From TPaCK to DPaCK – Digitalization in Education Requires more than Technical Knowledge

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Introduction

The Challenges of digital transformation in STEM education are discussed on many levels of the educational system. Up to now, political initiatives (DigitalPakt Schule, 2019) and guidelines of the German Standing Conference of the Ministers of Education and Cultural Affairs on education in the digital world (KMK, 2017) have set a financial and generalized framework from a predominantly media education perspective. In contrast, there are still few concepts considering the specific subject-related and content-driven potentials and challenges of technology-enhanced learning in teacher training programs. For coordinated pre- and in-service teacher education and training, however, these models are crucial to provide a professional and evidence-based framework to decide for relevant knowledge and competences that are particularly important for STEM teachers. According to the KMK the competences in the digital world (KMK, 2017) include the transfer of knowledge beyond the subjects: on the one hand every teacher is expected to possess basic knowledge in the field of digitalization and the related technology. This, as provided also in the DigiCompEdu-model (https://ec.europa.eu/jrc/en/digcompedu), includes the ability to select digital education and training material based on deeper educational reflection, to design and to distribute it. Knowledge and skills should be applied reflexively,to create and to assess learning processes in an adequate way considering contemporary (digital) technology. On the other hand teachers should be used to apply transfer strategies facilitating students competence development competence development for students possible. Thus the expected profile of future teachers consists of general pedagogical content knowledge (Shulman, 1987) and its technological enrichment or - according to the SAMR-model (Puentedura, 2006) - technology-based transformation of teaching and learning.

A well-known model to describe this specific and essential teachers' professional knowledge is the TPaCK-model (Technological, Pedagogical and Content Knowledge, Koehler, Mishra & Cain, 2013). It illustrates and relates the *Technological Knowledge*

(Technologisches Wissen, TK) to the PCK areas mentioned by Shulman (1986) as an intersectional model (Fig. 1, detailed description of this model is provided as online supplement to this article). One intersection, the *Technological Pedagogical Content Knowledge (TPaCK)* (Koehler, Mishra & Cain, 2013), seems to be particularly crucial. The *Technological Pedagogical Content Knowledge* is understood as educational knowledge integrating technological tools in subject and content teaching.

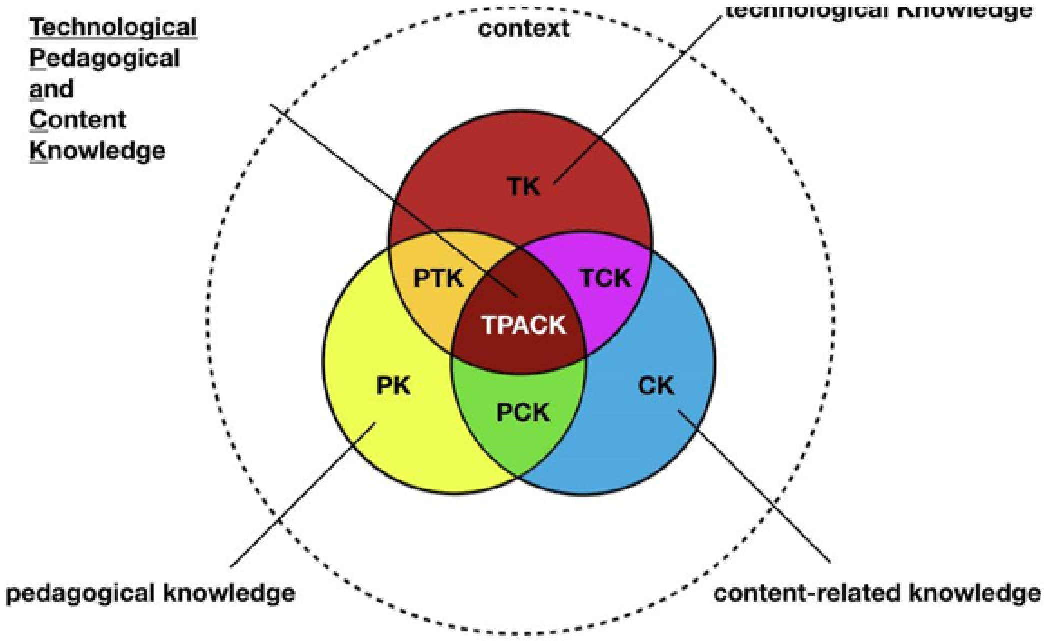

Figure 1. TPaCK-Model (Koehler, Mishra & Cain, 2013)

Content knowledge itself is an important foundation for teachers to act professionally – but it is not enough. The concept of competence (e.g. Weinert, 2001) includes not only mere knowledge and skills but also the willingness and motivational readiness to actually use them in various situations. One of the variable situations In the field of digitalization is the inclusion of techniological progress requiring the constant and ongoing professional development. This, for example, can be anticipated by the following question: “Does it make sense to have students write blogs in STEM class?” To answer this question it is obvious that TPaCK is necessary. Relating the question to an actual teaching topic, it is primarily inevitable to analyze learning potentials in the context of literacy, of the writing or designing a webblog against the background of a certain topic area. One must be willing - first mentally - to engage in such a teaching scenario, to confront critical considerations to added value for the subject learning of the pupils, to analyze specific tasks and aids. 21st century teaching and learning (EC, 20017) considers the challenges and potentials of a digital transformation highlighting the need of an adequate training to increase specific facets of teachers’ professional knowledge include technology in STEM teaching.

Challenges of Digitalization – Professional Knowledge in Reply to Digitality

Technological knowledge on its own does not meet the needs of digital transformation processes of the recent past and near future. Problem solving and responsible decision-making in everyday life intertwined with digital components goes beyond pure technical knowledge and must take into account problems and risks of technical solutions as well as developments triggered by the use and usability of communication systems in social and cultural areas. Those developments equally influence the individual thinking and acting: Stalder (2018) argues that digital technology reorganizes how people thing and act: For instance, information is no longer institutionally filtered (e.g. by newspaper editors), it is available to everybody without social or cultural filters and each individual conected to the internet becomes a publisher.The linking of information and its unmanageable quantity lead to "changed practices of filtering and thus orientation" in a "chaotic sphere of information" (ibid., p. 10), so Stalder.

Since this kind of structure and handling of information also influences the perception of reality and learning, four terms are essential to define the requirements for teachers' professional knowledge:

1. digitality,
2. referentiality,
3. community and
4. algorithmicity

and their features, which are explained in detail below.

The term digitality is a neologism of the words digital and materiality/reality (cf. Stalder, 2016).The area of action and perception in people is therefore extended by digitally transmitted spaces. Stalder (2016) differentiates referentiality, community and algorithmicity as basic features of digitality: referentiality encompasses the creation of a separate reference system, according to which an individual organizes the encountered information and experiences. It starts with drawing attention to particular information. But every post in social media (e.g. posts in facebook, pictures on instagram and the associated reactions), for example, creates an image reflecting the common interests of a social group sharing it. This commonly sustained frame of reference stabilizes meaning, generates options for action and and allows purposeful access to resources. The world of food and fitness youtubers and influencers might be a good example: Here, sensory connections are generated which indeed seem conclusive for the audience and followers (in some cases up to 5 million followers!), but usually lack a foundation when inspected from a scientific perspective. Many myths are currently emerging about scientific phenomena, in which social media activity about chemtrials for instance, are only the top of the iceberg. To bring back order to the unmanageable flood of information, filters are necessary which are provided by algorithms: analysing individual search and surfing behavior on the internet, preferences and interest of a single person is detected easily and precisely this information is offered with preference. The knowledge about this algorithmicity on the other hand is crucial for individuals to asses the information provided by a social group and to categorize it in sense of referentiality.

Those processes of change must be acknowledged within STEM teaching, because both the social discourses as well as the planning and design of educational processes will be significantly shaped by the, multi-perspective reflection of digital transformation and the processes of cultural change linked to it. From an educational perspective, many learners are not only to be adapted to the societal changes, but must also be put into position to design those processes (Kammerl 2015, Kerres 2018).

In addition there is another aspect: even STEM research creates and is visibly making use of a methodological spectrum (e.g. data mining in large databases) affected by digitality which also challenges teachers' professional knowledge. Another example is "in silicio research", in which entire living systems are digitally modeled and used to gain knowledge, such as the simulation of dendritic networks, population dynamics or biochemical simulations.

Pivotal companions of learning processes in the sight of a digital transformation are well educated teachers, who should be able to establish a digital-analoguous balance within educational contexts. Considering the process of cultural change outlined above the already mentioned TPaCK- model (Koehler, Mishra & Cain, 2013) falls short and should be expanded by the perspective of digitality enabling to look at pedagogical and scientific problems densely interrelated with referentiality, community and algorithmicity. A description of the TPaCK-model and its components is provided in the online supplement of this article. Below, a model will be developed according to the goals set by the KMK standards, after which digitally literate and responsible acting students shall be educated. Digital literacy is understood as a diversity of partial abilities and skills to use and design digital spheres including all technical, social and political components (Beck et al., 2018). The learners should thus be capable to use digital platforms appropriately and self-determined, to detect and avoid the concomitant risks, to maintain appropriate contact and to pursue their interests constructively (CMGT, 2019). At the same time educational systems and teachers should take on the potentials of the digitality's communicative practice for learning processes and make use of it. For this, teachers must have corresponding professional knowledge to take on digitality's communicative potentials and, consequently, topromote digitality-related competences in students (cf. competences in the digital world). For this reason the existing TPaCK- model should be extended by the aspect of digitality.

The "*Digitality-Related Pedagogical and Content Knowledge*"- Model (DPaCK): The Extension of Technical Knowledge Through Digitality

The perspective of digitality reveals that the technical change, which could be easily experienced by everyone on a daily basis by the means of, for example, the handling of certain devices and systems, shows less observable alterations on a societal, communication-theoretical or social level. The fact that online shopping is now technically possible anytime and anywhere has resulted in side effects that go beyond logistic and changed purchase behavior and must be critically evaluated by ecological (movement of goods, demolition of returns) as well as societal (the emergence of a problematic low-wage sector for logistics companies) aspects. Furthermore, through rating systems in online shops and video portals new forms of exchange emerge, which are often more relevant for the selling of products than traditional marketing measures or test reports in professional magazines. Not only delimited or virtual worlds are created like, for example, game worlds or simulations. Digital systems and realities (e.g. assistant systems with huge data pools, so-called "Big Data", digital images of persons for the determination of credit ratings) are rather interacting and interfering to such an extent that "the digital" and "the analog" connect (Baecker 2017, Kerres 2018). This connection of digital and analoguous reality and the resulting facets, goes beyond a pure technical digitalization. The extended understanding of digitality and digitalization needs appropriate skills like social, systemic, semiotic knowledge in the matching scientific context to be able to assess options in decision-making situations, to appraise after-effects and to act competently and deliberately. In this way, for example, the self-concept of adolescents is also constituted mirroring the body images and life concepts shared in the social media (cf. Klapp & Klötter, 2019) Therefore an increased prevalence of developing psychological disorders increases throughout permanent social comparison (e.g. Lup, Trup & Rosenthal, 2015). But also the public perception of challenges of the 21st century like, for example, climate change depends to a large degree on visual communication in social media (Wang et al., 2018).

Hence, the task is not only to provide scientifically proper arguments, but to reflect the target groups' collective reference frame – in this case pupils – for educational communication processes.

Based on an incomplete, pure technical perspective of the TPaCK-model, the first extension necessary seems to be the reflection of the socio-social, cultural and communication-related challenges of the digitality concept (Fig. 2). Since digitality transmitted through the algorithmicity contains all aspects of the technical knowledge as a foundation for further deliberations, it is useful to replace the technical knowledge with digitality knowledge. This way the listed challenges for this area of expertise can be portrayed without loosing the "TK" aspects of the TPaCK-model of to Mishra et. al (2013).

As a result, facets of digitality are taken into account, for example social, societal or ethical aspects, which are then linked to the respective intersections of CK and PK.

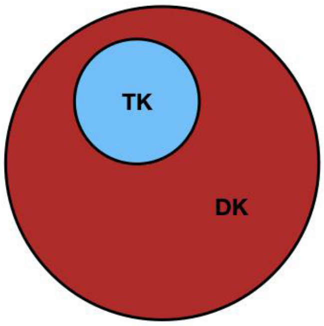

Figure 2. Relation of Technological Knowledge (TK) and Digitality-related Knowledge (DK)

The substitution of the technological knowledge with digitality-related knowledge also results in new intersections with the areas of Shulman (1986), analogous to the TPaCK-model (Fig. 3).

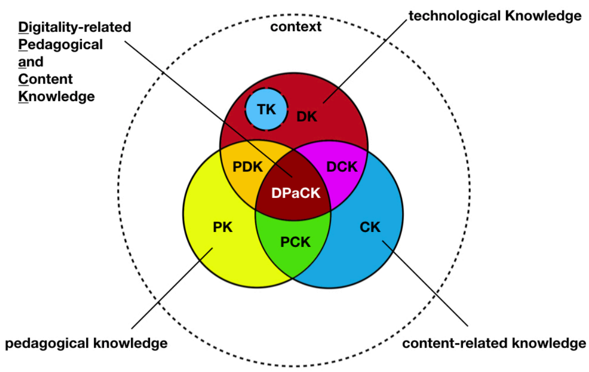

Figure 3. The DPaCK-Model: Extension of the TPaCK- Model of Koehler et al. (2013) with Aspects of Digitality

In addition, however, there is digitality-related analytical competence based on these areas of knowledge (Fig. 4, see also section 5 below). Not least, this competence helps at a meta-level to keep professional knowledge stocks up to date in the sight of advancing developments through corresponding review and evaluation. In the following, the areas of digitality-related professional knowledge, which is a central prerequisite for digitality-related analytical competence, are described in more detail:

- Digitality-related knowledge (DK) encompasses the digitality knowledge about the handling of technologies. This includes all aspects of the original technological knowledge (Koehler, Mishra & Cain, 2013) extended by the aspects of digitality that go beyond technical knowledge.

Examples: In a culture of digitality people need not only an understanding of mechanical procedures and algorithmic processes, but also competences of interaction in altered cultural spheres. The usage of digital technologies for thinking, working and handling processes equally demands competences to the utilization and selection of new forms of digitality. For example, learning with explanatory videos in science lessons (beyond educational or pedagogical knowledge, see below for more information) requires not only technical mastery of the camera, but also skills in the cinematic design of information units and in the opportunities of communication in the discourse systems linked to the publication (forum discussion, referencing, remix).

- Digitality-related and pedagogical knowledge (DPK) encompasses the intersection of digitality-related knowledge and the understanding of recent concepts to design approaches for training and learning processes.

  Examples: Like this, teachers have to reflect and consider in what way, for example, income-dependent effects can occur in the classroom when choosing digital-technical educational resources. This results, for example, into a BYOD concept (bring your own device) problem, if it comes to new forms of bullying ("You don't have an iPhone!"). In fact, this form of bullying exists already for some time, but it obtains a greater relevance given the fact that the student is forced to reveal that he/she does not have the latest smartphone due to the application planned by the teacher. Another example to be mentioned are the changes of symbolic systems and technologies in learning contexts as well as the concomitant altered communication forms in educational processes. Explanatory videos, for instance, facilitate not only the individual perception (e.g. individualizing of learning pace and sequence) but also flipped classroom scenarios (Seibert, Kay & Huwer, 2019). In addition, the use of animation software, innovative visualization formats and machine learning or learning analytics allows the design of adaptive, multimodal and multicodal learning environments. Designing customized and tailored learning environments necessitates teachers' knowledge of digitality that goes beyond DK and TPK.

- Digitality-related and content-related knowledge (DCK) includes the intersection of digitality-related knowledge and scientific knowledge or scientific methods of the subject with regard to the handling of technologies.

  Examples: The trisomy 21 blood test, which would not be possible without digital devices allowing quantitative PCR (polymerase chain reaction), has triggered a discussion, by changing abortion decisions, about terms such as "selection", "discrimination against the disabled" and the right to live with a disability. Individual medicine orrisk rates in health insurances would not be possible without digitalization in research and diagnosis and would lead to the question which consequences digital techniques entail. Public scientific databases e.g in genomics or climate research are essential resources for researchers all over the world, but they are also considered as pandora's box related to data storage and analysis issues in the public perception. Techniques like CRISPR/Cas as key for designer babies, selective medicine, special insurance plans based on genetic testing and data mining, data recording of the driving style in automobiles with integration of big data algorithms imply how intensively resulting societal questions related to the economic exploitation within the digital transformation processes should be debated with an informed and scientific background. Those examples show that in this area the professional element joins the digitality-related knowledge.

Digitality-related pedagogical and content-related knowledge (DPaCK) encompasses die intersection of digitality-related knowledge, pedagogical knowledge and content knowledge. It therefore creates the foundation for the design of subject-specific teaching and learning processes with technologies. Examples: For instance, the answer to the question, if it is useful within a specific educational content to make students write blogs needs DPaCK, because not only the digitally supported scientific method of a subject needs to be reflected, but also its combination with the content structure of the subject topic. The know-how, when and with which methodological setting it is useful to motivate students using a digital tool to solve a mathematical problem (e.g. the phase of exploring the properties of a geometric figure around a dynamic geometry system or phase of outsourcing a complex transformation to a computer algebra tool) would be another example.

Suggestions for Teacher Education and Training

STEM teachers are challenged on the one hand to keep up with the subject-specific and content-related dimensions of digital transformation in their educational disciplines, on the other hand they must reflect rapidly changing individual and societal media practices in the lives of adolescents when they are planning educational processes and learning opportunities (Allert & Richter, 2017). Considering the different scientific subjects' competence fields formulated by the KMK (2004) it is useful to offer commensurate occasions of reflection from the perspective of digitality within teacher education and training. The model provided in figure 3 gives an orientation to organize these occasions and to derive distinct goals for pre- and in-service teachers' professionalisation .

In addition, the model provides a foundation for the interdisciplinary exchange and collaboration within STEM education, media education and educational sciences. Not least of all, an orientation potential emerges for practice-oriented research of STEM teachers' professional knowledge. In return, the results can help to develop the digitality-related education and teacher training.

For example, in the competence area "knowledge acquisition", the methods of digital research (e.g. molecular modelling in the subject chemistry) are to be taught as well as the associated effects for each scientist and the epistemological consequences: Scientific theory occupies itself with what "science is and could be" (Frank 2003, 289) and therefore with knowledge principles, methods, goals and results of scientific research (Kornmeier, 2007). New methods, enabled by digitalization, are shifting the goals and intended results of science and in that way require a new ethical consent of scientists for which limits. So it becomes necessary, especially in the competence field "assessment" to orientate on professional content-related and ethical arguments, as well as to reflect on the effects of individual and social media practices.

In response to the question what precise consequences for the design of (STEM) class looks like, a critic reader will determine at this point at the latest that those challenges are difficult to be mastered; for sure, the interactive whiteboards installed in schools all over Germany can only be a desperate attempt to keep up with the speed of digital transformation. But how can the university teaching in science education assume responsibility and consider the concept of digitality, as well as the integration of rapid technological developments in the different disciplines? It remains to be answered here as well, how a inter- and trans-disciplinary collaboration between media education and educational sciences can be realised in order to meet this challenge in a coordinated and interconnected manner. Several development and research projects have currently been initiated at national and international level to address these challenges and they will deliver insights for educational design and teacher education in the next few years (e.g. the "TPACK 4.0" project as part of the state initiative digital@bw).

The DPaCK model offers an approach for discussion to STEM teachers to conceptualize a framework for educational design in the context of digitality. Building on this, the model offers a systematic-conceptual foundation for Educational-Design-Research (McKenney & Reeves, 2018) in the field of diagnosis (e.g. acquisition of individual competency profiles), as well as for the development of harmonized curricula (e.g. obligatory mediation of DPaCK in teacher training studies).

Consequences for Scientific Discussion

The DPaCK-model encounters ambiguous challenges: On the one hand it considers the concept of digitality which reflects highly dynamic changes in society and culture. This is an evolution of its ancestorical TPaCK model widening the perspective of digitally enhanced STEM-teaching. On the other hand a fixed model is counteractin exactly the dynamical nature of the digitality concept. Against this background, the present model can only be used as baseline and it serves as starting point for discussion in the community of STEM educators. Finding a balance between structure and openness, a constant exchange between teaching practitioners and STEM education research is needed to succeed in the change process. We would also like to discuss whether socio scientific issue could be another dimension of knowledge.

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References

Allert, H. & Richter, C. (2017). Culture of digitality instead of digital education revolution (Kultur der Digitalität statt digitaler Bildungsrevolution). *Paedagogische Rundschau*, *71*(1), 19-32.

Ball, D., Thames, M.H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special?. *Journal of Teacher Education, 59*(5), 389–407.

Baecker, D. (2017). How is digitization changing our thinking and our way of dealing with the world? (*Wie verändert die Digitalisierung unser Denken und unseren Umgang mit der Welt?)* In R. GLÄß & B. LEUKERT (Eds.), *Handel 4.0: Die Digitalisierung des Handels – Strategien, Technologien, Transformation*, 3-24. Berlin, Heidelberg: Springer.

Beck, R., Greger, V., Hoffmann, C. et al. (2018). Digital maturity. An analysis of the ability of citizens in Germany to constructively and confidently deal with digital spaces. Final Report of the National (Digitale Mündigkeit. Eine Analyse der Fähigkeiten der Bürger in Deutschland zum konstruktiven und souveränen Umgang mit digitalen Räumen. Abschlussbericht des Nationalen) E-Governement Kompetenzzentrum. https://negz.org/wp-content/uploads/2018/06/NEGZ-ISPRAT-Studie-Dig-M%C3%BCnd-Abschlussbericht.pdf (13.09.2019)

BMBF (2019). Administrative Agreement DigitalPakt School 2019 to 2024 (Verwaltungsvereinbarung DigitalPakt Schule 2019 bis 2024), https://www.bmbf.de/files/19-03-15_VV_DigitalPaktSchule_Wasserzeichen.pdf (15.09.2019)

CMGT (2019) http://www.cmgt.uni-leipzig.de/projekte/digitale_muendigkeit.html (23.09.2019)

European Commission. High Level Group on Science Education, European Commission. Science, & Economy. (2007). Science education now: A renewed pedagogy for the future of Europe (Vol. 22845). Office for Official Publications of the European Communities.

Frank, U. (2003): Some reasons for the revival of scientific theory (Einige Gründe für die Wiederbelebung der Wissenschaftstheorie). in: Die Betriebswirtschaft, *63*(3), 278-292.

Kammerl, R. (2015). Media education - an educational offer in which media literacy comes out the back? (Medienbildung - ein Bildungsangebot, bei dem Medienkompetenz hinten rauskommt?) *Kinder- und Jugendschutz in Wissenschaft und Praxis*, *60*(1), 3-7.

Kerres, M. (2018). Education in the Digital World: We have the choice. (Bildung in der digitalen Welt: Wir haben die Wahl.) *denk-doch-mal.de, Online-Magazin für Arbeit-Bildung-Gesellschaft*, *02*(18). http://denk-doch-mal.de/wp/michael-kerres-bildung-in-der-digitalen-welt-wir-haben-die-wahl/ (31.09.2019).

Klapp, A. & Klotter, J. (2019). # Fitness vs. # BodyPositive - the different social construction of health on Instagram. Prevention and health promotion. (# Fitness vs. # BodyPositive – die unterschiedliche soziale Konstruktion von Gesundheit auf Instagram. Prävention und Gesundheitsförderung.) [online first, https://doi.org/10.1007/s11553-019-00708-5].

KMK (2017). Education in the digital world (*Bildung in der digitalen Welt*) https://www.kmk.org/fileadmin/Dateien/veroeffentlichungen_beschluesse/2018/Strategie_Bildung_in_der_digitalen_Welt_idF._vom_07.12.2017.pdf (15.09.2019)

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education*, *193*(3), 13-19.

Kornmeier, M. (2007). Science theory and scientific work. (Wissenschaftstheorie und wissenschaftliches Arbeiten.) Heidelberg: Physica-Verlag. DOI 10.1007/978-3-7908-1919-9.

Lup K., Trub, L., & Rosenthal, L. (2015). Instagram# instasad?: exploring associations among instagram use, depressive symptoms, negative social comparison, and strangers followed. *Cyberpsychology, Behavior, and Social Networking*, *18*(5), 247-252.

McKenney, S., & Reeves, T. C. (2018). *Conducting educational design research*. London: Routledge.

National Research Council Committee on Information Technology Literacy. (1999). *Being fluent with information technology literacy*. Washington, DC: National Academy Press.

Schier, A. (2018). Identities in digitality from “digial lifestyle” to “design your life”. Generation and political culture in the sign of changed living environments in Germany in the digital discourse in advertising. (*Identitäten in Digitalität vom „digial lifestyle“ zu „design your life“. Generation und politische Kultur im Zeichen gewandelter Lebenswelten in Deutschland im Digitalitäts-Diskurs in Werbung.)* Hamburg: Kovacs.

Seibert, J., Kay, C., & Huwer, J. (2019). EXPlainistry - Documentation, explanation and visualization of chemical experiments supported by ICT in schools. *Journal of Chemical Education, 96*(6), 2503–2509. doi:10.1021/acs.jchemed.8b00819

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Stalder, F. (2016). Culture of digitality. (*Kultur der Digitalität)*. Berlin: Suhrkamp.

Stalder, F. (2018). Challenges of digitality beyond technology. (Herausforderungen der Digitalität jenseits der Technologie. *Synergie. Fachmagazin für Digitalisierung in der Lehre*, *5*, 8-15.

Wang, S., Corner, A., Chapman, D. & Markowitz, E. (2018). Public engagement with climate imagery in a changing digital landscape. *Wiley Interdisciplinary Reviews: Climate Change*, *9*(2), 509.

Weinert, F.E. (2001). Concept of competence: a conceptual clarification. In D. Rychen & L. Salganik (Eds.), *Defining and selecting key competencies* (S. 45-65). Seattle: Hogrefe and Huber.

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