 2002), any tool needs individual appropriation processes by the learners before its potential can unfold. Learners must become familiar with the tools and be supported to engage in related practices consistently. In line with this argument, introducing a tool and its basic operating functions would, per se, be only a modest contribution to digital educational goals.

A more valuable contribution to general digital education goals might unfold when learners acquire skills to use the digital mathematics tools in various ways in a goal-oriented manner and develop accordingly critical reflection skills and related motivational and personal aspects of digital competence. So, the following paragraphs will complement an analysis of the potential of mathematics education to contribute to digital general education goals with a focus on possible modes of use of subject-specific technologies (*use-oriented analysis*). According to the framework presented above, the modes of use *learning* and *taking action, solving problems, and producing* are considered as examples since these are discussed more intensely in mathematics education research.

Using digital tools for *learning* mathematics is currently a dominant perspective, with numerous researchers illustrating the potential of digitally supported mathematical learning processes (for an overview, see, e.g., Roth, 2019). From the perspective of mathematics education, digital worksheets are a format suited to support mathematical learning. Digital worksheets are analogies to traditional worksheets and represent assignments structured as a sequence of tasks, which can also be part of larger learning environments. Digital worksheets are often skillfully designed and built on subject-specific as well as general educational research. Typically, they represent highly pre-structured learning opportunities to support individualization, e.g., in terms of temporal structuring.

However, the potential of such modes of use of digital tools for learning regarding general digital educational goals from a broader perspective may be questioned. First, learners may encounter such ways of using mathematics tools primarily in the school context. In contrast, in other contexts, more informal, possibly problem-based, and open learning requirements seem to gain relevance. Second, when digital tools are pre-selected and already prepared for specific uses, learners may not experience opportunities to learn how to decide for (or against) and modify a tool for their own learning process. Strong pre-structuring might even impede the formation of self-regulation skills for learning (Scheiter, 2021). Despite these concerns, studies that systematically investigate how using digital tools for learning mathematics in highly pre-structured settings may affect future learning skills are largely missing (and also methodologically a challenge).

Digital mathematics tools are also used in less pre-structured learning processes as tools in the narrower sense, where modes of use related to *problem-solving/producing/taking action* become relevant. For example, by using a calculator or CAS to outsource certain steps in a solution process, learners may handle more complex learning situations by reducing temporal or cognitive demands. On the one hand, experimental phases of problem-solving processes, e.g., when trying to understand a situation or develop a model, can be digitally supported. On the other hand, solutions can be produced directly in the tool. The instructional activity to solve the road connection problem in calculus (Weigand & Bichler, 2010) or exploratory investigation of data distributions may serve as examples.

A fine-grained distinction can be made between whether the used functionality of a digital mathematics tool represents a white or black box for the learners. In the first case, learners know the implemented procedure, and they even might be able to solve the problem at hand without the tool, although perhaps only in simple situations. It is argued that mathematical tools which constitute white boxes for the learner may contribute to developing digitization-related critical reflection skills, for example, as they can autonomously validate the results and do not have to rely solely on the tools. In the second case, tools used as black boxes, learners have not (or only phenomenologically) been exposed to the implemented procedure. For example, regression lines may be determined by clicking without having built up an understanding beyond a basic idea as modeling the latent relationship by "leveling out deviations." As another example, learners might simulate random numbers with the help of a function in a spreadsheet application without any idea about how the random numbers are determined and whether there are possible threats to randomness. Fischer (2012) argues that especially the conscious use of (mathematical) tools as black boxes can be informative regarding the societal principle of division of labor so that its critical reflection has the potential to foster cross-cutting competences according to the presented framework. In this respect, both black box and white box modes of (mathematical) tool use offer starting points for developing digitization-related critical reflection skills. In any case, concise research and evidence on how mathematics education may succeed in using these potentials are rare in Germany.

Overall, it has to be considered that tool-based problem-solving starting with an "empty screen" – like problem-based learning in general – is difficult to implement at school. In principle, the conditions for problem-based learning are more favorable in the upper secondary school years due to the enhanced self-regulation skills of older learners. At the same time, the required modes of use are – at least today – usually not systematically developed in the lower secondary grades, so problem-based learning with digital tools remains challenging, even in the upper grades. New developments make digital mathematics tools increasingly accessible and easy to install and operate. However, for solving mathematical problems with these tools, it remains necessary to learn elaborate practices of how to use them to solve these problems. This also requires the learner to hold substantial mathematical knowledge and a range of available mathematical structures to develop solution ideas. What research on digital mathematics tools from the last decades clearly could show is that using digital mathematics tools only occasionally and expecting students to be immediately able to use them proficiently in problem-based learning environments is illusory.

In summary, mathematics education may directly support the development of general digital educational goals, which was shown mainly regarding subject-specific digital tools. With appropriate support, this lays the ground to develop personal and motivational aspects of digital competence, for example, by experiencing oneself as a person who can use digital tools in a goal-oriented manner. For reasons of space, we could only sketch that critical reflection skills may be developed along the way, for example, by reflecting on the transparency of tools or possible non-use-cases of tools (e.g., a visualization of a geometrical configuration in DGS may not suffice as a proof).

At the same time, the very modes of use found to be decisive for general digital educational goals are hardly implemented in mathematics instruction in Germany today. Hurdles to implementation, such as a lack of equipment, teacher qualifications, or the prevalent non-digital instructional practices, are as well-known as affordances, such as consistent tool use or supporting structures at the school level. However, the lack of successful implementation research has partly spread disillusion despite high idealism (e.g., Weigand, 2012), so some mathematics educators even advocate that digital problem-solving with mathematical tools may be an outdated practice (Roth, 2019). As argued, if these challenges are not addressed, only a limited direct contribution to digital educational goals can be expected from digitally supported mathematics instruction. In the worst case, digital mathematics tools would be (further) used primarily in narrow and pre-structured situations in mathematics education so that because of a limited transferability and the context-boundedness of the applied modes of use, only a small share of the potential regarding general digital educational goals would be expected to unfold. It is important to consider that this analysis does not suggest any inference on the general educational value of mathematics education in total, as general *digital* educational goals are only a small part of it.

3. Conclusion and discussion

The advance of technology more than 50 years ago sparked a discourse on general educational goals. As one result, a set of goals for mathematics education emerged that can, to date, still be considered to constitute a consensus widely used to inform the decisions regarding German mathematics education (Winter, 1996). With the ongoing digitalization, shifts regarding general educational goals are discussed again and mandated by policy action. Hence, it seems necessary to investigate how subject-specific general goals and possible digital educational goals resonate, which was done in this paper for the subject of mathematics.

Unfortunately, a consensus model for digital educational goals is still lacking in Germany to date. Hence, the contribution first reviewed traditional discourse lines relevant to understanding general digital educational goals in Germany. Bearing in mind the goal of reflecting on subject-specific contributions to general digital educational goals, the contribution proposed a synthesized framework as a working model that may provisionally serve to structure these goals for this purpose.

In a second step, potential contributions of mathematics education to digital educational goals as outlined through the framework were analyzed. On the one hand, secondary school mathematics instruction was found to have a certain potential to contribute to digital educational goals. However, in some points, the contribution may easily be overestimated at first sight, especially regarding the possible indirect contribution of mathematics education to the area of *basics of computer science and technology*. By means of several examples, the paper argues that despite mathematics being at the foundation of digitization, this foundational nature does not suffice to substantiate an argument that mathematics education per se contributes to digital educational goals. In contrast, it was argued that a potential indirect contribution could manifest only after the mutual relations between the subjects are well-known and used to establish relevance and understanding. It should be considered a joint responsibility of mathematics and computer science education research to work towards this goal since the disciplinary sovereignty of the two points of reference is (nowadays) uncontroversial.

In the analysis regarding the potential direct contributions of mathematics education to digital educational goals, it became clear that the introduction of digital mathematics tools aligns with the current goals of mathematics education. However, a tool-oriented analysis is only partly informative as coherent instructional concepts that span grades and topics are still missing. The practices-oriented analysis made clear that whether mathematics education can make a broader contribution to general digital educational goals depends on the modes of use mathematics instruction strives to establish. In essence, as communicated in the national educational standards, current general educational goals of mathematics education clearly target relevant practices like solving problems or communicating mathematically with digital tools. But it is also known that educational expectations and realities typically show substantial disparities, especially regarding the ambitious practices that seem to be crucial for developing general digital educational goals with relation to the subject, and, on the grounds of these experiences, critical reflection skills as well as motivational and personal aspects of digital competence. So, using the multifaceted potential of mathematics education to foster general digital educational goals is not a low-hanging fruit.

Looking at the limitations, the contribution aimed at portraying the discourse in Germany and, particularly, some issues marked as unresolved issues in this context may already be under investigation in international research. The analysis further mainly considered possible indirect contributions to the area *basics of computer science and technology* and direct contributions regarding the *subject-specific area*. It was not considered, for example, to what extent mathematics education may contribute to the *cross-disciplinary area* as outlined in the framework. Second, the paper represents, first and foremost, the perspective of a researcher who works in the field of mathematics education and, in addition, holds a master's degree in computer science, so the perspective may not be representative of all perspectives within mathematics education research in Germany.

As a closing remark, it should be stressed that the paper does reflect on the possible contributions of mathematics education to general digital educational goals and does not suggest focusing secondary mathematics education exclusively on such goals related to digitization. First, doing so would emphasize a utilitarian view on mathematics education and question its unique contribution to general education, hence revising the current understanding of the general educational value of mathematics education substantially. Second, without a strong, double-rooted foundation of mathematics education in the nature of mathematics – being, on the one hand, a deductive science of its own and, at the other hand, a set of techniques used for a growing number of applications – mathematics education would face the danger of being increasingly subject to arbitrary curricular decisions, which would certainly hamper the endeavor to provide high-quality mathematics education.

The argument in the last paragraph may be considered generic and be applied in analogy to any school subject. However, some subjects, certainly computer science and mathematics and other STEM subjects, may especially need a clear perspective of their educational value in Germany, as multiple challenges are emerging (e.g., teacher shortage, declining student proficiencies). At the same time, renewed discourses on the educational value of the subjects might also support endeavors to delineate and conceptualize general digital educational goals more coherently and make mutual expectations and responsibilities transparent. Finally, trying to network subject-specific perspectives may inspire much-needed research on how to foster general digital educational goals in shared responsibilities.

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Artificial Intelligence and Machine Learning in Schools: Literature, Policy and Practice

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1. Introduction

This paper provides a brief overview of the current context of the teaching and learning of artificial intelligence (AI) and Machine Learning (ML) in schools. It is presented as a scoping review of prior work, a presentation of current European policy efforts, and examples of tools that are likely to affect classroom practices in the immediate future. We then present a brief discussion about the future of the teaching and learning of AI/ML in schools. This paper sets the scene for what educators should consider when developing curricula (formal or informal) and/or designing content that aims to build general or specific AI/ML competencies. Additionally we discuss the challenges facing school teachers in terms of current research, policy, tools and practice, and in some cases, lack thereof.

2. The Literature

To provide context, we conducted a scoping review of the literature relating to AI/ML in pre-university settings to illustrate the growth of interest as well as areas of focus. Our inclusion criteria were being not less than three pages and being focused on the teaching of i) artificial intelligence or machine learning content; or ii) the use of AI/ML tools in a school setting. The review included formal and non-formal settings, short- and long-term interventions, and online or hybrid settings, with students and/or teachers as participants. We examined workshops, pilot studies, tutorials, literature reviews, case studies, and expert discussions as well as regular research papers. Selecting search terms for a broad and inclusive review of introductory literature proved challenging, but after some trial and error with a range of databases, we selected a search string that seemed to capture our area of interest: ("artificial intelligence" OR "machine learning") AND ("school" OR "k-12"). We then conducted a search of the ACM Full Text Collection on August 10, 2022. The search returned 197 papers. 11% of these were from 35 year period from 1973-2007 and 89% of these were from the last 15 years. 25% were from 2021, illustrating the explosive growth of interest in the area, as shown in Figure 1.

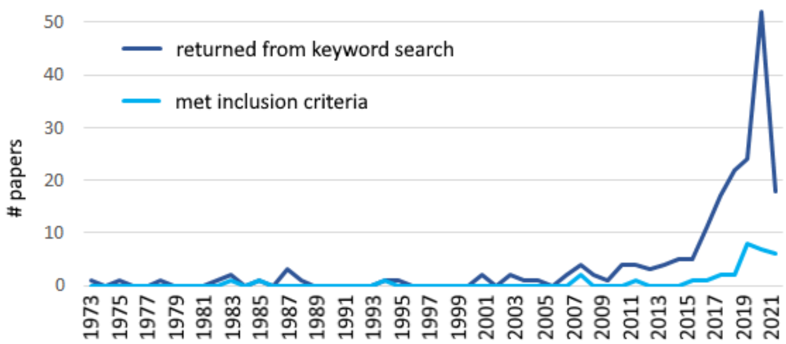

Figure 1 – Search results from the ACM Full-text Collection on Aug 10, 2022. 197 papers were returned form a keyword search and 33 met acceptance criteria.

62 papers (31%) were excluded as they were less than 3 pages in length. Another 102 (52%) discussed AI/ML applied to different disciplines, addressed a different age range, or otherwise did not meet our inclusion criteria. This left 33 (17%) as solidly addressing AI/ML education at the pre-university level. The number of student participants ranged from a single student to over 1,000. 24 papers (73%) related

to hands-on approaches where students were attending and AI/ML course or workshop, or interacting remotely. 30 papers (91%) focused on students' learning, and 7 (21%) of these papers also addressed the role of the teacher. Only 3 (9%) of the papers had a specific focus on teachers. Specific programming languages appear in 14 (42%) with Python being the most commonly referenced, appearing in 5 (15%). The most commonly used teaching tools were web-based interfaces or applications (27%), robotics, smart devices or bots (24%) and block-based programming (18%).

In general, there was a notable emphasis on the concepts of data & analysis, algorithms & programming; and the impact of computing. There was some exploration of natural language processing, computational biology, explainable AI (XAI), and reinforcement learning. The topics computing systems, and networks & the internet, did not feature prominently. The areas of the environmental impact of computing, quantum computing, and neuromorphic computing were present but scarce. There was a notable lack of privacy, safety & security. These results reveal a wide range of course delivery methods and lengths, from short workshops to year-long programs. Only 6 (18%) were found to be linked to a specific framework or a national curriculum. There is little evidence in these results of qualitative research that involved experts, the school community, or parents.

3. Policy

Recent developments, guidelines and acts by the European Commission (EC) have started to frame policy for AI and sub-components of AI such as ML and data, not only for the broader community, but in the context of education specifically. This section presents a succinct view of recent developments in this space.This section discusses EC developments that directly affect the use of AI/ML in schools. By *use* we mean the use of tools and systems that incorporate both 'Good Old Fashioned AI' (GOFAI) and machine learning, that can directly impact students. High-level examples include recommender systems, adaptive learning environments, automated assessment, enrollment systems and grade prediction systems.

3.1. Ethics Guidelines for Trustworthy AI and the ALTAI assessment list

The most recent significant policy development was a set of deliverables from the High Level Expert Group (HLEG) on AI[1]. The AI HLEG has worked closely with the European community of AI stakeholders through the AI Alliance, an online forum with over 4,000 members representing academia, business & industry, civil society, EU citizens and policymakers[2]. The AI Alliance also reviewed and suggested amendments to the AI HLEG deliverables. The first of deliverables, published in draft in December 2018, was the *Ethics Guidelines for Trustworthy AI*[3]. These guidelines centered around the core concepts that AI should be ethical, lawful and robust. They also identified several key requirements for the development of trustworthy AI: human agency & oversight, technical robustness & safety, privacy & data governance, transparency, diversity, non-discrimination & fairness, societal & environmental well-being, and accountability. In addition to key requirements, the AI HLEG developed the *Assessment List for Trustworthy Artificial Intelligence* (ALTAI)[4] which allows for the self-assessment of guideline adherence by providers and users.

3.2. EC Expert Group on AI and Data in Education

The EC proposed the development of ethical guidelines on AI and data in education and training based on the Ethics Guidelines for Trustworthy Artificial Intelligence, presented by the AI HLEG in 2019. In July of 2021 the EC Directorate-General for Education, Youth, Sports and Culture set up the EC Expert Group on AI and Data Education[5] in July 2021. This group concluded their work in June 2022, which is expected to be published in September 2022.

3.3. The AI Act

With the Ethics Guidelines for Trustworthy AI and the ALTAI assessment published, the EC decided to develop an *Artificial Intelligence Act* that would ensure more compliance than guidelines – while acknowledging the value of the guidelines and the foundation that they laid. The current proposal was last published in April 2022.[6] The expected completion/publication date and when the act will become lawful is to be determined. Education is discussed in several places in the proposal, and most notably is categorised as high risk, where the students' fundamental rights was a core concern. For example, point 35 states: "AI systems used in education or vocational training, notably for determining access or assigning persons to educational and vocational training institutions or to evaluate persons on tests as part of or as a precondition for their education should be considered high-risk, since they may determine the educational and professional course of a person's life and therefore affect their ability to secure their livelihood." Annex III lists the following specific AI in Education areas: 1) AI systems intended to be used for the purpose of determining access or assigning natural persons to educational and vocational training institution; and 2) AI systems intended to be used for the purpose of assessing students in educational and vocational training institutions and for assessing participants in tests commonly required for admission to educational institutions.

3.4. Digital Education Action Plan and Digital Competence Framework for Citizens

Two significant policy documents that impact both teachers and students are the *Digital Education Action Plan* (DEAP) 2021-2027[7,8] and the closely-linked *DigComp 2.2: The Digital Competence Framework for Citizens - With new examples of knowledge, skills and attitudes*[9]. The DEAP is is the second iteration of policy document (with the first in service from 2018-2020[10]) that presents a common vision for "high-quality, inclusive and accessible digital education in Europe, and aims to support the adaptation of the education and training systems of Member States to the digital age". This current iteration lists priorities for the EC and EU around challenges such as COVID-19 and AI to "present opportunities for the education and training community (teachers and students), policy makers, academia and researchers on national, EU and international levels". DigComp 2.2 is a general competency framework for all citizens, including education. It defines competencies as a set of skills, knowledge and attitudes. The framework was developed with organizations such as the UNESCO Technology and Artificial Intelligence in Education Unit (focusing on the AI aspect), and ties closely to the DEAP 2021-2027 policy document. For the development of the policy in Section 3.2, DEAP and DigComp 2.2 were significant foundations.

DEAP has two strategic priorities: 1) Fostering the development of a high-performing digital education ecosystem; and 2) Enhancing digital skills and competences for the digital transformation. For priority 1 the main goals include new approaches to: teaching & learning practice, student assessment, and teacher professional development. The resulting actions will range from AI/ML education to the use of AI/ML tools in education. For priority 2 the EC's goals are to build competencies such understanding the digital world, addressing gender gaps in digital and STEM education, and developing basic and advanced digital skills. The actions for this include an updated European Digital Competence Framework to include AI/ML and data-related skills, and to support the development of AI/ML learning resources for education and training.[11] Linking these policies together specifically for AI/ML is DEAP priority 2, action 8 which is to "update the European Digital Competence Framework to include artificial intelligence and data-related skills".[12]

4. Practice: AI for Use in Schools and By Schools

This section provides two examples of AI/ML and how it can be used in schools. There are myriad examples that could have been chosen. We chose the first as it illustrates rapidly emerging AI/ML technology that can be used in the classroom today, affecting both teachers and students. We chose the second as an example of how AI/ML can be used in an educational setting but not necessarily in the classroom, but affecting teaching and learning nonetheless. Although the studies mentioned in this section took place in or were aimed at higher education, there is little doubt that these tools will impact school education soon, if they aren't already.

4.1. Using AI/ML in the Classroom

Most AI/ML taught in schools teaches students *about* these topics such as how AI/ML works, how it can be used, and ideally topics such as ethics and bias. However, recent developments have provided the opportunity for students – particularly those in post-primary levels – to *use* AI/ML tools. This provides interesting, context-based, and potentially effective ways to teach students about AI, including topics such as ethics and bias which our scoping review in Section 2 indicates may be lacking. Several impressive new AI/ML tools have become freely available in the last year or so, including GPT-3 (Brown et al., 2020) a large language model from OpenAI[13] that uses deep learning to produce human-like texts (Floridi & Chiriatti, 2020) from natural language prompts. Tools such as GPT-3 are already proving to have novel educational approaches. One such study instructed students to harvest information from GPT-2 (GPT-3's predecessor) and integrate that information into an assessed essay (Fyfe, 2022). The final section of the essay was written exclusively by the students themselves - this being a reflection on the following: "How easy or not was it to write this way? What worked or what didn't? How did the AI-generated content relate to your own? How did it affect what you might have thought about or written? Do you feel like you 'cheated'? To what degree is this paper 'your' writing? Do you expect a reader would notice GPT-2's text versus your own? Would you use this tool again, and in what circumstances? And, ultimately, what ideas about writing, AI, or humanness did the experiment test or change?" All essays included an appendix where students provided a "revealed" version of their essay highlighting the AI-generated text. Most students reported that despite thinking this approach would be easier than generating an essay from scratch, the vast majority reported that using GPT-2 made the task more complicated – largely due to the work taken to interpret, edit, critique, correct, and integrate the AI-generated text into a final essay. Students also grappled with topics such as academic integrity, algorithmic bias, and misinformation while constructing their essays, and how the AI-generated text would represent themselves when the essay was submitted.

Codex[14] is a model based on GPT-3. Codex takes natural language prompts and generates code in a number of programming languages. It is used to power tools such as GitHub Copilot[15] which is free for student use. In a recent study, Codex was given first-year university-level exam questions and scored in the upper quartile of a group real students who took the same exam (Finnie-Ansley, Denny, Becker, Luxton-Reilly, & Prather, 2022). Another study used Codex to generate programming exercises, sample solutions, test cases and code explanations (again, for university-level) (Sarsa, Denny, Hellas, & Leinonen, 2022). The authors found that the majority of the exercises generated by Codex were sensible, novel, and included appropriate sample solutions. Additionally they found that the explanations covered a large majority of the code. Although some inaccuracies were present, most could be easily be rectified by instructors or teaching assistants.

4.2. Predicting Student Performance

In addition to using AI/ML for classroom activities, teachers and administrators may use AI/ML for tasks such as auto-grading or to make enrollment decisions. AI/ML systems that predict grades are one such tool. If used ethically and a student is predicted to be at risk of failing the teacher/school could provide interventions to try and improve the student's chances of improving and continuing. Another use may be to stream classes based on current performance or engagement, measured with predictive power and with a finer granularity than traditional assessments and observations may allow. In this way AI/ML systems could be used to tailor the educational pathway of the student (Becker, 2017). Over the past two decades several models have aimed to predict performance, such as using aptitude (Fowler & Glorfeld, 1981), using fine grained clicker data (Porter, Zingaro, & Lister, 2014) and student participation (Cukierman, 2015).

PreSS (**Pre**dict **S**tudent **S**uccess) is a prediction model that aims to predict students at risk of failing or dropping out of an introductory programming module (Bergin, Mooney, Ghent, & Quille, 2015; Quille, Culligan, & Bergin, 2017; Quille & Bergin, 2015, 2016b). The use of PreSS can have both positive and negative outcomes depending on how it is used. Its intended use is the identification of students who may fail or drop out, and would lead to suitable interventions to try and reduce the attrition rates in university-level introductory programming. Quille and Bergin trialed several interventions with PreSS (Quille & Bergin, 2016a, 2020). While this may be considered a positive use of this tool, it could be used unethically, as most AI/ML tools could.

5. The Future

Considering the tools that are now available, AI/ML have the ability to have significant impact on school education. A clear observation is that the development, capabilities, and use of such tools is currently moving faster than policy can adapt, although efforts are being made for policy to catch up. With developments such as the guidelines for AI and Data in Education and the AI Act, changes are on the horizon. It is also clear that AI tools will need to be trustworthy for schools and educators to adopt them. Key to trustworthiness is being as transparent as possible. For many AI/ML developers, this will be a challenge. In addition to being able to understand and teach AI/ML, teachers will be expected to have a basic level of competence in using AI/ML tools. These basic competencies are a focus of DEAP and DigComp 2.2.

5.1. Students Learning AI

The research is somewhat limited in terms of the student perspective of learning AI. This is perhaps understandable as the field is only emerging in K-12 (and arguably only recently emerging in third-level). There are some US and global initiatives such as AI4K12[16] that provide guidelines and resources. Much of the literature described in this paper focus on the tools rather than the student perspective or pedagogical approaches. It is likely that the tools are advancing faster than their use at this stage. This is somewhat common when new technologies emerge. There is often a gap where the first focus is on "getting things working", and pedagogical discussions only happen later. The clear shortfall of research and resources in AI/ML for K-12 is compounded by a lack of mature policy. While the teaching of AI/ML is in its infancy at school levels, the EC now expects basic and advanced competencies in these area. These competencies could be delivered in a cross curricular approach. This however, will most likely be delivered via computing teachers. This puts an extra onus of responsibility on teachers to possess AI/ML competencies. Both computing and non-computing students will experience some form of AI/ML education in the coming years, and a significant amount of research is required to understand how to best approach this.

5.2. Teachers Teaching AI

Increasingly, teachers in non-core computing subjects (who often do not have computing backgrounds) will find themselves teaching some aspects of AI/ML as well as using AI/ML tools. The current literature is sparse with respect to teacher professional development and learning, something likely necessary to enable non-computing teachers to confidently and effectively deliver AI/ML education. The little research that has been conducted focuses on tools and measurements of trust. This aligns with many of the EC's policies working in this area, such as the guidelines for AI and Data in Education and Training. Adding to the foundations of DEAP and DigComp 2.2 that will be needed to build basic competencies for students in AI/ML, teachers will also soon be facing the EC Guidelines on AI and Data in Education and Training. This new policy means that all teachers will need to have some basic competencies in AI/ML tools that they use. For teachers that are closer to core computing, advanced competencies will be needed to deliver formal AI/ML education – an area that requires much more research.

6. Conclusion

Despite dramatic interest in the last few years, this study has found that there is currently a notable deficit in research on pedagogical approaches, tool use, and even agreement on what AI/ML topics should be taught in schools, and how. The relatively slow pace of progress in research and policy lies in stark contrast to the rapid development of advanced tools that have the ability to deliver real change in real classrooms in present day. Additionally, the pool of content knowledge that teachers may be expected to teach and students may expect to learn grows with continued political, corporate, and media attention paid to AI/ML. Policy makers are making efforts to keep up with this ever changing landscape. However, the reality is that teachers and students will need to grapple not only with content knowledge and tools that are advancing at a ferocious pace and have great potential for misuse, but will need to do so within contexts that are falling under the remit of new and unfamiliar policy. There is urgent need to ensure that above all else, teachers are not only equipped with the competencies required to teach AI/ML effectively, and to use AI/ML tools safely, but are kept up to date as the landscape rapidly advances. Research plays an important role in this process. It is imperative that research on AI/ML education in schools keeps the responsibilities of teachers and the best interests of students central.

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Notes

[1]https://digital-strategy.ec.europa.eu/en/policies/expert-group-ai

[2]https://digital-strategy.ec.europa.eu/en/policies/european-ai-alliance

[3]https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai

[4]https://digital-strategy.ec.europa.eu/en/library/assessment-list-trustworthy-artificial-intelligence-altai-self-assessment

[5]https://ec.europa.eu/transparency/expert-groups-register/screen/expert-groups/consult?do=groupDetail.groupDetail&groupID=3774

[6]https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0206

[7]https://education.ec.europa.eu/focus-topics/digital-education/action-plan

[8]https://education.ec.europa.eu/sites/default/files/document-library-docs/deap-communication-sept2020_en.pdf

[9]https://publications.jrc.ec.europa.eu/repository/handle/JRC128415

[10]https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0022&from=EN

[11]https://eu.eventscloud.com/file_uploads/406af1d6d35813b61af830b70a00c20b_D2-1-DIMITROVGeorgi-NewDigitalEducationActionPlan-EasternPartnership-04122020-v3.pdf

[12]https://education.ec.europa.eu/focus-topics/digital-education/action-plan/action-8

[13]https://openai.com/

[14]https://openai.com/blog/codex-apps/

[15]https://github.com/features/copilot

[16]https://ai4k12.org/

Computing Education in (the digital) Transformation

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1. Computer Science, Computing Education, and the Digital Transformation

Since its beginnings, computer science (CS) is characterized by continuous change, that throughout history is reflected in the corresponding K-12 subject. CS started out as a specialized subdomain within other disciplines such as mathematics and electrical engineering, focusing on hardware and computers. Correspondingly, one of the first approaches for an independent subject in K-12 education, developed about 50 years ago, was called "Rechnerkunde"[1]. It aimed for an understanding of the hardware of real data processing systems by focusing on mathematical-technical fundamentals such as circuits and architecture (Frank & Meyer, 1972). Over the course of the recognition of computer science as a new scientific discipline and its triad of theoretical, technical, and practical computer science, CS attained more and more influence on everyday life, in particular, due to the spread of personal computers. Once more, this change became apparent in the notion for a K-12 subject as well, as algorithms and applying programming to solve real-world problems gained importance. Going further, especially in the last decades we see a much broader perspective of what is considered CS. Fields that investigate the interactions between CS and society – thus going beyond the solely technical aspects of CS – are more prominent than ever. This was also reflected in computing education, as educational standards for CS such as the German "Bildungsstandards" (Brinda et al., 2008) or the American CSTA K-12 computer science standards (Tucker, 2003) included respective competencies.

Currently, another evolution for computer science and its significance in our daily lives is taking place: CS is the key driver of the so-called digital transformation that leads to fundamental changes in the way we communicate, use technology, work, or gather information. Furthermore, we see a growing importance of CS in science and research as a consequence of these developments. This becomes most apparent when looking at different application fields: disciplines such as bioinformatics, legal informatics, business informatics, geoinformatics, and the digital humanities investigate discipline-specific issues building upon CS approaches (Riedel, Streit, Wolf, Lippert, & Kranzlmüller, 2008). The discussion on Computational Thinking is also partly rooted in the increased importance of CS in other disciplines (Csizmadia et al., 2015). However, this is not limited to specific areas. All scientific disciplines are significantly affected by the digital transformation, e.g. by new methods with simulation or data analysis considered as the third and fourth pillars of science, new topics that emerge, or new tools that are used to solve problems (Tolle, Tansley, & Hey, 2011). This is becoming increasingly relevant for K-12 education as well, as this shift in the scientific disciplines is also reflected in the corresponding subjects. In consequence, CS skills are also needed to address corresponding subject-specific phenomena (such as digital business models or the ethical implications of artificial intelligence) appropriately (Seegerer, Michaeli, & Romeike, 2022). For computing education, this raises the question of what computer science competencies everyone needs to deal with these changes in a responsible manner.

Typically, the term "digital education" is used to describe competencies necessary for participating in a "digital world". However, the debate in politics, media, and society as well as parts of the scientific community is mainly limited to a reductionistic understanding in form of "digital" or "media literacy". This way, phenomena in students' daily lives as well as the aforementioned changes in all K-12 subjects – which go far beyond using media – are not even remotely taken into account. Furthermore, the digital

[1] roughly translates to "becoming knowledgeable in the subject of computers", see `digitalkunde.info`.

transformation is an ongoing process. Technology – and education on how to use it – that currently is relevant, might be outdated in the near future due to this rapid and dynamic transformation. Therefore, it is crucial to identify and convey the time-independent underlying ideas, concepts, and principles of the digital world, that are based on computer science (Denning, 2004).

In summary, these developments result in an updated "mission statement" for computing education in consequence of the digital transformation: Computing education can be considered as the foundation for digital education and *aims at empowering everyone to understand the digital world and its phenomena as well as getting involved in shaping it* (see for example (Brinda & Diethelm, 2017)).

2. Implications for Computing Education

Like CS itself, computing education has to transform to meet this purpose. While already aiming at everyone and general education ("Bildung") in K-12 – and not just preparing professionals –, the significance of CS concerning the digital world has to be emphasized. This results in several challenges, that will be discussed in the following. Not all of those are necessarily new (focusing on ideas, incorporating the impact of CS, or constructionist learning in meaningful contexts). However, they gain importance in light of the digital transformation and for computing education as the foundation for digital education.

2.1. Embracing the socio-cultural impact of computer science

In the German discourse, the so-called "Dagstuhl triangle" (Brinda & Diethelm, 2017) forms a widely accepted model for digital education. It proposes three perspectives on digital phenomena or systems: A "technological perspective", considering how they work, a "socio-cultural perspective" questioning the interaction with individuals and society as well as an "user-oriented perspective", focusing on their creative and effective usage. Various approaches in other (inter)national contexts essentially emphasize similar perspectives using other terms or structures (Brown, Sentance, Crick, & Humphreys, 2014). Using this categorization, CS curricula as well as the actual teaching in the classroom typically are focusing predominantly on the technological perspective – and thus "core CS" –, while the user-oriented perspective is mostly attributed to media education. In contrast, the socio-cultural perspective is widely overlooked. However, only a profound understanding of underlying CS principles of digital systems and phenomena enables a well-founded analysis and evaluation of possibilities, limits, and mutual interdependencies of technology, individuals, and society. Therefore, to fulfill its role as the foundation for digital education, computing education has to emphasize and explicitly include this perspective in a truly multi-perspective manner – despite being challenging and possibly out of teachers' comfort zone.

2.2. Re-evaluation of traditional content according to the requirements of the digital world

Furthermore, typical CS curricula and content areas have to be evaluated from the perspective of digital education. The topic of data management provides an impressive example of this: Traditionally, content such as database systems, the relational representation of data using tables, modeling entities and their relations, or database queries in SQL dominate respective CS curricula. However, from the perspective of digital education, a lot of (new) ideas gain importance, such as metadata, redundancy, consistency, synchronization, data analysis, big data, or data security (Grillenberger & Romeike, 2014). At the same time, this also reflects the development in CS, as the scientific field of data management evolved in the last 15-20 years from a focus on relational database systems towards areas such as NoSQL, data mining, data stream systems, Big Data, and so on. This calls for a re-evaluation for other "traditional" CS content in the classroom as well. The example of data management shows, that it's not solely about the underlying technology used to store or handle data, but the overall way we gather, process, and share data is influenced by the digital transformation. These skills are, what learners need in a digital world.

2.3. "New" content in consequence of the digital transformation

In recent years, more and more areas of our lives are heavily influenced and shaped by artificial intelligence (AI) and machine learning, in particular. As a result, an increasing number of CS curricula are being extended to include the topic of AI. This case is thus exemplary for "new" topics in the CS classroom to address the challenges of the digital world, as besides increasingly powerful computing systems only a steadily growing volume of data as a consequence of the digital transformation enabled those technological advancements. The same goes for other topics such as data science, cyber security, or embedded ubiquitous systems. For computing education research, this provides a huge challenge: To prepare students for their lives in the digital world in the long term, those competencies that are fundamental to those subject areas need to be identified, without falling for short-lived technological developments or "hypes". For artificial intelligence, we propose a curriculum of learning objectives, based upon the Dagstuhl-triangle, taking into account the significant impact AI has on society and allowing for merging them into CS curricula (Michaeli, Romeike, & Seegerer, 2022). With quantum computing, another possibly disruptive technology that promises opportunities, but might also pose new challenges for our society is already on the horizon (Seegerer, Michaeli, & Romeike, 2021). To fulfill its role as the foundation for digital education, computing education has to make the corresponding fundamentals, applications, and implications of these technologies accessible. Once more, this also emphasizes the reflection of the development of CS within computing education.

2.4. Focus on abstract ideas, not technological details

In computer science, abstraction allows for making supposedly hard things easy – even trivial – and in consequence focus on things such as how CS impacts society instead of details of implementation. To achieve the goal of preparing students for their lives in the digital world, so that even in 20, 30, or 40 years they are able to have a certain level of understanding of situations and phenomena surrounding them, we have to provide them with very abstract ideas and principles of technology. Nevertheless, in computing education, there is still the tendency to emphasize the most elementary aspects. An infamous example for this is the binary system – in perfect tradition of the "Rechnerkunde" approach from 50 years ago. Obviously, teaching has to make things concrete and work on tangible examples. However, understanding binary won't allow students to explain phenomena from the digital world – not to mention getting involved in shaping it. Therefore, the ultimate goal is the abstract idea, such as representing information digitally. However, the binary system or even the conversion in other systems is often a prominent content of CS curricula. This holds also true for currently discussed topics such as AI, where a lot of curricula and teaching concepts focus on a single perceptron or neural networks. In contrast, putting the spotlight on abstract ideas such as supervised learning and its applications for classification or regression problems (that can be implemented e. g. using neural networks) might actually help to understand phenomena in the students' daily lives – independent of technological details.

2.5. Not just what but also how

While talking a lot about *what* to teach and incorporate in curricula, the perspective of *how* to do this is equally important. Again, AI will serve as an example, as numerous unplugged approaches are typically used for introducing this topic to students. Those approaches are a great teaching method and particularly suitable as they allow for focusing on the actual abstract idea and not technological details in a fun and engaging way. However, they do not allow for actively and creatively designing computational artifacts and experiencing their effects. Given the goal of empowering students to not just understand but also be involved in shaping the digital world, staying on an understanding level doesn't suffice. Therefore, teaching must go further than unplugged and enable students to create and construct (see (Michaeli, Seegerer, Kerber, & Romeike, 2022) or (Jatzlau, Michaeli, Seegerer, & Romeike, 2019) for examples that show that this doesn't require low-level technological details such as programming pitfalls). Furthermore, the digital transformation provides an abundance of interesting opportunities for contextualizing CS concepts in a personally meaningful manner which should be harnessed for education.

2.6. Provide the basis for digital education in other subjects

As pointed out, as a consequence of the digital transformation CS is influencing other K-12 subjects as well. Therefore, as long as there is no mandatory coverage of CS skills in K-12, computing education has to provide teachers of all subjects with necessary competencies that go beyond "technological knowledge" for using media in their classroom (Koehler & Mishra, 2009), but allow them to assess and address the CS-related changes to their subject (Döbeli Honegger, 2021) and respective new topics, methods, and tools. To this end, the developments in other subjects with regards to necessary CS competencies have to be investigated together with domain experts, for example by examining changes in the corresponding scientific disciplines(Seegerer & Romeike, 2018). Such an approach will not result in a "CS light" course, but a specific selection of necessary competencies in a heavily contextualized manner (Seegerer et al., 2022) that emphasizes the specific requirements for digital education.

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Practices in Computer Science Education: It's what we do that matters!

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1. Introduction

Computer Science has been rapidly evolving from its beginnings as an emergent subfield of mathematics to a full-fledged discipline that not only combines theoretical and engineering approaches, but also imparts its methods as a means of scientific inquiry on almost all other sciences (Wing, 2008). During this rapid development (just remember Facebook's motto "Move fast and break things", Naughton, 2022), the "body of knowledge" has also expanded considerably. Transferring such a fast-paced discipline into a slow-moving system like K12 education requires new ideas of how to keep curricula relevant for "long enough" (Lodi & Martini, 2021).

At the same time, demands towards computer science education have been a moving target as well. Beginning from learning goals centred around algorithms in the 1970s, the basic use of computers and typical applications, the safe use of the internet and more were considered a relevant part of computer science education in schools (cf. Forneck, 1990). Most recently, demands for including ethics and broadening participation have been voiced, in particular also internationally (Kallia & Cutts, 2021).

To avoid that computer science curricula simply are a list of learning goals picked from the shifting body of knowledge and shifting demands towards the subject at their time of writing, several attempts have been made to provide didactic models or common ideas / themes / foci on computer science in K12 that help with selecting relevant topics. Historically among the first in Germany, there are:

- *Systems oriented approach*: Guided by the idea of modelling computing technology as a socio-technical system, computer science education should focus on deconstructing and constructing such systems (Magenheim, 2001).
- *Information oriented approach*: Based on the triangle of information, matter and energy, computer science is the science associated with the study of information. Computer science education should focus on information transforming processes (Breier & Hubwieser, 2002).
- *Fundamental ideas*: This approach, void of a specific normative idea of computer science education, proposes to align teaching with (theoretically derived) fundamental ideas of the discipline that structure and connect all topics (Schwill, 1994).

Other STEM-subjects have chosen similar approaches to the fundamental ideas in order to structure curricula in K12 (both in Germany and internationally), even though these sciences typically are far less prone to change than computer science. For natural sciences, there are "basic concepts" (e.g. energy for chemistry), for mathematics there are, for example, "guiding ideas" (e.g. "functional dependency").

In this article, I will argue for another way of structuring topics in computer science education by placing more emphasis on the activities (i.e. practices) and less on the topics themselves. To this end, first the relevance and prevalence of practices for and in learning computer science are described, followed by an analysis of existing approaches and curricula for CS and other STEM subjects both for Germany and the USA are and finally a discussion of the findings.

2. Practices in Education

Following the idea of "legitimate peripheral participation" of (Lave & Wenger, 2011), practices are a set of defining (i.e. common) activities or actions within a domain that serve as a way to form a shared identity of practitioners (*community of practice*). By participating in the authentic actions of e.g. a computer scientist, learners can come to identify themselves with CS, it can create a "sense of belonging" – much more so than a shared body of knowledge would. Even more fundamentally, the (constructivist) theory of *situated learning* postulates that learning is always tied to a social context and as such may even prove to be inseparable from the actions performed during learning.

It is also in particular skills that are deemed most relevant for educating the future generations – the so called "21st century skills" that are not tied to a specific body of knowledge. For example, the 2030 learning compass of the OECD (OECD, 2019) suggest basic literacy (e.g. numeracy) and a set of transferrable skills (e.g. creativity or problem solving) as relevant goals of general education. Instead of seeming them as a by-product of subject-specific teaching, subject-specific teaching should focus on these skills explicitly, using examples of their own domain and thereby introducing relevant subject-matter knowledge.

2.1. Practices in Computer Science

Historically, Papert has suggested *constructionism* as a computer science specific approach to constructivism that specifically encompasses the construction of artefacts (e.g. a programmed robot) as a way of learning, even going as far as postulating a great potential for using computer science as a method to learn in other subjects based on this constructionist approach (Lodi & Martini, 2021). Others also have pointed out that the engineering approach that computer scientists employ is a perfect instantiation of constructivist practice and therefore especially well-suited for K12 education (cf. Forneck, 1990).

Looking at the didactic models presented above, the first two each focus on a very specific practice. The systems-oriented approach has the (de-)construction of systems as a focal point, whereas the information-oriented approach has modelling of information and processes as its central action. Even the fundamental ideas contain practices, with two of the three "master ideas" being "structured dissection" and "algorithmization". In Germany, also the theory of *Handlungsorientierung* has in the past caught attention within the computer science education community (e.g. Schubert & Schwill, 2011). In the same vein as Lave & Wenger's theory it requires learners to perform typical actions of a domain as a way of learning. Emphasis is placed on the authenticity and "completeness" of the action, even going as far as considering this to be more relevant than coverage and (scientific) rigor (cf. Schelten, 2000).

Most recently, the idea of *computational thinking* as a specific way of thinking that is assumed to be both inherent to computer science and relevant far beyond it has caught attention. Most often defined as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (cf. Lodi & Martini, 2021), i.e. a specific way of problem solving and therefore also a practice. Conversely, (Shute, Sun, & Asbell-Clarke, 2017)- based on a systematic literature review - identify several facets relevant for computational thinking that are all practices: Decomposition, abstraction, algorithms (used in the sense of designing algorithms), debugging, iteration (used in the sense of iterative refinement of a solution), generalization (used in the sense of transferring ones skills to other domains).

In summary, practices have always been present and relevant for computer science education and its didactic models and the idea of increasing diversity and improving retention based on a shared identity is also apparent in the research literature, yet there is not much evidence collected so far (Große-Bölting, Gerstenberger, Gildehaus, Mühling, & Schulte, 2021).

2.2. Practices in Current Curricula

The suggestions of the German Informatics Society (Arbeitskreis »Bildungsstandards SII« der Gesellschaft für Informatik e. V., 2016) for K12 computer science education in the federal states of Germany distinguish between content and process-oriented competences, the latter being divided into "modelling and implementing", "reasoning and evaluation", "structuring and combining", "communicating and cooperating" and "presenting and interpreting". Some of the competences in these areas are rather generic, e.g. "students evaluate their own or groups' work process and its results and draw conclusions for their future actions", others are more specific to computer science, e.g. "students test an implementation using given test cases".

Internationally, the K12 Computer Science Framework is a reference for K12 computer science education in the US (K12 Computer Science Framework Steering Committee, 2016). The framework distinguishes between practices and topics. The practices are partly similar to an iterative development cycle (practices 3 to 6 in Fig. 1) not unlike typical iterative approaches in software engineering. The others are more general practices that are similar to what is found in other STEM subjects (e.g. communicating about the subject). Again, there are specific competences for each of these areas, for example "evaluate whether it is appropriate and feasible to solve a problem computationally".

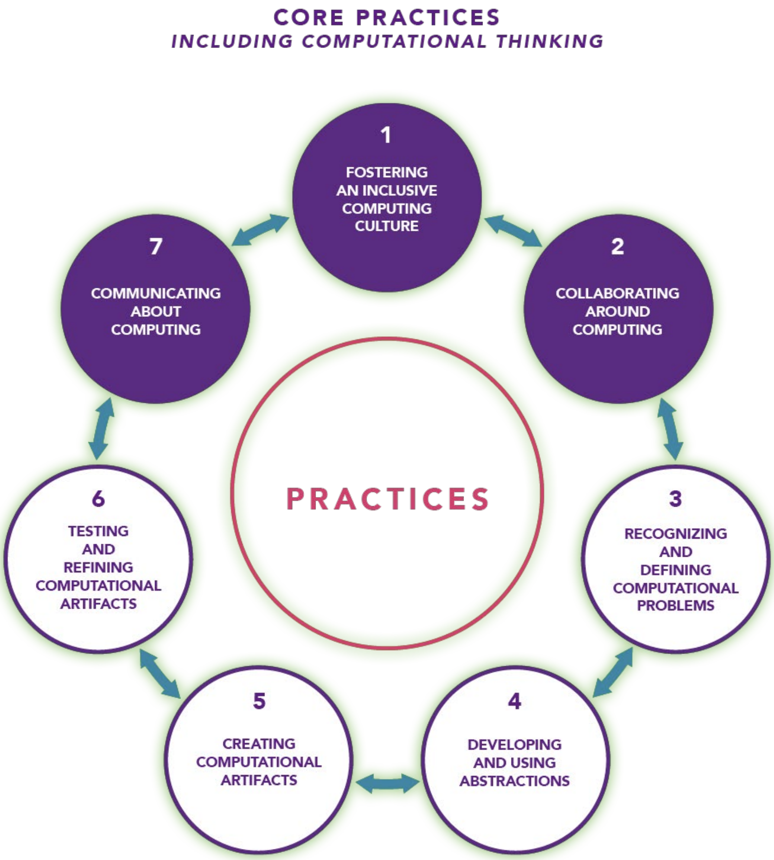

Figure 1: The practices of the K12 Computer Science Framework (K12 Computer Science Framework Steering Committee, 2016)

2.3. Practices in Other Subjects

For natural sciences in the German K12 system, there is a common structure of competences that distinguishes between competences related to content, inquiry, communication and evaluation (e.g. for physics: KMK, 2020). In particular, the competences related to scientific inquiry are what constitutes the practices of the natural sciences.

For science education in the USA, the National Research Council provides a framework that is built upon "disciplinary core ideas", "cross-cutting concepts" and "science and engineering practices" (Committee on a Conceptual Framework for New K-12 Science Education Standards). This encompasses not only scientific inquiry for natural sciences but also the design- and engineering-based practices, even including computational thinking.

For mathematics, specific competences are seen as a combination of one of the guiding ideas and one of several "general mathematical competences": Communicating, using symbolic, formal or technical mathematical elements, using mathematical representations, mathematical modelling, mathematical problem solving and mathematical reasoning (KMK, 2015).

Again, comparing this to the USA, the National Council of Teachers of Mathematics provides standards and principles for mathematics education in the US (National Council of Teachers of Mathematics, 2000). The standards are also divided into content and process-oriented aspects. The five processes that "highlight ways of acquiring and applying content knowledge" are: "Problem solving", "reasoning and proof", "communication", "connections" and "representations".

3. Discussion and Conclusion

Based on the preceding sections, there are three observations to be made:

1. Practices are relevant for learning and additionally offer a way of identifying with a subject. Placing more emphasis on them is also in line with modern approaches to education.
2. Practices have been historically present in various approaches to computer science education and are still present in current reference frameworks.
3. In contrast to other STEM subjects, in particular the natural sciences, there seems to be less agreement on what constitutes the relevant practices in computer science education.

By placing the emphasis of CS curricula more on the practices than on the body of knowledge, it will be easier to adapt the topics over time as the subject will no longer be defined by the – fast changing - "what" of the lessons but instead of the "how" that has been more permanent over the last decades. Still, skills need to be taught and trained embedded in topics and these need to be from computer science in order to provide an authentic learning experience for students. Also, following the idea of general education and literacy, a certain body of knowledge about computer science will remain relevant for future education.

Placing more emphasis on practices also requires us to identify what those constituent practices of computer science are and how me might adapt them to K12 teaching. In the models for computer science education presented above, there are three different, yet not fully distinct, approaches to determining relevant practices: 1) Singling out a small number of authentic practices that are then emphasized in the curriculum, 2) determining all "fundamental" practices and recurring on those and 3) focusing on a computer science specific way of problem solving as a core practice.

While the third approach is most compatible with the demands to teach transferrable skills - of which problem solving is a very central one - the first two are better suited to the idea of authentic participation in computer science in a K12 context. On the other hand, neither focussing on very specific practices nor representing the full width of fundamental ones might be good to foster inclusive community of practices as it may either convey a wrong image or overwhelm students that are not already committed to the subject.

There is, however, also a middle ground that should - in my opinion - be explored more deeply by the computer science education community: Focusing on a subset of *relevant* (i.e. *authentic*) practices that – taken together - capture at least the full breadth of the *engineering* approach inherent in (modern) computer science. This offers a contrast both to the problem solving that is central to (K12) mathematics and to the practice of scientific inquiry, central to the natural sciences. In other words, it would strengthen the unique part that computer science can offer for STEM education (see also the comprehensive framework of the NRC) and at the same time is well aligned with computer science itself and the 21st century skills that future education should focus on.

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“Digitalkunde” as a Challenge for School Development? A Proposal for Discussion

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1. Introduction

In Germany, media education is part of the educational mandate of schools. Educational policy agents like the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany (KMK) declared ten years ago: “Media literacy has become another crucial cultural technique alongside reading, arithmetic and writing“ (KMK 2012, 9). Further KMK strategy papers (2017, 2021) emphasise the phrases “competencies for a digital world“ and “digital competencies“. The term “digitality“ has been used in this context for more than ten years to refer to a “digital culture“ that is evident in newly emerging “economic, social, and cultural spaces“ (Zorn 2011, 196). The changes associated with this culture of digitality are a challenge for educational institutions. (KMK 2021; Schiefner-Rohs 2017, Zorn 2011). On the one hand, educational institutions must recognise digitisation's influence on many areas of life and work and create appropriate orientation and qualification opportunities (Kerres 2020). On the other hand, it is a matter of understanding digital artefacts and structures as elements that can be shaped and changed and making them tangible in schools (Irion 2020).

Despite these proclamations, the educational practice in Germany is somewhat disillusioning if you look at school conditions and processes (Eickelmann et al. 2019). Therefore it is not surprising that the scientific commission of the KMK highlighted the need for action in digitising the education system with their last report (SWK 2022). The need for computer science and teacher education is particularly emphasised (SWK 2022, 11-12).

This article discusses if “Digitalkunde” as a subject or the integrative teaching of digital skills could contribute to mastering these challenges. Therefore the scholarly discourses of “Digitalkunde“ should not be limited to content-related questions. It seems worthwhile to consider the implementation of “Digitalkunde” as a school development task.

2. Dimensions of School Development

The distinction of different dimensions can be used as a heuristic framework to consider “Digitalkunde” as a school development task. Following Schulz-Zander (2001) and Eickelmann and Gerick (2017), the article discusses five dimensions of school development: Instructional development, staff development, organisational development, cooperation development, and technology development.

2.1. Instructional development

The dimension of instructional development includes questions about subject-specific content, organisational formats, and learning culture within the classroom. With a focus on learning with and about digital media, the article distinguishes two fundamental perspectives. Using the phrase “learning with media", media are understood as (digital) tools. The central question is how effective their use is in teaching and learning situations (Herzig 2014) and how to use the potential to establish contemporary teaching and learning formats (Schulz-Zander 2001; Brägger and Rolff 2021). Using the phrase “learning about media", media are understood as digital technologies, practices and phenomena. Media is considered the subject of teaching and learning situations. From this perspective, researchers ask what content students should learn and how to develop competencies to act self-determined and responsible in a digitally shaped world (Vuorikari et al. 2016; Tulodziecki et al. 2021).

On a conceptual level, there are promising approaches to bring together computer science and media education ideas (Brinda et al. 2019; Döbeli Honegger 2017). However, for teachers and political decision-makers for school practice, corresponding considerations often appear abstract. For this reason, it seems worthwhile to concretise and translate interdisciplinary concepts such as the “Frankfurt

Triangle” (Brinda et al. 2019) as orientation knowledge for practitioners. Providing informed guidance makes it more likely that related ideas can be taken up for core curricula. At the same time, we need versatile reflections and contributions, like at this conference, on which current and concrete topics teachers should teach in the classroom. These are challenges for integrating “Digitalkunde“ as a single subject and an integrative approach.

2.2. Staff Development

Staff development encompasses “staff training, staff management, and staff promotion“ (Rolff 2018, 25). This article focuses on the challenges of staff development in the context of societal transformation processes of digitalisation. These questions concern content and competence-oriented goals as well as possibilities to reach these goals. Corresponding plans exist, for example, as competence models for media education (Tulodziecki 2012; Vuorikari et al. 2016). At the same time, the practice of teacher education on a university level and further and continuing education in Germany appears to be very different (Endberg et al. 2021).

The question of how teacher education and continuing education can approach the respective goals barely leaded to a transformative practice so far. This issue appears to be a problem for implementing “Digitalkunde“ as a subject. As for computer science education in schools, which is mostly taught as a specific subject, there needs to be more teachers with professional education. So “Informatik“ (cse) in schools is often taught by teachers who have specialised for different subjects. But the question also arises in an integrative approach because every teacher must have specific competencies. This task is not only school-specific but ultimately applies to all actors in the education system.

2.3. Cooperation development

In the sense of Schulz-Zander (2001), cooperation development encompasses support services and opportunities to promote cooperation between teachers within the teaching staff, enable networking between schools, and establish a partnership with institutions outside the school. A heuristic framework for describing “teacher collaboration in the age of digitisation“ is formulated by Drossel et al. (2020, 48) with a four-field table. They focus on teacher collaboration and distinguish “teacher collaboration (1) with and (2) without digital media about aspects of digitisation“ as well as “teacher collaboration (3) with and (4) without digital media not about aspects of digitisation.“ This framework already shows the possibility of investigating and promoting cooperation among teachers.

Suppose “Digitalkunde“ is thought of as a single subject. In that case, there are hardly any potential cooperation partners available within the school, analogous to computer science lessons, due to the limited number of hours. Establishing networks across schools seems to be a relevant task here. Suppose digital literacy is thought of as an integrative task. In that case, the question arises as to how the knowledge exchange among teachers can be promoted, e.g., through mandatory sharing of material or creating open educational resources.

2.4. Technology Development

The dimension of “technology development“ includes questions of technical equipment, access to hardware and software, and their respective framework conditions (Eickelmann and Schulz-Zander 2008). In this regard, there are technical issues (e.g., concerning the network, devices), ecological issues (e.g., energy consumption), economic issues (e.g., maintenance costs) and social issues (e.g., in the case of equipment for self-financed devices). On the one hand, the technical infrastructure is a necessary prerequisite for learning with digital media and the outlined possibilities for instructional development. At the same time, consideration of digital technologies also shows an enormous ecological footprint and pose an economic and social challenge (Grünberger and Szucsich 2020).

If “Digitalkunde” aims at enabling self-determined and socially-responsible action in a digitally influenced world, various questions arise for school outreach. To what extent should decisions for equipment and technical concepts such as “Bring Your Own Device“ (BYOD) or “Get Your Own Device“ (GYOD) be made by individual schools or school boards? Who is responsible for the administration and management of devices? The current practice in many German schools, where teachers are responsible for Level 1 support, hardly seems sustainable in light of the shortage of teachers and the increase in devices in schools.

2.5. Organisational Development

Organisational development encompasses organisational change processes that are accompanied by groups of people involved in terms of time and content. Rolff (2018, 17) describes an organisational development process as a learning process for people and organisations (Rolff 2018, 17). According to Rolff (2018) changes with implications for organisational development can start at different levels and include various aspects: e.g., the school program, the school mission statement, and team development. Prerequisites for organisational development are prior consideration of goals and structures, process and role awareness.

In this development field, questions arise, among others, as to what extent “Digitalkunde“ should also contribute to further developing the school's learning and organisational culture. This raises questions about rethinking school communication processes in a culture of digitality. At the organisational level, questions range from enabling hybrid parents' evenings to the culture of communication with digital media among teachers. In addition, the question arises as to how “digital literacy“ should bring new content into the classroom or can contribute to the transformation of the learning culture.

3. Perspectives for Discussion

It seems worthwhile to address questions of “Digitalkunde“ to prepare future generations for a self-determined and socially responsible life in a digitally shaped world. It seems particularly relevant that these considerations do not remain in scientific discourse but also represent an impulse for practice. The school development dimensions presented here offer a wide range of opportunities to think about, discuss and shape the discourse on “Digitalkunde“ practically.

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The Interdisciplinary Nature of Computer Science Education

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1. Introduction

On the occasion of the workshop "From Rechnerkunde to Digitalkunde – Talks on K-12 Computing Education Philosophy" we aimed to discuss the nature of computer science education (CSEd) and grand challenges that lie ahead for the CSEd community. Therefore we discussed in workshop groups different facets of CSEd nowadays, one of which is the appearance of computer science in the context and as a part of STEM education. The English acronym `STEM` stands for science, technology, engineering and mathematics, whereas computer science is included as an intersection, for example in the 'T' and 'E'. Recently the acronym expanded to `STEAM` to integrate arts as well, which seems to be logic in respect to multiple CSEd projects like 'Arts & Bots' (Hamner & Cross, 2013). The German equivalent for STEM is `MINT`, an acronym for mathematics, informatics, natural sciences and technology. In our understanding, STEAM or MINT education encompasses different subjects, which are closely connected to each other. Therefore, interdisciplinary modules can be designed to address phenomena, contexts, processes and competencies, which are part of involved disciplines. This connection between subjects makes it possible to analyze complex real-world problems (for example climate change) from different perspectives and can have a positive influence on the students' motivation because of meaningful contexts (Cetin-Dindar, 2015). This report briefly presents discussed contents, related literature and interdisciplinary STEAM projects to give an overview about the field. Afterwards, a few questions which arose in the workshop are presented and the workshop discussions are summarized.

2. Examples for Interdisciplinary Projects

In computer science education and related subjects many examples for interdisciplinary lessons or modules can be found. Especially in the context of physical computing the connection between STEAM subjects appears to be natural. One example is the project 'Arts & Bots'(Hamner & Cross, 2013), in which students construct meaningful artifacts with microcontrollers. Therefore, multiple contexts are presented on how to integrate computer science while constructing a theater, a historical figure or an anatomical arm. In the area of robotics we can also find interdisciplinary approaches aiming to combine STEM on the level of similar addressed competencies, for example in a survey that was conducted with teacher students (Schulz & Pinkwart, 2015). In the following paragraph this interdisciplinary module, which was recently held in a university course, is described in more detail.

Description of the interdisciplinary module: Data Literacy for Teachers. "Data Literacy for Teachers (Data Literacy Education) – an interdisciplinary module in the context of climate change" is a voluntary research workshop for all teacher students (independent of their subject) at the Universität Hamburg. This project was developed by the research groups of geography education and computer science education as part of the "Digital and Data Literacy in Teaching Lab".
The students attend the research workshop for two semesters to conduct a research project. The context of a research workshop is to investigated hypotheses in the context of weather and climate change. This format offers students the opportunity to design and experience small research projects in a practical way and to pursue individual research questions. For this purpose, the students construct and program their own weather stations with microcontrollers to record data during excursions to various parts of the city (for example to measure urban heat islands). The data obtained in this way is then analyzed,

interpreted and visualized using apps in order to be able to derive possible actions from it. The focus here is on urban climate issues. In this workshop on university level the students learn how to program and construct a microcontroller to collect climate data. It is planned to adapt this module for classroom use in schools.

A real-world, authentic and current topic is covered as context, which can increase student motivation (Cetin-Dindar, 2015) and can positively affect learning (Deci, Vallerand, Pelletier, & Ryan, 1991). The connection to STEAM/geography has the potential to introduce students to computer science who were not interested in it before. The course material has been published and is reusable (Kreinsen, Sprenger, & Schulz, 2022). The project presented is just one example of valuable interdisciplinary connections of computer science with other subjects. For the conference a discussion of factors for successful implementation of such modules in computer science education is important. For this purpose it is necessary to define requirements for the construction of interdisciplinary modules.

Designing interdisciplinary modules encompasses different challenges. One of which is the integration of two or more STEM subjects, where competencies in all of the subjects are enhanced. To show a realistic picture of the subject and to underline the value of interdisciplinary projects, it is important that non of the subjects are only seen as tools or general context. There must be a benefit for each involved subject.

The starting point for the discussion of the workshop "From Rechnerkunde to Digitalkunde" was the question: what are obstacles and chances of STEAM education for computer science education?

3. Discussion

3.1. STEM: where are the limits?

In the workshop we discussed if interdisciplinary projects in computer science are limited to STEAM subjects. We agreed that there are many contexts in which computer science phenomena should be discussed, for example in social sciences (Connolly, 2020), because computer science is nowadays highly affecting the daily life. One example is the influence of digital devices on students' lives, how students reflect presented information in social media and how the information is filtered.

Furthermore, in the original meaning of the German STEM equivalent, geography education is not meant or included in MINT. However, in geography education exist different areas that are closely connected to chemistry. This is one of many reason why geography education is not supposed to be excluded. In general, there is no need to define limits for the interdisciplinarity in the context of computer science. Overlaps with multiple areas are possible, because of the wide spread integration of technical tools and computer science methods. We could conclude, that we should make a bigger effort to search for commonalities instead of distinctions. To be successful with this approach it may be important to redefine the role of computer science, because it is oftentimes only integrated as a tool to solve problems. One integration of computer science could be in the context of systems thinking (Easterbrook, 2014). The idea is to shift the focus from a computational thinking approach, concentrating on problem-solving, to an approach closer to sustainability.

An other discussion in this context was, where to teach interdisciplinary modules in school, because there are clearly defined subjects in school. To tackle this point it is necessary to construct modules with a benefit for all involved subjects. In this way it might be possible to teach the modules in regular lessons. It is nevertheless important that teachers of the related fields get in contact with each other and make sure they are educated enough to teach in this field, to guarantee high quality education. Beforehand it will be necessary to construct and evaluate suitable material and to hand it over to the teachers.

3.2. Relation to Digitalkunde

One goal of the workshop "From Rechnerkunde to Digitalkunde – Talks on K-12 Computing Education Philosophy" was to identify grand challenges for computer science education, that should be tackled in the future. One grand challenge can be the problem-based character which can go hand in hand with interdisciplinary STEAM lessons. Problem-solving competences are very important in computer science and other STEAM subjects. Research on how to enhance the students' problem-solving skills is complex because of the lack of competence tests in many fields of computer science education. A lot of effort has been made in other disciplines to describe problem-solving processes (Klahr, 2000) in detail and to construct scaffolding, for example in natural sciences. Building on this established empirical research can be valuable for all involved disciplines.

Other challenges in computer science education are how to bring more diversity into computer science. One main solution can be the integration of a compulsory subject of computer science for all grades in schools (in Germany this is rare until now). For a long time there has been discussion on how to increase the motivation of girls for computer science. In respect to results regarding physical computing and e-textiles the students interest and participation can be increased in this context (Jayathirtha & Kafai, 2019). Because of the above mentioned approaches of STEAM modules in the context of interdisciplinary physical computing projects, a STEAM education approach could be part of the solution to bring more diversity into computer science.

3.3. Scientific Investigation

There exist promising literature for theoretical links between STEAM education (Priemer et al., 2020). However, empirical studies are needed not only to uncover interdisciplinary potentials but also to empirically investigate effects on learning outcomes such as subject-related competencies and networked knowledge in multiple disciplines. Interdisciplinary modules need to be constructed. Furthermore, validated test instruments need to be found or constructed to measure the outcomes. Afterwards a classroom intervention with experimental and control groups seems to be appropriate to evaluate the effects of interdisciplinary modules on students' competencies and connected knowledge.

Many obstacles seem to exist for conducting high-quality interdisciplinary research and to integrate it into schools. But when we clearly define the goals for this effort, it will be worthwhile for CSEd.

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Culturally Relevant Pedagogy: Relevant in K-12 computing lessons?

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1. Extended Abstract

At the Digitalkunde presentation, we would like to explore culturally responsive pedagogy in K-12 computing education.

Background and Context: Computing in K-12 is often noted as being hard to teach and hard to learn, with problems attracting girls and students from diverse backgrounds to the subject. Culturally relevant pedagogy (CRP) has been heralded as a general education approach for educators to address equity and diversity issues.

Aim: To investigate CRP in K-12 computing education.

Current objectives: Investigate K-12 computing teachers' uses of CRP in classroom teaching and how this might be influenced by CRP professional development (PD).

Method: To achieve our aim, we are working through a programme of studies investigating CRP in K-12 computing contexts. This includes four recent and planned research activities; further studies will follow. Our studies so far are:

1. Define what CRP is for K-12 computing by co-creating with computing teachers a set of CRP guidelines
2. Building on the guidelines, develop PD to introduce CRP for K-12 computing teachers, trial it, and discover teachers existing use of CRP (Workshop 1)
3. Discover what changes teachers make to lessons after the PD (Workshop 2)
4. Discover what impact the PD has on teachers' values and beliefs about equity and diversity and CRP (Follow up Interviews)

Findings: Our work is in progress, so far we have completed step 1 and are analysing data from step 2 and have scheduled step 3. For step 1

- A literature review of CRP has been completed (H. C. Leonard & Sentance, 2021)
- CRP guidelines co-created created with 11 K-12 educators (H. Leonard et al., 2021a)
- The process of co-creating guidelines described (H. Leonard et al., 2021b)
- Various research to practice artefacts have been created and shared e.g.a video about CRP in K-12 computing, a teacher facing blog [1]

For step 2, we have adapted the guidelines to produce a PD workshop and delivered this to 23 teachers across 10 schools. By August 2022, we will have analysed the workshop recordings and have more to share. For step 3, we have scheduled the follow-up workshop with schools to discover what resources

[1]https://www.raspberrypi.org/culturally-responsive-pedagogy-for-computing-education/

were created and delivered by teachers in response to the PD. By August 2022, we will have initial impressions of the responses. For step 4, we will be interviewing teachers in August and September.

Discussion: We have made significant progress in starting our research programme on CRP in K-12 computing education. However, our experience is situated in the context of the 11 teachers in England who co-created the guidelines, the 23 teachers attending PD workshops and the 7 researchers who have worked across these projects. Culturally relevant pedagogy is by its nature situated in the context that it is being used in and shaped by the bias of those involved. Therefore, importantly, any generalisation beyond that context should be questioned. At the Digitalkunde presentation, we would like to discuss our findings so far with researchers from other international contexts to discover what does or does not resonate. This discussion will support us in the development of frameworks for the topic. We are interested in exploring several potential theories, frameworks and models related to the field. A brief introduction of related research is outlined in Section 2.

Contribution of the presentation: The contribution of this presentation activity will be to add to the body of knowledge, for research purposes, about equity and diversity in K-12 computing education with a particular focus on culturally responsible pedagogy by comparing international perspectives.

Limitations of the presentation: The presentation's effectiveness will be limited by who attends the presentation, the background knowledge of participants, and how well the activities are run to enable all participants to share their perspectives.

Implications of the presentation: Supporting K-12 educators to address the inequity and lack of diversity in computing classrooms is a critical issue to address. Culturally relevant pedagogy is an emerging approach in tackling this issue. A presentation reviewing CRP research in K-12 computing education could increase interest in research activity in the field, improve the quality of research work, and increase the impact of such research.

2. Related Research

Since the 1990s, cultural relevance and responsiveness have been the focus of several key theoretical frameworks in education in the US. Culturally Relevant Pedagogy (Ladson-Billings, 1995), Culturally Responsive Teaching (CRT) (Gay, 2000), and Culturally-Sustaining Pedagogy (CRP) (Paris, 2012) are frameworks that highlight the importance of incorporating students cultures and identities into learning to ensure activities are meaningful to them and hence leading to academic success. These frameworks counter "deficit thinking" (Yosso, 2005, p.75) in relation to students from underrepresented groups and aim to address personal and structural biases in the education system that create barriers for these students from achieving their full potential.

Figure 1 – A culturally relevant teacher education pedagogy (CRTEP) (Major & Reid, 2017)

CRP and CRT have been explored in research in computer science teaching. Scott, Sheridan, and Clark (2015) developed a framework to create a computing-specific theory, Culturally Responsive Computing (CRC). CRC notes that digital and technological innovation is achievable for all students and increases when students are encouraged to reflect on their identities and cultures. The role of educators is to create a learning context that supports this reflection, that teaches students to understand biases in technological development and apply technology in innovative ways to tackle issues that are meaningful to them and their communities (Scott et al., 2015). CRC encourages a critical engagement with computing amongst all students, emphasising issues of equity and social justice and highlighting the vital role digital innovation has in addressing these themes (Scott et al., 2015; Madkins, Howard, & Freed, 2020).

For a different specific learning domain, science, science capital has become an alternative, or perhaps complementary, conceptual tool to CRP and CRT to address inequity. Formulated in the UK by Archer, Dawson, DeWitt, Seakins, and Wong,(2015), science capital builds on sociological theories of Bourdieu (1977) and his work on capital and social reproduction. Longitudinal research of 11 to 14-year-old students indicates the positive impact of families with more science capital (science-related knowledge, attitudes, experiences and resources) in supporting their children to see science in school and as a job as more "thinkable" (Archer et al., 2012). Despite potential benefits from family-generated science capital, classroom practice can serve to gate-keep subjects, such as physics, leaving girls feeling science is not for them (Archer, Moote, & MacLeod, 2020).

For teacher education, research has looked at how CRP and CRT can be introduced. For example, Major and Reid (2017) have suggested a participatory action research and culturally relevant teacher education pedagogy (CRTEP) including consideration of the history, the policy and the the place of learning (see Figure 1).

A further model that may be useful to teachers to support their professional development is pedagogical content knowledge (PCK) (Magnusson, Krajcik, & Borko, 1999). PCK is a familiar framework for researchers and educators. Recently PCK has been updated to incorporate teacher and student beliefs, orientations, prior knowledge and context and depicts how these can amplify or filter the intended

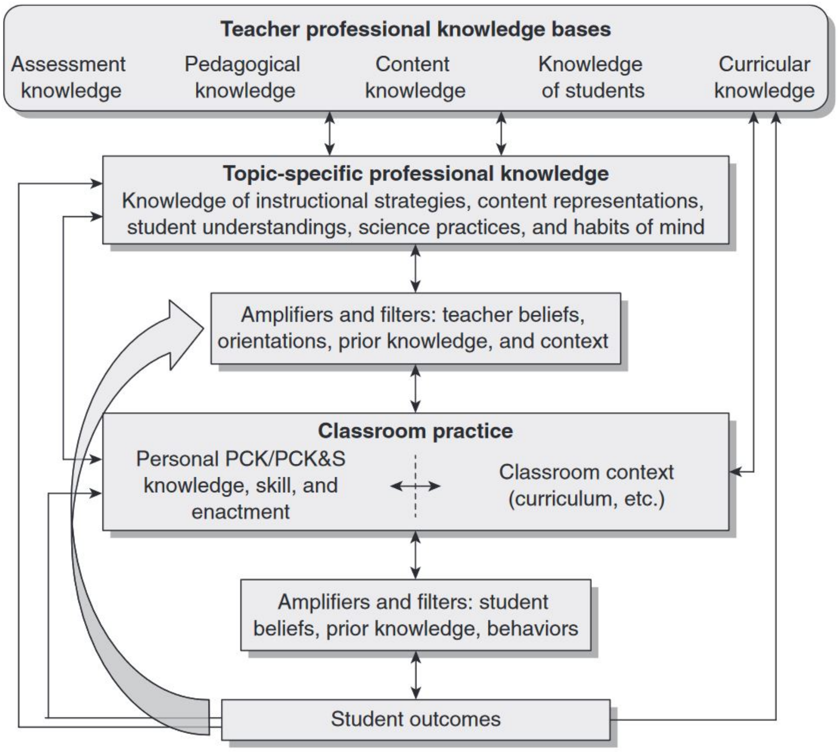

Figure 2 – Model of teacher professional knowledge and skill, including PCK and influences on classroom practice and student outcomes from (Gess-Newsome, 2015)

curriculum to classroom practice (Gess-Newsome, 2015) (see Figure 2).

We suggest CRTEP and the new PCK model may serve as interesting starting points to reflect upon CRP, CRT and science capital and how these frameworks might translate to computer science in different countries for teachers and their students from different social and personal contexts.

Time to discuss!

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Let's get started!

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From October 5th to 7th 2022, exactly 50 years after a workshop on the first educational approach targeting something one might today call Informatics in Germany, a workshop called Digitalkunde was held in Paderborn. In the 70s, computing devices, which where back then often called "electronic brains", became an important topic. Even though not being correct in all their assumptions, researchers at the time already foresaw that the new technology would transform many aspects of society and of individual human lifes. Since those early ideas of "Rechnerkunde" as a topic the general public should be taught about, the degree of digital penetration has changed significantly. Today, virtually everyone lives in a world full of digital artifacts and is influenced both directly as well as indirectly by the effects of digital technology. This pervasiveness of digital technology results in new challenges for the educational system, one result of which is a newly gained focus on subjects like Informatics, Computer Science and Computing (which for the sake of simplicity, I will just call Informatics in the remainder of this text.)

In our workshop on Digitalkunde, we tried to take a step back by basically asking the same question which has been asked those 50 years ago, namely what a curriculum targeted at making students be "kundig" in the digital world, would look like. The very German notion of being "kundig" can be translated in numerous ways. Two translations, which were proposed during the workshop, are quite helpful for my personal explanations of what we intended. It can best be understood by comparing it with other instances of "kundig". Being "ortskundig" means being able to know a place not necessarily to the degree one knows everything about it, but to the degree necessary to find one's way around. Similarly, being "sprachkundig" means being fluent in a language which, in a similar way, does not mean having a university degree in a language and therefore knowing every peculiarity but being fluent in the sense that one can use the language in a way which allows one to use it not only in standard situations but flexibly in numerous and even unforeseen situations. Being "digitalkundig" in this sense would hence mean not being versed in every minuity of Informatics, which would factually mean being a computer scientist oneself, but knowing one's way around in the digital world and being able to handle digital artifacts fluently. The required set of knowledge, skills, and competencies for being "digitalkundig" would go beyond just knowing how to use things but also would allow one to reflect on its usage and application both on a personal and on a societal level.

The question now is whether this "Digitalkunde" is just a broken-down version of Informatics. If this were so, one could teach something like "Digitalkunde" by just extracing the essence from existing Informatics courses – an approach which is clearly behind many Informatics curricula for children of all ages. I would like to argue that this approach falls short of what is actually the issue when becoming digitally fluent or knowing one's way around in the digital world. A specific utterance made during one of the discussions of the workshop really stuck with me. Unfortunately, I do not remember who made the comment, but someone called Digitalkunde "Computer Science for the rest of us". At first, this might sound quite belittling. However, a very similar utterance, namely "The computer for the rest of us" was actually the slogan of Apple computer when introducing the Macintosh in the middle of the 1980s. Without trying to exaggerate what the Macintosh contributed to the world of personal computers, what the slogan was indicating surely was not that a "computer for the rest of us" was somehow less sophisticated, less useful, or less powerful. What made it be "for the rest of us", was not it being something lesser but in some cases something more or at least something quite different. Using the Macintosh definitely required fewer knowledge about things like hardware addresses, command line statements, and, in general, less of what seemed to be necessary knowledge before, but at the same time, it introduced completely new concepts like the notion of files as documents and directories as folders, of window handling and of graphical user interfaces in general. The user interface afforded new ways of using the computer and required a new set of skills and knowledge needed to "know one's way around" to use it "fluently" or to be "kundig".

In my understanding, Digitalkunde actually is indeed "computer science for the rest of us" in this sense. It is not unrelated to what is typically considered Informatics but it is not a mere subset of it, as it also highlights specific aspects of the digital world which lead to specific knowledge, skills and competencies beyond classical Informatics. Without making it explicit, most computer scientists or Informatics researchers already use this knowledge frequently. As computer scientists, we all are often consulted by friends and family when they are having trouble with their digital devices. Most of the time, we can indeed help them with their problems but when we question ourselves what piece of knowledge it is we have put into practice which they lack, or which skill we have which they do not, it is often not at all easy to put into words. Furthermore, when reflecting on it, we have to realize that this knowledge and these skills are nothing we explicitly acquired in any Informatics course, neither at school nor at university. We have picked it up somewhere, it emerged when interacting with digital devices and when acquiring general knowledge about the digital world in magazine articles, internet forums or in discussions with pears, but it was almost never taught to us in the classical sense. This kind of knowledge, which makes us "digitalkundig" is not unrelated to what we know as professional computer scientists, but it definitely goes beyond that. There hence is more to it than what "general informatics" would have to offer.

What do I mean by "general informatics"? When having a look at what we teach in the first semesters of an Informatics bachelor, the canon of content is way more stable than the notion of the presumably fast-changing science of Informatics might suggest. Students learn how to model problems; they implement those models and thereby learn how to solve problems using programming, they are introduced into the processes of professional software development, learn the basic of digital electronics and of basic algorithms and data structures. Today, this canon is often complemented with the basics of machine learning and data science. This basic cannon of contents and its associated methods and skills are quite thoroughly mirrored in school curricula in Germany and many other countries. What is taught at the university level is also taught at school in a broken-down fashion, even for younger children.

Informatics education recently has found itself a buzzword which promises to guide its contents and goals. The term "computational thinking" was made popular through an opinion article by Janet Wing and has since gained traction resulting in numerous interpretations, some of which we have covered in the workshop. A maybe somewhat simplistic but rather accurate characterization, which explained the concept to me, was that computational thinking presumably means thinking like a computer scientist and this thinking in turn presumably means identifying problems in the world and in consequence solving them with means and methods of computer science, i.e., by modelling, programming, constructing hardware and so forth. Such an interpretation I would consider questionable by itself, as by far not every computer scientist does work this way, but let us, for the sake of the argument, define this kind of "computations thinking" as that set of knowledge, skills and competencies a computer scientist indeed has. Teaching this knowledge, these skills and these competencies can indeed have a lot of value as it would enable pupils to use computers to solve real world problems with means of computer science. It makes Informatics as a subject, programming as a skill and computing devices as tools means they can use for their own purposes and interests. This interpretation is very much inspired by what my dear colleague Sven Hüsing is developing as "Epistemic Programming", where pupils use means of programming to explore their world according to their own interests. Learning about computing in this sense is very valuable, as long as we take the interests of pupils actually seriously instead of just using them as a trojan horse with the hidden purpose of just teaching the same old content without any relevance to those learning it.

This being so, when referring to "knowing your way" and "being fluent", computational thinking can hardly be enough, as it does not focus on the existing digital artefacts inhabiting the pupils' world. It would not enable them to tackle the issues of their digital devices and it would not enable them to combine different existing artifacts of the digital world in a way they serve their own purpose better. It would not help them to understand what is happening behind the scenes when typical interactions with digital artifacts are made. It would not enable them to realize that digital artifacts are the way they are not because they necessarily have to be that way but because they have been designed that was as the consequence of complex interrelations in the past. Computational thinking in the way sketched above can, when done well, make the foundations of "general informatics" accessible for everyone but it lacks a lot of what is needed for "computer science for the rest of us".

An example can help to illustrate this: WhatsApp, or rather the phenomenon of sending a text message to a group of friends using WhatsApp. The approach of computational thinking here would not be helpful to begin with as we are not in the situation of having to identify a problem in the world and subsequently solving it with means of computer science. We do have a real-world desire – the desire to send some piece of information to a number of people – and we do already have the means to do so. If computational thinking were the gauge to whether something is considered Informatics, this particular phenomenon would not be Informatics– and indeed many computer scientists might agree with that verdict. Nevertheless, one cannot dispute the fact the part of a competent, self-determined way of "finding one's way around" would require a lot of knowledge, skills and reflective potential when using apps like WhatsApp. Can "general computing" contribute to this? Sure, Informatics covers many of the architectural aspects behind what happens when sending messages using WhatsApp. Communication protocols, encryption, or data encoding in general surely are something a computer scientist would learn eventually but this knowledge would be detached from actual phenomena and would mostly neglect what all of that means for the individual, how it impacts society, and how interactions by individuals and interrelations with society have shaped the digital world in such a way that products like WhatsApp even support end-to-end encryption. Such questions are among the important ones to be "kundig" but they are not what computer scientists typically deal with professionally.

Digitalkunde as "computer science for the rest of us", in my argumentation, hence needs to be more than "general computing". This could mean that it would constitute a subject of its own. Indeed, in discussions here at the department, I have often spoken in favour of such a new subject, often even stating that we should get rid of Informatics as a mandatory subject. To keep the record straight, I was never intending to prevent anyone who is interested in Informatics from learning it, and I do believe that getting a low-threshold introduction into it, be it by "computational thinking" or preferably by concepts like Epistemic Programming, could or even should be part of education for everyone. All this is not the issue. What is indeed the issue is the "for the rest of us", i.e. which additional subject matter there is and how to convey it. If one would embrace the associated questions, cover them in curricula and still call the resulting courses Informatics, the school subject Informatics would emancipate itself from the scientific discipline of Informatics. I would very much appreciate that. If history turned out this way, it would be the ideal result and actually be something that other subjects have gone through decades ago. However, utterances on our own workshop have clearly shown that calling it Informatics means that the kind of "general informatics" we already know is seen as the starting point and what is indicated as Digitalkunde ends up just being a perspective on "general informatics", having the alleged fundamentals of computing always looming in the background. In this sense, developing something new might be a good vehicle for the development of a curriculum which could serve the purposes laid out above. It would also bridge Informatics with disciplines like media education which in part already knows way more about what is necessary for our goal. It would less likely end up in a somehow disguised informatics course in the creation of which some others were allowed to also include minor parts. I therefore think developing something new could be the easier way, while transforming our existing subject of Informatics should perhaps be our final goal.

Let's just get started!