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Modelling Digital Competence by Combining Computational Thinking with General Learning Taxonomies

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Abstract: In the context of a rapid digital transformation, digital competence is now regarded as a fourth cultural skill complementing reading, writing, and arithmetic. We argue that a well-structured and sound competence model is needed as a shared foundation for learning, teaching, pedagogical diagnostics and evaluative schemes in the school system. Every competence model should build upon a consistent, theoretically sound framework for teaching and learning. We consequently develop a competence model for digital competence by drawing on the concept of computational thinking as well as on general learning taxonomies. By combining different knowledge and process dimensions with essential facets of computational thinking a cube model of digital competence can be constructed. Hence, we develop and substantiate a structure model for digital competence building upon the concept of computational thinking that goes beyond the existing frameworks only focusing on the subject-related context and present this for discussion. The next step would then be to supplement the structure model with specific learning objectives, so that developing approaches to teaching and learning digital competence has a sound basis.

Keywords: *Computational Thinking, Digital Competence, Competence Models, Learning Taxonomies*

Introduction

Digital education has gained in relevance in the past decades, ‘because of the progressive digitalization in schools, training, work as well as in coping with everyday challenges in a world, which is characterized by digital transformation’ (Senkbeil et al., 2019, p. 81; see also Ferrari, 2013; Brandhofer et al., 2019). Introducing digital competence in K-12 education has therefore become an important objective and various attempts have been made in introducing digital competence or related components into curricula (Rich et al., 2019). The concept of computational thinking (CT) has thereby become a common conceptual basis (for an overview see Grover & Pea, 2013, p. 40 f.). Practices of computational thinking as problem representation, abstraction, decomposition, simulation, verification, and prediction are fundamental to computing and computer science, but ‘also central to modelling, reasoning and problem-solving in a large number of scientific and mathematical disciplines’ (Bower et al., 2017, p. 54; see also National Research Council (U.S.), 2010). Additionally, research has been conducted in finding approaches to implement digital education in classes (see e.g. the systematic reviews on fostering CT-skills using Scratch by Zhang & Nouri, 2019; or on using robotics by Zhong & Xia, 2020).

Most of this research goes back to the working definition on computational thinking from Wing, who defined computational thinking as ‘solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science’ (2006, p. 33). There is a huge body of research on the concept of CT (for a recent systematic review see Tang et al., 2020). The definitions presently used vary (Bower et al., 2017; Eickelmann et al., 2019; Zhang & Nouri, 2019). Román-González et al. (2017) distinguish between three categories of definitions: first, generic definitions such as Wing's (2011), which focus on the thought processes involved in formulating problems and their solutions; operational definitions, which define CT as a problem solving process including formulating problems, organizing and analyzing data, abstraction, automating, identifying, analyzing and implementing solutions, and generalizing and transferring problem solving processes (ISTE & CSTA, 2011); and educational-curricular definitions in the form of frameworks for developing CT in the classroom and other educational settings such as the one by Brennan and Resnick (2012).

While the current definitions of CT used vary, they have in common to be made up by lists of dimensions included in CT (e.g. Palts & Pedaste, 2020). We argue that a comprehensive competence model for digital education on the basis of CT is needed as a shared foundation for learning, teaching, pedagogical diagnostics (as formative assessment practices, grading and development of teaching) and evaluative schemes in the school system. Developing digital competence in a fundamental and professional way requires a competence model, which describes and structures the manifold and specific demands. The present paper aims at developing a competence model for digital competence. Thus, we will first argue that models as a means to describe reality in general are more than mere lists (of content). We will consequently discuss competence models as a possible foundation for teaching, learning and evaluation. Based upon established definitions of CT, we will then develop a model of digital competence in two steps. We argue that first, the general dimensions of learning and teaching need to be discussed. Based on those, specific dimensions of digital competence can be integrated, so that a structure model for digital competence can then be proposed.

Constitutive Concepts

The Concept of Competence

In addition to reading, writing and arithmetic, digital competence increasingly gains in importance in relation to full participation in society (Senkbeil et al., 2019, p. 81). The term »competence«, originates from Latin competere (see https://www.etymonline.com) meaning to be sound, capable, applicable, relevant, sufficient, adequate, competent, admissible. White already described competence as early as in the 1950s as ‘effective interaction (of the individual) with the environment’ (1959, p. 317), giving ‘fitness or ability’, ‘capability, capacity, efficiency, proficiency, and skill’ as synonyms. In accordance with Sadler (2013, p. 13), we use the term competence for ‘what may be conceptualized as an integrated and large-scale characteristic, capability or attribute’, and the term competencies for ‘smaller-scale identifiable elements that contribute to such an attribute’.

Especially in central Europe, the definition by Weinert (2001) has become the central point of reference for the term competence (Wiesner & Schreiner, 2020a). Competences are ‘individually available or learnable cognitive abilities and skills for solving certain problems, as well as the thus connected motivational, volitional and social readiness and abilities to be able to successfully and responsibly use these solutions to problems in variable situations’ (Weinert, 2001, pp. 27–28, translation International Handbook of Curriculum Research). According to Weinert’s understanding, competence is ‘not directly observable, but can only be extrapolated from specific actions’ (Eder &

Hofmann, 2012, p. 72). Using competence-orientation as a didactical principle, the learners and the knowledge, skills and readiness they have acquired take centre stage (Ziener, 2016, p. 18 ff.).

Models Systematically Describe Reality

The term »model« originally was composed 'based on the French noun modèle' (Stachowiak, 1973, p. 129), which is derived from Italian modello and originates from Latin modulus. Modulus originally meant measure, scale, but also shape. By extending and further specifying the term, it gained the meaning of 'effigy of something as well as […] precedent for something' (Stachowiak, 1973, p. 129). A theoretical model stands as 'image' (Stachowiak, 1973, p. 131), 'gestalt' (Schaefer, 1992, p. 46) or 'indication' (Stachowiak, 1989, p. 219) for something else, makes phenomena comprehensible, and interdependencies accessible (Schaefer, 1992, p. 68 ff.; for details on theories and models see Wiesner & Schreiner, 2020a).

Generally, models don't capture all attributes, but only those, which seem relevant from the respective theoretical perspective (Stachowiak, 1989, p. 219; Wiesner & Schreiner, 2020a). Models are characterized by an 'element of elementariness, as only those characteristics of the archetype are included, which are important to the designer' (Saam, 2009, p. 517). Therefore, each model is always broader than the specific instance that it describes (Balzer, 1982, p. 10). Having said this, models are to be understood as 'solutions' (Greshoff, 1994, p. 126). Models always are theoretical constructs, which are used to represent an item or a process of the real world in their main features (Burkart, 1998, p. 478). Insight is 'ever "insight for whom" and "insight for what", even though the what-for component often remains without reflection' (Stachowiak, 1973, p. 57). Despite all the complexity that is inherent to the specific research objects 'scientific progress [consists] to a great extent also of pronouncing trivialities' (Maletzke, 1998, p. 58). Maletzke (1998, p. 56) interprets triviality as simplicity in order to be able to portray the real world in models and to make processes 'thereby comprehensible and viable'. Models capture reality 'always only from a certain perspective' (Bonfadelli & Jarren, 2001, p. 25) and are based on 'relationships existing between different components' (Balzer, 1982, p. 14). Decisions on the quality of a model are based on 'usefulness and fruitfulness in regards of the existing problem' (Bonfadelli & Jarren, 2001, p. 26). Therefore, models generally are 'neither true nor false' (Bonfadelli & Jarren, 2001, p. 26).

Three prerequisites for models can therefore be summarized (Schaefer, 1992; Stachowiak, 1973): (1) models are effigies of something, (2) models are simplifications, and (3) models are subject to pragmatism, they often are trivial, but always designed to serve a special purpose.

Competence Models as the Foundation for Teaching, Learning and Assessment

Structure models of competence aim at determining, which and how many different dimensions a competence comprises and how the different dimensions are interrelated. The internal structure of a competence can for example be determined by the cognitive processes that are required to master different demands, by different content areas or different forms of knowledge (Fleischer et al., 2013, p. 8). Hence, a competence model structures a competence according to competence dimensions.

The origins of conceptualizing competencies in the form of models can be seen in two major traditions; first, the work by Guilford (1956, 1959, 1967) in the context of modelling intelligence, and second, the efforts to establish a sound basis for diverse testing purposes by McClelland (1973) and later Shavelson (2013).

With the conceptual modelling of intelligence, Guilford (1956, 1959, 1967) established an important starting point for all competence models. Guilford's model discarded the idea of a hierarchy of intellectual abilities (Kail & Pellegrino, 1988, p. 39) and was designed contrary to a concept of a single intelligence factor. Guilford postulated 120 different intellectual abilities, which he arranged in three dimensions, which form the 'structure of intellect' (Guilford, 1956; see also Parr, 1984). Guilford's facet model opened up one dimension to differentiate knowledge and content ('content categories', Guilford, 1967, p. 61), a process dimension to describe mental activities ('operation categories', Guilford, 1967, p. 62), and a product dimension ('product categories', Guilford, 1967, p. 62), to show results or units to aim at. Thinking processes arise based on the knowledge and? the process dimension. Each ability is defined by its specific position on each of the three dimensions in every structure theory of intelligence (Kail & Pellegrino, 1988, p. 41).

A second important starting point can be seen in McClelland's work (McClelland, 1973), taken up by Shavelson (e.g. 2013). McClelland (1973) arrives at the concept of competencies by arguing that measuring intelligence is not a sound predictor for students' succeeding in their later professional lives. Instead of trying to approximate specific future demands by measuring intelligence, the competencies should be measured that will in fact be needed directly to fulfil future requirements. McClelland's concept of competence is a functional-pragmatic one, deliberately situating test situations in real-life contexts, but not further elaborating on the concept of competence as such (Klieme et al., 2008). In McClelland's tradition, competence modelling is predominately applied in the context of testing. As the major purpose is in many cases to conceptualize the construct to be measured in acceptance tests or selection processes (for several examples: Shavelson, 2013), a connection to acquiring competences seems unimportant in their work. Therefore, modelling competences is essentially discussed from a measurement perspective. Similarly, the Priority Program of the German Research Foundation ('DFG-Schwerpunkt') on competence modelling (Fleischer et al., 2013; Hartig & Klieme, 2006; Klieme et al., 2010) has a strong focus on measurement, using theoretical competence models predominantly as the basis for psychometric models and consequently the construction of tests (Klieme et al., 2008). The German Priority Program is situated in the context of national large-scale assessments in the school system with the purpose of measuring outputs of the school system in the form of student competences in fundamental subject areas of the school curriculum (Schreiner et al., 2020). The strong focus on the measurement perspective when conceptualizing a competence in form of a theoretical competence model brings forth problems in the use of resulting measures. By focusing on the measurement perspective when modelling the competences, the subsequent use of the assessment results by policy makers and particularly teachers and schools faces significant communication barriers. The terms used in modelling the competences for measuring purposes typically differ from the terminology teachers are used to and therefore need to be re-translated into the school terminology (Pant, 2013), so that results can become meaningful for teachers and schools and applied to their context.

We argue therefore, that conceptualizing a competence in form of a competence model should be situated much earlier in the process of teaching and learning, because 'a deeper understanding of learning and knowledge organization can contribute to designing curricula, preparing teaching materials and devising assessment standards that promote both students' development and their social needs more efficiently' (Csapó, 2010, p. 12). In accordance with Anderson et al. (2001), modelling competences can particularly support the description and design of teaching and learning situations by the following leading questions. By elaborating on them, we also aim at tackling the often neglected what-for component (Stachowiak, 1973, p. 57) of models.

The learning question

What is important for students to learn (particularly in the context of limited time resources for learning in schools) (Anderson et al., 2001)? The first question takes us back to curriculum development and policy decisions on the learning objectives of schools. '[E]ducators' interest is in teaching and learning processes that result in worthwhile knowledge' (Csapó, 2010, p. 13). Why do we want children to go to school? Csapó (2010) gives three possible goals for schools; (1) transmitting knowledge accumulated by scientific inquiry, (2) cultivating children's intellect and improving their abilities, and (3) prepare students for life outside of school. While in the history of education the weight between the three goals to decide on the contents of the curricula varied, in an optimal world, the three should be kept in balance. All three can be applied to argue why digital competence should be taught in schools in the 21st century. Developing a competence model of digital competence can subsequently support deciding on specific learning objectives to gain a notion about what the goals of teaching digital competence are supposed to be. The competence model serves the purpose of keeping the whole competence construct in mind, as it not only lists the different components the competence comprises, but also structures them. Thus, the competence model captures the relationships between the components and dimensions.

The teaching question

How is teaching and learning planned and implemented (Anderson et al., 2001)? The knowledge about the components of a competence and their internal structure is an important basis for planning teaching and learning. The competence model can give orientation, so that classes overall cover the whole width of the competence. It helps to keep balance between the components and supports a clear notion regarding the learning objectives.

The assessment question

How do we choose relevant assessment instruments and procedures in order to gather relevant information on students' learning (Anderson et al., 2001)? The third question targets the basis for pedagogical diagnostics in the form of formative assessment (Black & Wiliam, 2009) as well as for grading purposes. The clear idea of the learning objectives mentioned above serves first, as a basis for monitoring progress in learning through classroom assessment (by teachers, peers and self-assessment) in order to plan successive learning steps. Second, the competence model makes up a transparent foundation for summative assessment in the form of grades and certificates.

The alignment question

How do we ensure that the pursued learning objectives, teaching practices and assessment design are consistent with each other (Anderson et al., 2001)? The theory of learning and knowing (Pellegrino et al., 2001) discusses the interrelatedness of the triad curriculum – instruction – assessment. Another approach to connect intended learning outcomes, teaching/learning activities and assessment tasks is the concept of constructive alignment (Biggs & Tang, 2007). When learning objectives, teaching and learning as well as the instruments for formative and summative pedagogical diagnostics are based on a shared foundation in the form of the competence model, a solid footing for an alignment of these elements is laid down. The competence model serves as connecting element between goals, processes and evaluation. Regarding the context of CT assessment, Tang et al. (2020) stress the need to investigate a theoretical framework of learning and assessment.

Results: Developing a Model for Digital Competence

In the following, we put forward a model for digital competence. Modelling a competence requires two major components. The first element is a sound theoretical model of different levels of complexity in the demands, which can be independent of the specific competence. The second major element comes from the content-related structure of the competence itself. For the first requirement, we will draw on the taxonomies by Bloom et al. (1956) and Anderson et al. (2001), modelling the complexity of demands by introducing a process and a knowledge dimension. The second requirement will be tackled by drawing on existing frameworks of computational thinking as the content-related basis. Combining those two components will yield a three-dimensional competence model for digital competence.

Knowledge and Process as the Basis for Modelling Digital Competence

Aiming at conceptualizing a model of digital competence, Anderson's (et al. 2001) taxonomy is a valuable foundation, which can be broken down to four knowledge dimensions as well as six process dimensions. Every competence model should build upon a consistent, theoretically sound framework for teaching arrangements and contribute to describing and designing situations in regards to learning theory and didactics.

Learning objectives can be organized by four knowledge dimensions and six process dimensions according to the level of complexity in terms of a 'double relatedness' (Adler, 1930, p. 205). Phrasing learning objectives comprises according to Anderson et al. (2001) a verb to describe the process dimension and an object differentiating the related general knowledge dimension. The construction yields at first a two-dimensional framework resulting from the interaction between process and knowledge.

The knowledge dimensions build upon each other in terms of a continuum ranging from the concrete to the abstract. For example, procedural knowledge needs ‘a static, often even rather sound and solid basis’ (Baumgartner & Payr, 1999, p. 22), because without such a ‘static basis … learning procedures is [often] useless’ (Baumgartner & Payr, 1999, p. 22). ‘[C]onceptual knowledge can also be regarded as a higher, more complex level of factual knowledge’ (Wiesner & Schreiner, 2020b, p. 331), if declarative knowledge is meant, which constitutes a deeper understanding (Renkl, 2015, p. 4). The four knowledge dimensions differentiate according to Anderson et al. (2001) between factual (declarative) knowledge, conceptual, procedural and meta-cognitive knowledge (cf. Table 1). Conceptual and procedural knowledge therefore overlap.

Table 1

Knowledge dimensions (see Anderson et al., 2001; Wiesner & Schreiner, 2020b)

Knowledge dimensions	Description	Examples
Factual knowledge	static factual knowledge and explicit basic knowledge about specific issues and content; what can be reported upon (‘knowing that’)	isolated facts, terminology, specific details and elements
Conceptual knowledge	organized and networked knowledge and contextualized relationships; verbalizing and visualizing cross-links (‘knowing what, when, and where’)	classifications and categories; principles and generalizations; theories, models, and structures
Procedural knowledge	knowledge related to action and problem solving related to action and problem solving; verbalizing approaches to solving a problem (‘knowing how’)	procedures; techniques and methods; decomposing processes, criteria for the use of appropriate procedures
Metacognitive knowledge	knowledge about one’s own strategies; refection on one’s own learning; ability to judge; knowledge about the meaning of thinking or learning strategies; self-evaluation and control strategies (‘meta-knowing’)	observation, planning and regulating thinking and learning; attitudes and beliefs

As process dimensions, the well-founded concepts by Bloom et al. (1956) and Anderson et al. (2001) can be mentioned (cf. Table 2; see Renger & Wiesner, 2006). They also facilitate ‘a simplified distinction of learners in novices, skilled and experts’ (Wiesner & Schreiner, 2020b, p. 332).

According to Anderson et al. (2001), the processes are divided into six dimensions: remember, understand, apply, analyse, evaluate, and create. Building upon the description of the process in the form of a verb related to the supposed complexity in connection with a knowledge dimension, can-do-statements can be developed (Schreiner & Wiesner, 2019, p. 22). The wording results in a specific ability, e.g. the combination of »remember« as process and the knowledge dimension »factual knowledge« results in »being able to list something«. Researchers at the IOWA State University have developed a grid giving the distinct operation belonging to each combination of process and knowledge on the basis of Anderson’s (et al., 2001) taxonomy (cf. Figure 1). Connecting those two dimensions allows for nuanced descriptions of objectives and can-do-statements as starting points for competence specificities, however initially from a general perspective independent of the subject matter.

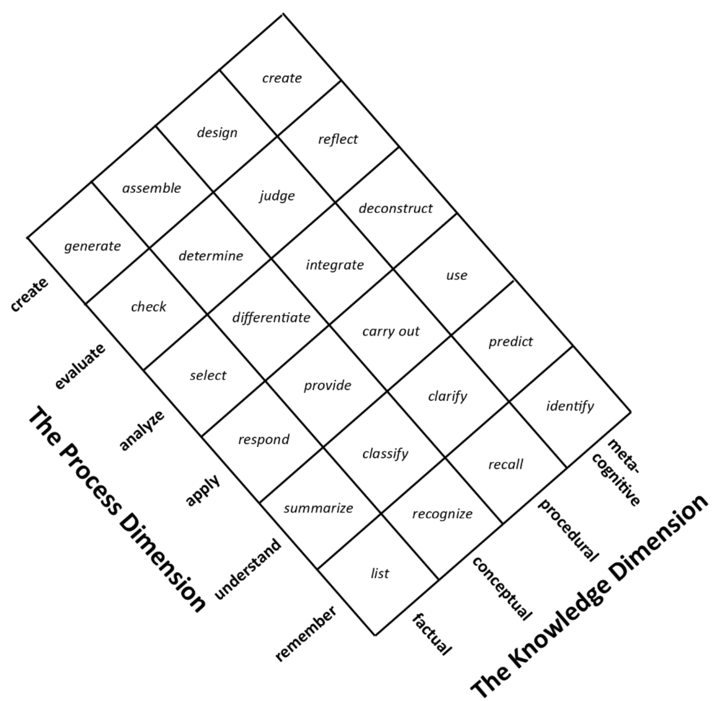
Table 2

Taxonomies for thinking and learning – a comparison between Bloom et al. (1956) and Anderson et al. (2001)

Bloom et al.		**Anderson et al.**	
Process dimensions	exemplification	Process dimensions	exemplification
Knowledge	state, remember, show, depict, select, replicate	Remember	recognize, retrieve, identify, select, repeat
Comprehension	explain, justify, describe, exemplify, interpret	Understand	summarize, compare, explain, exemplify
Application	integrate, calculate, generate, use	Apply	execute, operate, use, implement
Analysis	decompose, examine, verify, assign, organize	Analyse	differentiate, organize, attribute
Synthesis	plan, design, combine, develop, construct, create	Evaluate	discover, judge, criticize, check, monitor
Evaluation	assess, draw conclusions	Create	generate, plan, visualize, produce, construct

Figure 1

Grid-model of process and knowledge dimensions as the base area for a model of digital competence (cf. IOWA State University, 2012)



Computational Thinking as Specific Product Dimension

In section 3.1, a general basis has been laid for modelling competences. By combining the general foundation with a subject-specific dimension, a competence model for a particular competence can subsequently be formed. In the following, we present six facets of computational thinking as an enhancement of a model conceptualized in a national context (Wiesner & Schreiner, 2020a) in accordance with the model derived by Shute et al. (2017) based upon a recent literature review. These facets can then be added as the specific element (product dimension) in order to form a model of digital competence. Competences can be depicted in a cube model (Guilford, 1967), 'in order to show the interrelation between simpler and more complex aspects and levels of competence-oriented learning' (Wiesner & Schreiner, 2020b, p. 335). Thereby, it is possible to look at the manifold complexity levels from a holistic perspective (Baumgartner & Payr, 1999, p. 99).

The learning objectives of computational thinking (CT) are regarded as the new key competence of the 21st century (Ainley et al., 2016; Senkbeil et al., 2019; Siddiq et al., 2016; Voogt et al., 2015; Wing, 2008), as these competence aspects demand competently managing new technologies, which goes far beyond the analogue area of media competence. Computational thinking represents a cluster of both fundamental as well as interdisciplinary competencies, which enable solutions for complex challenges, tasks and problems of digitalization using digital media. Thus, digital competence grows into a fourth cultural skill, which also results in cultural resources (Bachmair et al., 2011; Kerres, 2017). Reading, writing, and arithmetic 'cannot be considered without digital technology, and this pervades all subjects and topics of life' (Kerres, 2017, p. 90; Wiesner et al., 2020).

In the context of modelling digital competence according to Guilford's concept (Guilford, 1967), we refer to 'computational thinking' (CT) by Papert (1980, p. 182, 1972) as well as the advancement by Wing (2006, p. 33, 2008). Thus, CT is used as the product dimension of the model, representing the specific structure of digital competence, which depicts the subject-related contents as products. Thinking like a computer is not paramount, but meeting digital challenges and solving digital tasks and problems is (Wing, 2006, p. 35).

CT combines competencies, 'which comprise phrasing a problem, collecting and analysing data, abstracting, modelling, algorithmic thinking, developing solutions, using digital tools, displaying data, disaggregating problems in sub-problems, and automation' (Senkbeil et al., 2019, p. 99). Thereby, CT is about focusing on problem solution and thinking strategies of general relevance, in order to comprehend the relationship between sequential and parallel processes of algorithms, modelling as well as formalizations of the digital learning environment. The procedures and relationships are not inherent in 'reading, writing, arithmetic' (Kerres, 2017, p. 85) as 'cultural skill' (Kerres, 2017, p. 85) 'go far beyond using hard- and software' (Senkbeil et al., 2019, p. 101).

Computational thinking consists for learners of a conglomeration of a multitude of competencies with direct reference to digital media including sub-competencies, techniques and strategies. Taking up the structure proposed by Shute et al. (2017), CT can be characterized by the following six design elements. The facets of CT, decomposition, abstraction, algorithms, debugging, iteration, and generalization, have a high degree of overlap with the widely used framework by Selby and Woollard (2013) and others. Below, they are characterised on the basis of the definitions and descriptions given by Shute et al. (2017) as well as in reference to other definitions and frameworks.

Decomposition –dividing complex problems into smaller parts in a logical, structured, and systematic way

- ‘Dissect a complex problem into manageable parts’ (Shute et al., 2017, p. 153)
- ‘Formulating problems entails the decomposition of a problem into smaller manageable parts and specifying and systematizing the characteristics of the task so that a computational solution can be developed’ (Eickelmann, 2019, p. 58).
- ‘Breaking down a complex problem or system into smaller, more manageable parts’ (BBC – Bitesize, 2020).
- ‘Breaking down data, processes or problems into smaller, manageable chunks’ (Google for Education, 2020).
- ‘Process of breaking down a large problem into smaller sub-problems or details’ (Ch’ng et al., 2019, p. 251).
- ‘Process of breaking down problems into smaller parts that may be more easily solved’ (Atmatzidou & Demetriadis, 2016, p. 664).
- ‘The skill to break a complex problem into smaller parts that are easier to understand and solve (Angeli et al., 2016, p. 50).

Abstraction – developing concepts

- ‘The essence of computational thinking is abstraction’ (Wing, 2008, p. 3717).
- ‘Abstraction is discussed in relation to the classical definition given by the philosopher Locke [1689] as the process in which ideas taken from particular beings become general representatives of all of the same kind’ (Hoppe & Werneburg, 2019, p. 22).
- ‘Extract the essence of a (complex) system’ (Shute et al., 2017, p. 153) including data collection and analysis; pattern recognition; and modelling.
- ‘Focusing on the important information only, ignoring irrelevant detail’ (BBC – Bitesize, 2020).
- ‘Identifying and extracting relevant information to define main idea(s)’ (Google for Education, 2020).
- ‘Remove unnecessary details and focus on the important data’ (Digital Technologies Hub, 2020).
- ‘The skill to decide what information about an entity/object to keep and what to ignore’ (Angeli et al., 2016, p. 50).
- ‘Observing patterns, trends and regularities in data’ (Google for Education, 2020).
- ‘Looking for similarities among and within problems’ (BBC – Bitesize, 2020).
- ‘Analyse the data, look for patterns to make sense of the data’ (Digital Technologies Hub, 2020).
- ‘Identify and extract relevant information to define the main idea(s)’ (Palts & Pedaste, 2020, p. 122).

- ‘The process of creating something simple from something complicated’ (Atmatzidou & Demetriadis, 2016, p. 664).

Algorithms – logical-analytical instructions and designing solution patterns

- ‘Logical steps required for constructing a solution to a given problem’, (Ch’ng et al., 2019, p. 251; Lee et al., 2014).
- ‘Developing a step-by-step solution to the problem, or the rules to follow to solve the problem’ (BBC – Bitesize, 2020).
- ‘Creating an ordered series of instructions for solving similar problems or for doing a task’ (Google for Education, 2020).
- ‘Create a series of ordered steps taken to solve a problem’ (Digital Technologies Hub, 2020).
- ‘Design logical and ordered instructions for rendering a solution to a problem’ (Shute et al., 2017, p. 153) including algorithmic design; parallelism; efficiency; and automation.
- ‘Create a series of ordered steps taken to solve a problem’ (Digital Technologies Hub, 2020).
- ‘The skill to devise a step-by-step set of operations/actions’ (Angeli et al., 2016, p. 50), including sequencing and flow of control.
- ‘A practice of writing step-by-step specific and explicit instructions for carrying out a process’ (Atmatzidou & Demetriadis, 2016, p. 664).

Debugging – systematic testing, finding and fixing errors

- ‘Detect and identify errors, and then fix the errors’ (Shute et al., 2017, p. 153).
- ‘The skill to identify, remove, and fix errors’ (Angeli et al., 2016, p. 50).
- ‘Test the algorithm methodically and systematically’ (Anderson, 2016, p. 228)
- ‘Systematic testing and debugging, efficiency and performance constraints, error detection, etc.’ (Palts & Pedaste, 2020, p. 123).
- ‘Develop strategies for dealing with – and anticipating – problems’ (Brennan & Resnick, 2012, p. 7).
- ‘Clearly identifying the issue, systematically testing the system to isolate the source of the error, and reproducing the problem so that potential solutions can be tested reliably’ (Weintrop et al., 2016, p. 140).

Iteration – approaching a solution in multiple steps

- ‘Repeat design processes to refine solutions, until the ideal result is achieved’ (Shute et al., 2017, p. 153).
- ‘An adaptive process, one in which the plan might change in response to approaching a solution in small steps’ (Brennan & Resnick, 2012, p. 7).
- ‘Iterative, recursive, and parallel thinking’ (Grover & Pea, 2013, p. 40).

Generalization – recognizing, understanding and designing generalizing patterns and models, in order to be able to use those in different contexts of operation and to evaluate them

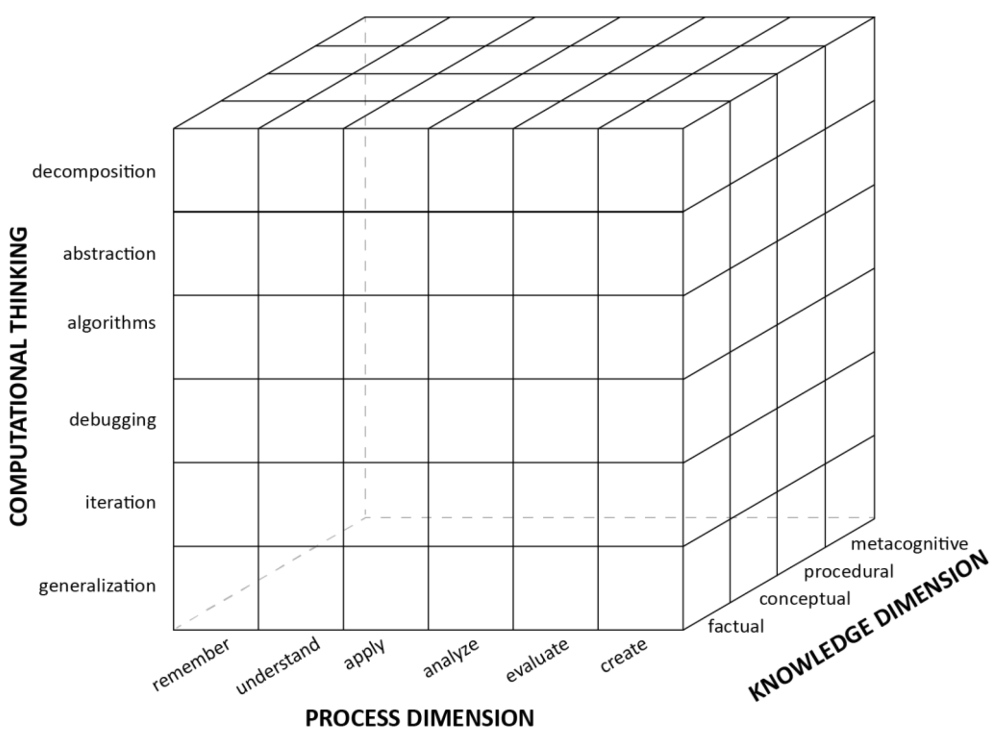
- ‘Solving problems of a similar type because of past experience solving this type of problem’ (Ch’ng et al., 2019, p. 251; Lee et al., 2014).

- ‘Creating models, rules, principles, or theories of observed patterns to test predicted outcomes’ (Google for Education, 2020).
- ‘Create models or simulations to represent processes’ (Digital Technologies Hub, 2020).
- ‘Determine effectiveness of a solution, generalise and apply to new problems’ (Digital Technologies Hub, 2020).
- ‘Formulate a solution in generic terms so that it can be applied to different problems’ (Angeli et al., 2016, p. 50).
- ‘Generalisation is transferring a problem-solving process to a wide variety of problems’ (Atmatzidou & Demetriadis, 2016, p. 664).
- ‘Transfer CT skills to a wide range of situations/domains to solve problems effectively and efficiently’ (Shute et al., 2017, p. 153).

The competence model’s product dimension represents the respective subject and its contents. The products derive from the subject-related perspective, which is then combined with the process and knowledge dimensions in the model of digital competence. Thus, the model for digital competence shown in Figure 2 has the knowledge and process dimensions as the base area of the cube with the subject-related dimensions of computational thinking on the horizontal axis.

Figure 2

Structure model of digital competence



Discussion

Relating to 'Education in an age of digitalization' (Brandhofer et al., 2019, p. 307) the paper presents the modelling of digital competence. A cube model is proposed in order to capture different dimensions of the construct as well as their interrelatedness. By combing subject-related facets with knowledge and process dimensions, a framework for defining specific learning objectives is constructed. Thereby, we follow the example of structural competence models, which have been constructed and implemented successfully in other disciplines: Guilford's (1967) facet model of intelligence as a structure-of-intellect (SOI), which has been widely used for an understanding of a systematic collection of abilities and functions for processing learning and which allows a combination of quite different elements (Suess & Beauducel, 2005); the Berlin Model of Intelligence Structure (BIS) by Jäger (Bucik & Neubauer, 1996; 1973; Suess & Beauducel, 2015); the cube model for self-regulated learning by Steuer et al. (2015) or the competence model for mathematics structuring lower secondary maths education in Austria (IDM, 2007) to name just a few. We introduce computational thinking and the structure-of-computational-thinking (SOCT) in a competence model as product dimension. Thereby, computational thinking is regarded as the recent key competence.

The proposed model for digital competence yields a high level of complexity due to the incorporation of relevant dimensions of computational thinking as well as of general principles of learning taxonomies. The complexity can be viewed as a possible limitation of the model, especially in its practical implementation for assessment purposes (see e.g. Klotz, 2015). At the same time, the complexity of the model can be regarded as an appropriate effigy of reality. Other well-established models, e.g. the model of intelligence by Guilford (1967), are of a similar extent and complexity. In general, the whole model including all its facets is foremost important on the level of curriculum development. Schools and teachers need to refer to the whole model primarily for orientation in order to situate particular learning objectives within the model in its entirety. When planning courses or teaching sequences, teachers will typically refer to a specific part of the model at a time.

The empirical validation of the model is desirable. Empirical evidence has been gathered in the past decades on different components of the model. The IEA has implemented a module on computational thinking within the International Computer and Information Literacy Study (ICILS) (Fraillon et al., 2019; Eickelmann, 2019). An empirical survey of student competencies in this area was conducted within ICILS 2018 as an optional component. While analyses show the scalability of the construct of computational thinking and therefore the possibility of empirically capturing the construct (Fraillon et al., 2020), there is still a lack of empirical evidence for differentiating the dimensions of computational thinking.

There is partial empirical evidence for Bloom's taxonomy (Bloom et al., 1956) and the revision by Anderson et al. (2001). Early attempts tried to validate the cumulative hierarchical structure of the process dimensions by analysing the difficulty level of item pools targeting the different levels (Kreitzer & Madaus, 1994). That might have to do with the fact, that while complexity and item difficulty are confounded, they are not the same. With later methodically more complex designs, empirical evidence could be produced for the cognitive hierarchy of the first four levels (Anderson et al., 2001; Kreitzer & Madaus, 1994).

The high level of complexity and the ambiguous evidence on the higher levels of the process dimension, could open up a discussion about reducing the process categories as has for example been done in the context of vocational adult education by Metzger and Nüesch (2004). In this respect, a high level of detail in order to capture the nature of digital competence as comprehensive as possible faces a slight simplification in order to raise manageability and enable easier empirical validation.

Conclusion

A theoretically sound framework is needed, which goes beyond mere lists or enumerations and has the potential to substantiate the structure of the competence in order to promote digital competence in class. The presented model of digital competence allows for a multitude of perspectives and foci so that the frame for a 'Computational Thinking Education' (Kong & Abelson, 2019, p. 6) can support the alignment of learning objectives, teaching, and assessment.

In this paper, we develop and substantiate a structure model for digital competence building upon the concept of computational thinking, which now needs to be supplemented by generating specific learning objectives as a next step. Therefore, can-do-statements need to be developed for the combinations of process, knowledge, and product dimensions in order to have available a sound basis for conceptualizing and implementing teaching and learning processes for digital competence. Thereby, the proposed model can serve as a framework which offers orientation: not only does the model help in structuring the subject-domain of computational thinking, it also draws a comprehensive picture to provide a mental image in order to structure the knowledge and skills learners are supposed to acquire.

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