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Computing with concepts using tangible, computational tools

- a 21st century competency for teachers and students in the humanities

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Abstract

The computational thinking (CT) method, *Computing with concepts using tangible, computational tools*, developed for humanistic subjects in higher education, is conceptualised as a 21st century competency in this theoretical article. The method aligns with the categories: Ways of thinking, Ways of working and Tools for working since it helps students build competencies in relation to generating ideas in novel and unconventional ways, in solving problems creatively and rigorously, and in representing and communicating ideas and solutions effectively and computationally. The method helps students engage in constructive dialogue, collaboratively explore abstract concepts and reflect on preferred ways of learning and personal biases, i.e. learn to learn. How CT activities map onto 21st century competencies is influenced by the learning theoretical framing, choice of technology and approach and the function of CT in the activity. The conclusion is that the CT method developed has potential not only as a relevant way for teachers and students in the humanities to work with CT and computational tools but also with respects to supporting students in building 21st century competencies.

Introduction

Computational thinking (CT) is considered an important 21st century competency for all citizens and all professions (Grover & Pea, 2018; Wing, 2006). Computing influences our private and work lives as well as the global economy to a still increasing degree, therefore CT is viewed as no less than a prerequisite for being a competent citizen (Voogt et al., 2015) and for experiencing well-being in and successfully navigating the digital workplace (Tikva & Tambouris, 2021). Furthermore, CT is seen as an essential element in preparing students for a future work life that will involve swift changes and unpredictability (Kite et al., 2021; Voogt et al., 2013) regarding the nature of the job tasks to be solved and the computational means available to do this. CT can also support students in becoming competent problem solvers (Haseski et al., 2018; Tikva & Tambouris, 2021) within all domains which makes it "especially relevant as a widely applicable thinking competency along with other critical thinking needed to solve the challenges posed in this century" (Grover & Pea, 2018, p. 22).

In this paper, CT is defined as "*the conceptual foundation required to solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with solutions that are reusable in different contexts*" (Shute et al., 2017, p. 151. Authors' emphasis). In CT, problem-solving revolves around the design and testing of algorithms which makes it a unique problem-solving approach. Inherent in the definition is potential automation, in which the problem-solving or parts of it is left to computers or computational tools that execute the algorithms and complete tasks for us (Denning & Tedre, 2021). Algorithms are thus a central part of CT and can be defined as a step-by-step action sequence, i.e., a procedure for completing a concrete task in a systematic way (Yadav et al., 2016). The algorithm does this by processing an input and transforming it to the wanted output (Skiena, 2020).

The algorithm is the manifestation of a potential solution to a concrete problem, and this potential solution is executed and tested through the processing of the algorithm.

There is a general call for the integration of CT as a 21st century competency at all educational levels and across subjects (Tekdal, 2021). However, many integration efforts take computer science as their point of departure with little consideration regarding how CT can enrich the teaching and learning of non-STEM subject domains which is the context of interest in this article. CT is often understood as thinking like a computer scientist (Wing, 2010) or as programming skills (Kite et al., 2021), and introduced as programming activities (Tekdal, 2021). CT does not equal programming, but programming is frequently emphasised as an important, effective and practical way to support students' development of CT skills (Bocconi et al., 2016; Voogt et al., 2015). This narrow framing often leads to CT being introduced as generic coding exercises with little connection to the content and learning goals of the courses or study programmes in which they are introduced, or to students' interests and experiences (Resnick, 2017; Resnick et al., 2009).

Many efforts to spread CT are linked to the promotion of computer science and the recruitment of students to this field, however CT should be endorsed as a means to "help the others solve problems they care about" (Denning, 2009, p. 30). Thus, teaching CT should enable people to think "like an economist, a physicist, an artist, and to understand how to use computation to solve their problems, to create, and to discover new questions that can fruitfully be explored" (Hemmendinger, 2010, p. 6). Indeed, CT is emphasised as cross-disciplinary (Yadav et al., 2016), as "a set of transferable and marketable skills that are appropriate for any domain" (Liao et al., 2022, p. 12), and it should be taught using an integrated approach so that students become familiar with computing ideas and principles in the setting of the specific subject domains they are studying (Yadav et al., 2016). E.g. CT can "improve [non-STEM students'] critical thinking skills while encouraging a more innovative and forward-thinking mindset to discover computational solutions" (Liao et al., 2022, p. 3) to the problems of their particular subject domain.

However, Tekdal (2021), in a literature review, concludes that there is a gap in the research regarding how CT can be integrated in non-STEM fields, especially at the level of higher education (HE), and a lack of variety in the types of learning technology applied in CT activities where visual programming applications, e.g. Scratch, and robotics dominate. Tekdal encourages research that examines "different programming tools, technologies, and environments that contribute to the development of CT skills and bring a new breath to the field" (2021, p. 6523). In response, this theoretical article presents a novel approach to the conceptualisation of CT that illustrates how teachers and students in the humanities can "use computation to solve their problems, to create, and to discover new questions that can fruitfully be explored" using Hemmendinger's (2010, p. 6) words, i.e. CT made relevant for humanistic subjects. The article also provides a theoretical examination regarding how the integration of CT can potentially support students in building 21st century competencies. The article investigates and proposes answers to the research questions:

- How can CT and computational tools be made relevant for humanistic subjects and how can they support students in building 21st century competencies?
- What are the implications for teachers?

More specifically, the article presents a non-STEM CT teaching method and tool (referred to as the CT method below) for higher education (HE), namely *computing with concepts using tangible computational tools*, that can provide an alternative to the present predominantly code-centric approach. Furthermore, the article provides a theoretical investigation of the potential of the CT method to infuse CT into the humanities in a way that can support students in building 21st century competencies. The article is aimed at teachers, educational developers, learning designers and others interested in the integration of CT and 21st century competencies into non-STEM courses and study programmes in HE.

Outline of the article

The first section provides the background and context for the development of the CT method, explains the theoretical underpinnings and how the CT method is anchored in the humanities. Then follows an account of the method and tool together with sources of inspiration for the design and connections to CT. Included is also an explanation regarding how one computes with concepts using a tangible, computational tool. This is followed by a theoretical exploration of the concepts of 21st century competencies and CT, identifying and discussing the nexus between these two concepts and conceptualising *computing with concepts using tangible, computational tools* as a 21st century competency for teachers and students in the humanities in HE. In particular, the section unfolds and maps onto Binkley et al.'s (2012) conceptual diagram of 21st century competencies, the idea of computing with concepts using tangible, computational tools. This will lead to a discussion of factors influencing the degree of overlap between CT and 21st century competencies, and how teachers in the humanities in HE can be supported in working with CT as a 21st century competency.

Background and context

The conceptualisation of computing with concepts using tangible, computational tools as a 21st century competency is based on the findings from a design-based-research (DBR) study that was initiated in September 2020. Below is a brief account of the study; a more detailed description can be found in Christensen (2023). The goal of the study was to investigate how to integrate CT into humanistic subjects in HE, i.e., a set rather than an open investigation of possible solutions. I collaborated with a teacher from Philosophy and one from Media Studies at a Danish university in order to identify a pedagogical challenge that the teachers experienced in their teaching, and which could form the basis for the design of interventions with the integration of CT and a tangible, computational tool as the possible solution. The interventions were underpinned by a theoretical framework viewing cognition and learning as situated and embodied, see below, and two iterations of empirical testing, data collection, evaluation and improvement were conducted. The study is now in the final phase consisting of data analysis, abstraction and generalisation of the findings. Rather than reporting on the empirical work, the present article is theoretical and based on this final phase.

A theoretical framework viewing cognition and learning as situated and embodied informed the development of the CT method. CT is often proclaimed to be a universal competency (Grover & Pea, 2018; Wing, 2006), and it is assumed that competencies can simply be transferred from the domain of origin to other domains. However, the transfer of abstracted forms of reasoning such as CT is often problematic. In situated learning, learning is understood as an integrated part of social practice, and the learning context, the specific social practice involved in the learning situation, influences what is learnt by shaping and adding content (Lave & Wenger, 1991). Likewise, knowledge is situated being to some extent the result of the activity, context as well as the culture in which it was developed and used. Therefore, rather than being neutral or subordinate elements of a learning process, activity and context are integral to what is learnt (Brown et al., 1989). Learning is therefore viewed as a situated activity, a participation process that includes "mind, body, activity and culturally organized setting" (Lave, 1988, p. 1). Both learning and knowledge are understood as relational to a specific social practice and context. Therefore the DBR-study investigated how CT activities with computational tools could be situated in specific, humanistic subjects to support students' professional development and be perceived as relevant, i.e., as integrated parts rather than decontextualised concepts since "abstract representations are meaningless unless they can be made specific to the situation at hand" (Lave & Wenger, 1991, p. 33).

The use of tangible, computational tools is viewed as an important aspect of situatedness. By manipulating tangible tools, it is possible for students to interact actively with and in the learning context. The students' sensorimotor movements, i.e., embodiment, in relation to the tangible, computational tools and the goal of the activity, are to situate and support students' learning of abstract concepts (Abrahamson & Bakker, 2016). A computational tool can make the abstract concepts studied "tangible, manipulable, and available for thought, action and imagination" (Pande, 2021, p. 464) because the tool constitutes an external representation of the domain in question. In order to support students' learning, one should adopt a task-oriented view and design for integrated forms of embodied learning in which the embodiment is necessary to complete the activity (Skulmowski & Rey, 2018).

The learning theoretical perspectives outlined above formed design constraints on the development of the CT method, which was empirically tested in various humanistic HE contexts. The two contexts for which the CT method was first developed are described below to illustrate the embeddedness of the CT method in the humanities.

In spring 2021 and 2022, the CT method was tested in the 10 ECTS subject *Media institutions, industries and systems* at the second semester of the Master's degree programme in Media Studies at a Danish university. The main goal of the course is to provide students with a comprehensive introduction to media institutions, industries and systems. Assessment is an oral examination based on a 10-page, individual synopsis. According to the teacher, the challenge is that students typically find it difficult to understand the concepts of the subject. From their undergraduate studies, students have experience analysing media products and so are familiar with the media consumption perspective. Therefore, many students initially fail to adopt the media institution perspective and do not fully comprehend what a media institution or system is until the exam. Indeed, students often approach the teacher when they embark on their synopsis and ask her to suggest ideas for problem formulations. For the teacher, the goal of the intervention was to facilitate students' early understanding of the core concepts of the subject and support them in independently generating synopsis ideas.

Also, in spring 2021 and 2022, the CT method was further tested in a workshop series for undergraduate Philosophy students on their fourth semester at a Danish university. The workshop series has the overall aim of preparing students for and facilitating their early start on their bachelor projects. The more specific aim is to support students' idea generation and formulation of problem statements. The teacher makes it clear to students that he expects them to take an active part in the workshops that include short presentations by the teacher followed by discussion in groups giving students the opportunity to reflect on the topics presented and possible directions for their own projects. The challenge identified by the teacher is that students are often superficial in their idea generation, discussion and peer feedback and tend to give more weight to the teacher's feedback receiving this uncritically. This means that the goals of supporting students in independently generating ideas and writing problem formulations and in helping them improve their skills to give and receive feedback are not realised. The teacher was looking for a way to make the idea generation process and the writing of a problem formulation more tangible for students and for ways to facilitate students' more substantial discussions and peer feedback.

Based on the empirical testing mentioned above, the following tentative conclusions about the contributions of the CT method to humanistic subjects were made: computing with concepts using a tangible, computational tool supports students in systematically investigating possible combinations of, e.g., topics, theoretical perspectives and methods (Christensen, 2023). The tangible, computational tool allows students to model and visualise ideas for bachelor projects, exam papers or the like, which can then be shared and discussed with fellow students who in turn can use the computational tool to suggest alternatives for consideration. In this way, the tool supports students' subject related conversations. The computation of concepts using tangible computational tools support students' individual as well as collaborative exploration of the abstract concepts of their subject-domains. There is evidence that the tangible computational tools encourage students to engage in divergent thinking and consider multiple ideas before deciding which direction to take. However, some students are reluctant to work with tangible tools and prefer more abstract ways of learning in HE and in connection with their subject domain.

The next section presents the CT method developed, accounts for sources of inspiration together with connections to CT and explains how to compute with concepts.

Introducing a non-STEM CT method and a tangible, computational tool

When integrating CT into a specific course, CT can either be the subject to be learnt or a tool to learn other subjects (Dohn et al., 2021). The latter is the case in the method and tool presented here.

The tangible aspect is important to make possible the investigation of students' embodied and situated learning with CT. An unplugged approach to CT (Caeli & Yadav, 2020) was adopted in line with Valente and Marchetti's (2020) concept of paper computing machines and their experiments with simple, paper-based artefacts for the design, execution, testing and debugging of algorithms. Based on their empirical work, Valente and Marchetti (2020) conclude that tangible materials are better than computers in supporting learners' active involvement and dialogue. Their observations reveal that learners tend to work one at a time when asked to engage in a shared activity involving a computer. In contrast, learners who worked with tangible materials more naturally engaged in small groups that allowed for eye-contact, dialogue and learner-learner and learner-material interaction.

The unplugged approach to algorithmic problem-solving is not new. A very early example is Ramon Lull's (around 1232 - 1316) 'ars magna' that was to contain the principles of all individual sciences and thus be able to answer any conceivable question, assisting scientists in discovering new and validating existing truths. One of Lull's goals was to construct a device that could help him find rational arguments that would convince the Muslim population in northern Africa to convert to Christianity (Bonet, 2011). Lull's work is believed to have sparked interest in the idea that logical reasoning is computation, and the ideas of a universal method for logical inquiry, combinatorics as a method for logical analysis and for solving logical tasks and last but not least, the use of mechanical devices for the combinatorial manipulation of symbols and for generating lists of combinations (Bonet, 2011; Sales, 1997). Lull constructed manually operated devices, some in the shape of concentric circles containing symbols and placed on top of each other, but independently manipulable, so that different combinations of symbols could be generated and tested (Sales, 1997). In this way, the devices constituted logical wheels that made computations possible (Bonet, 2011), see Figure 1a below. The figure is known as Lull's fourth figure and allows ternary combinations (Bonner, 2011), i.e., the selection and combination of a letter from each of

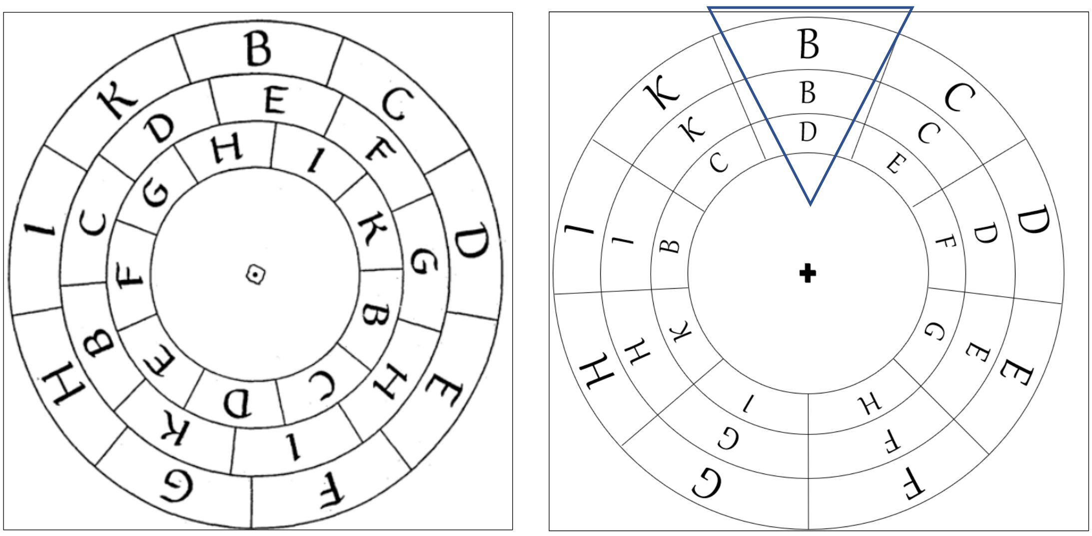

Figure 1a left. One of Lull's logical wheels (Bonet, 2011, p. 101). Reprinted with permission from the author. Figure 1b right. Computing with concepts by selecting a letter from each circle and aligning these. Selection marked with blue triangle above.

the three circles. Each letter derives its value from a table, "The alphabet of the *Ars brevis*", and can be interpreted as a question or rule, a subject, virtue or vice depending on its position in the figure (Bonner, 2011, p. 9). If for example, we select the letter B from the outer circle, again the letter B from the second circle and the letter D from the inner circle by aligning these letters in the figure, we have the combination BBD, see figure 1b above. Using the alphabet of the *Ars brevis*, B from the outer circle can be interpreted as *goodness*, B from the second circle as *difference* and D from the inner circle as *contrariety*. From the B of the outer circle, we also derive the question word to add to our combination, namely *whether*. We have now computed with concepts and can interpret the output from this computation as "Whether goodness contains in itself difference and contrariety" (example from Bonner, 2011, p. 14). Computation is understood as an intentional input-output process (Hansson, 2018). The purpose of a computation is transition, getting from an input state of symbols to an output state, i.e., a result, in one or more steps that manipulate and transform the symbols (Conery, 2010). Thus, a computation follows a specific procedure that can be expressed as a set of precise step-by-step instructions. Computing with concepts is thus a way of engaging with algorithms and with CT; more specifically Lull was dealing with an algorithmic problem of a combinatorial nature, i.e., in how many different ways can you combine a set of symbols, also known as permutation generation (Skiena, 2020).

Today, Lull's devices would be labelled computational tools, and the remarkable thing is that they aid us in computing with concepts rather than numbers (Uckelman, 2010) as illustrated in the example above; an idea otherwise discarded when the binary system was invented. Lull's logical wheels are especially relevant as computational tools in relation to humanistic subjects and has been a great source of inspiration as will become apparent below.

Computational tools and how to compute with concepts

In the following, the CT activities and tools designed for Media Studies and Philosophy will be presented to explain how the CT method is anchored in specific, humanistic subjects. Furthermore, it is explained how one computes with concepts in these subjects using tangible, computational tools. The centre of attention for the design process was how CT and computational tools could support students' investigation and manipulation of subject-related concepts and facilitate the generation, sharing and discussion of ideas. The result was the design of logical wheels for idea generation and a task description scaffolding students' individual and collaborative work around the tool. Appendix 1 shows the design pattern for Media Studies. When using the tool, students engage with algorithmic processes and compute with concepts. The tool is based on the core model of the subject which resembles Llull's logical wheel in that it consists of three concentric circles. A fourth circle has been added to the tool so that students can add empirical cases of interest to their synopsis. A marker triangle has also been added to record the theoretical perspectives students have selected for further scrutiny. The result is the *idea generation tool* shown in Figure 2 below that also illustrates the core model of the subject.

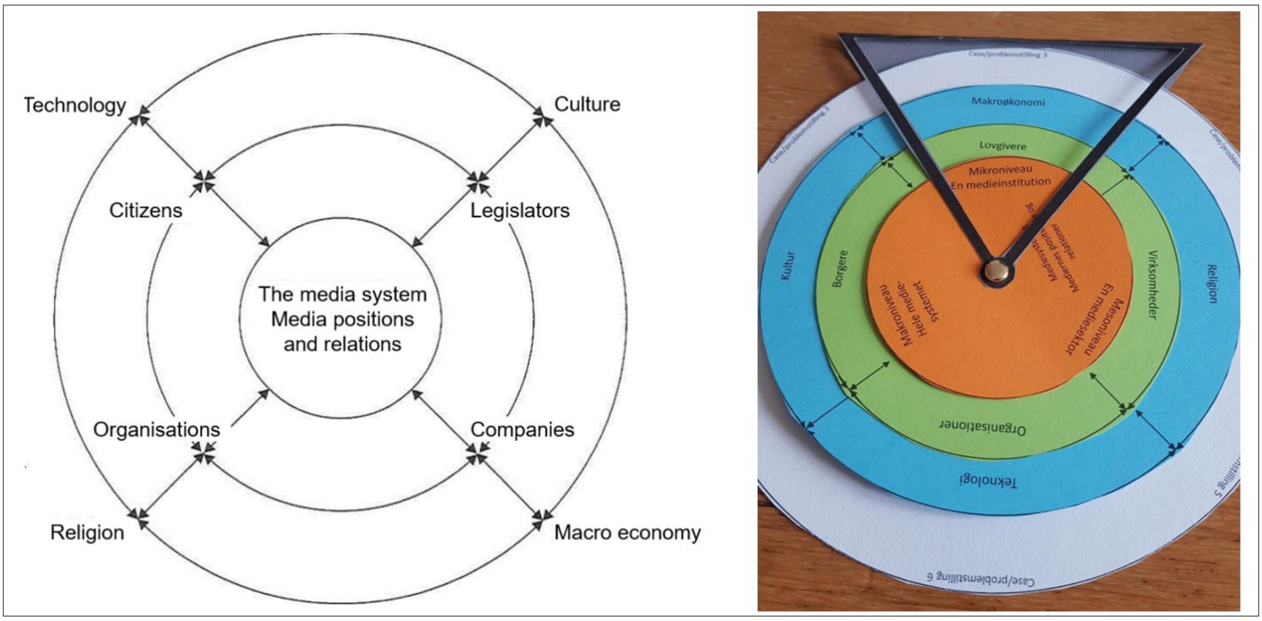

Figure 2. Left the model: Media, actors and macro structures of the media system (Vestergaard, 2007, p. 70. My translation.). Right the idea generation tool for Media Studies. Both images are from Christensen (2023).

The orange, green and blue disks each represents a category of theoretical perspectives in the core model. The computational tool allows students to investigate each of the concepts in the three categories by turning the disks. Students can add empirical cases to the white disk and turn one of these inside the black marker triangle. They can then consider and add a concept from each of the three theoretical disks to their selection. The next step is to consider what ideas and/or specific problem formulations can be created based on the combination that is now displayed inside the marker triangle. Students can make a note of ideas and explore alternative combinations. In this way, the tool can help students explore all possible combinations in a systematic and rigorous way. For each empirical case students have listed on the white disk, there are 48 possible ternary combinations if students choose a concept from all three disks (orange, green and blue) and 40 binary combinations if students choose a concept from only two of the disks. The tool is computational, cf. below, and makes it possible for students to engage with algorithmic processes and compute with media systems concepts which firmly situates the CT activity and students' idea generation within the subject. In this way, the tool becomes an object to think with, this thinking relating to theoretical perspectives for the analysis of media systems. Students engage with algorithmic processes in the following manner.

- Each disk is a tangible representation of possible values of a relevant variable and thus aids students' memory.
- Students can input own data in the form of empirical cases of interest on the white disk. They can then explore and select perspectives from the orange, green and/or blue disk that they find relevant for each case.
- Students change values/states by rotating each disk.
- The current state of each disk is marked by the selection triangle. This selection constitutes an intermediary result which is the input for students' formulation of a problem statement which in turn is the desired output of the algorithmic processing.
- The problem solved using the tool is students' formulation of a problem statement.

(Based on Christensen, 2023, p. 26)

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A similar, but more general tool was developed for Philosophy. It allows students to investigate and discuss the core components of a good problem formulation (Rienecker & Jørgensen, 2017), namely the categories: theory, method, question words and problem/topic. See Figure 3 below. The tool contains two disks for theories since students might want to select and contrast two different theories in their bachelor projects. Philosophy is a very broad field with many subdomains, therefore students were to help each other think of and type theories and methods that they had come across during their studies into the different disks of the tool, before turning the disks, selecting concepts and combining these to form ideas for problem formulations.

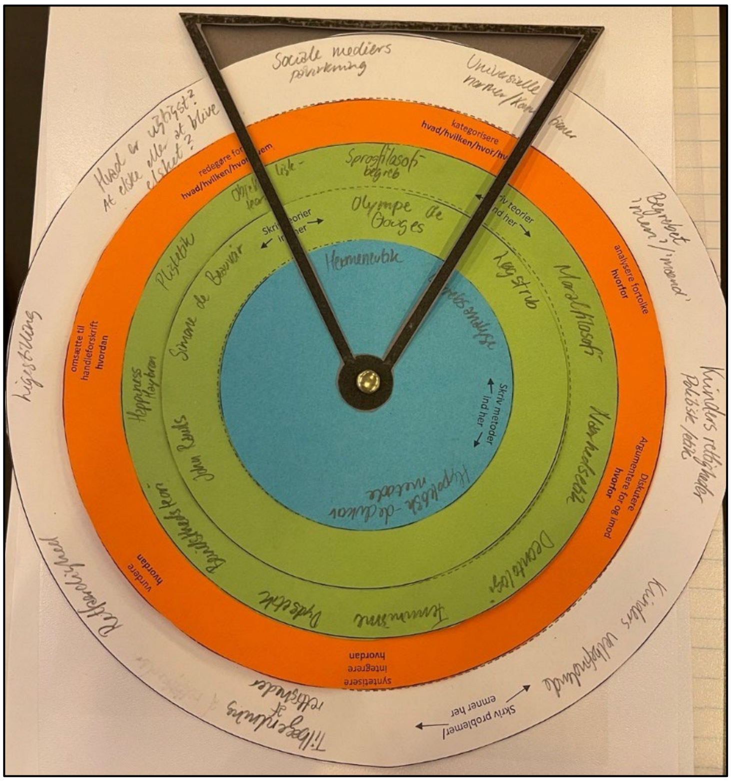

Figure 3. The idea generation tool for Philosophy – a student's completed version.

The design pattern developed for Philosophy, see Appendix 2, differs from the one developed for Media Studies in one respect. Philosophy students start with a collaborative activity in which they help each other populate the tool with methods and theories, before they generate ideas, share and discuss these with fellow students.

21st century competencies

In this section, the concepts of CT and 21st century competencies will be explored in more detail including the connection between the two. In the literature on 21st century competencies, both skills and competencies are used. According to Voogt et al. (2013), skills is the more common term in American research, whereas the term competences or competencies is used in Europe. In the present article, I use the term competency to denominate a person's "realisation of her skills and knowledge in response to the demands of the given situation." (Dohn, 2018, p. 11).

As outlined in the introduction, we live in a rapidly changing world in which technology influences and constantly redefines how we communicate, interact, learn, socialise, work etc. The educational system must mirror the move from the industrial society to the knowledge society so that education revolves around competencies connected to knowledge work, i.e. how ideas, knowledge and information are produced rather than how material things are manufactured (Erstad & Voogt, 2018). New, generic competencies “for living, working and learning in our current [global and digitalized] society” (Voogt & Erstad, 2018, p. 15) are needed. Binkley et al. more specifically state that success today

> “lies in being able to communicate, share, and use information to solve complex problems, in being able to adapt and innovate in response to new demands and changing circumstances, in being able to marshal and expand the power of technology to create new knowledge, and in expanding human capacity and productivity.” (Binkley et al., 2012, p. 17).

The quotation above highlights the competencies that are necessary in today’s global and digital society, and the goal of wielding these competencies to solve the complex problems that we face in the 21st century. Several frameworks outlining 21st century skills, key competencies or lifelong learning competencies exist (Binkley et al., 2012; Erstad & Voogt, 2018). Erstad and Voogt (2018) performed a meta-review of four such frameworks and conclude that across these frameworks, there is agreement that the following constitute the main 21st century competencies: “collaboration, communication, ICT literacy, and social and/or cultural competencies including citizenship, creativity, critical thinking, and problem-solving” (p. 26). These key competencies are not in themselves new and can be found in curricula across educational levels. However, in 21st century competency frameworks, these key competencies are highlighted and contextualised in a novel way (Erstad & Voogt, 2018).

For the following mapping of CT against 21st century competencies, Binkley et al.’s (2012) conceptual diagram is used. It was created on the basis of a meta-review and includes definitions of ten 21st century competencies divided into four categories: Ways of thinking, Ways of working, Tools for working and Living in the world, see Table 1 below. Binkley et al.’s diagram was chosen because it not only provides definitions of key concepts, but also operationalises these by explaining the implications for pedagogical practice. This operationalisation consists of the breaking down of each competency into **K**nowledge, **S**kills and **A**ttitudes/**V**alues/**E**thics using the KSAVE Model (Binkley et al., 2012, pp. 36-37).

Table 1. Conceptual diagram of ten 21st century competencies divided into four categories based on Binkley et al. (2012, p. 36).

Categories	**21st century competencies**
Ways of thinking	Creativity and innovation Critical thinking, problem solving, decision making Learning to learn, metacognition
Ways of working	Communication Collaboration (teamwork)
Tools for working	Information literacy ICT literacy
Living in the world	Citizenship - local and global Life and career Personal and social responsibility – including cultural awareness and competence

Computational thinking operationalised

In the introduction, CT was defined as algorithmic problem-solving. Yadav et al. (2016) provides a very concise account regarding what CT encompasses:

> “The essence of computational thinking involves breaking down complex problems into more familiar/manageable sub-problems (problem decomposition), using a sequence of steps (algorithms) to solve problems, reviewing how the solution transfers to similar

problems (abstraction), and finally determining if a computer can help us more efficiently solve those problems (automation)." (Yadav et al., 2016, p. 565).

A further operationalisation of CT can be found in Dohn (2021) who provides a characteristic of CT as a set of phases with associated competencies. Table 2 below provides an overview of CT phases and competencies based on Dohn's characteristic (columns 1 and 2) together with an explanation regarding how the CT method presented above aligns with these phases and competencies (column 3). Thus, the table illustrates and emphasises the links between CT and the non-STEM CT method developed.

Table 2. The non-STEM CT method aligned with CT phases and competencies. Based on Christensen (2023, p. 31).

Phases	Competencies	Non-STEM CT method
Problem formulation	Abstracting the problem from the specific situation. Decomposing the problem into small, manageable parts.	The tangible, computational tools are decomposed versions of abstract concepts within the domains they model.
Data generation and processing	Creating and collecting data, preparing data for analysis. Decomposing data, i.e. logical data analysis and organisation.	Students discuss, generate and input data in some or all of the circles of the tool depending on the subject domain.
Modelling	Abstracting certain traits/data as the most significant. Recognising/creating patterns on the basis of these traits. Model creation – analogue, bodily and computer-visualised.	Students engage in analogue and embodied modelling of possible ideas and problem formulations by turning, assessing and combining elements from the different circles.
Algorithm design	Writing step by step instructions/action sequences.	Students discuss and decide which circle to compute first, and how to proceed; the action sequence is negotiated and unfold in the moment.
Automation	Coding the algorithm for automatic processing, in program or IT-artefact Debugging and iterative testing.	The tool represents the coded algorithm for partly automatic processing – permutation generation. Each circle contains the possible states of a variable, and the students manually process each variable selecting and combining the preferred states. Debugging and iterative testing: students share, discuss, and challenge each other's ideas.
Generalisation	Abstracting pattern for problem-solving Generalising and transferring the problem-solving pattern to other domains.	Students can use the same pattern for their different ideas and support fellow students in applying the pattern to their ideas. Generalisation also involves the adaptation and testing of the CT method in new contexts.

Computational thinking and 21st century competencies

A search undertaken on 20 September 2022 on computational thinking or CT and 21st century competenc* or 21st century skill* and education in the Academic Search Premier (EBSCO) database brought back 672 peer-reviewed, English language papers from the period January 2000 to September

2022. Many articles simply state that CT is an important 21st century competency and some mention a few, select competencies which they see as the nexus, such as creativity, critical thinking and problem-solving (Lye & Koh, 2014), thinking creatively, reasoning systematically, and working collaboratively (Tikva & Tambouris, 2021, referring to Resnick et al., 2009) or critical thinking, problem-solving and other 21st century skills (Bocconi et al., 2016). The number of hits in the literature search indicates that a strong link is perceived between CT and 21st century competencies, and there is some agreement that the connection revolves around creativity/thinking creatively, critical thinking and problem-solving. The key connection, according to several researchers is problem-solving in relation to the challenges we face in the 21st century. And indeed, Yadav et al. (2016) equate CT with 21st century problem-solving in their paper titled: "Computational Thinking for All: Pedagogical Approaches to Embedding 21st century Problem solving in K-12 Classrooms". However, it is necessary to explore in more detail how CT and 21st century competencies are connected to obtain a more comprehensive understanding of overlaps and differences. Below, I will attempt to provide a more detailed account by examining how CT as computing with concepts using tangible, computational tools (the CT method) maps onto Binkley et al.'s (2012) diagram of 21st century competencies.

The CT method as a way of thinking

In its very essence, CT is a way of thinking that today is most manifest in computer science but is making its way into all levels of the educational system and introduced across subjects. CT enables the decomposition and analysis of complex problems, the design and testing of algorithms to provide computational solutions to these problems and thus brings rigour to the problem-solving process (Chongtay, 2018). Providing students in the humanities with tangible, computational tools supports them in adopting this novel and rigorous approach when working with the abstract concepts of their subject domain to generate ideas. This leads to students exploring several alternatives and engaging in divergent thinking before settling on the direction in which to move. In this way, computing with concepts using tangible tools becomes one of the "idea creation techniques" that 21st century students should know (Binkley et al., 2012, p. 38). Furthermore, students are supported in gaining several of the skills and working with some of the attitudes/values/ethics from Binkley et al.'s diagram. Worth noting is the power of the method to support students in acquiring the skill to "develop [...] and communicate new ideas to others effectively" and to help each other "elaborate, refine, analyze, and evaluate [...] ideas in order to improve and maximize creative efforts" (Binkley et al., 2012, p. 38). The CT method also challenges the attitudes/values/ethics of students by requiring them to be open and responsive to new and worthwhile ideas and diverse perspectives, and to integrate input and feedback from fellow students into their work.

Under the heading of competency 2. Critical thinking, problem solving, decision making, the CT method helps students gain knowledge on systematic thinking and understand systems and strategies for tackling unfamiliar problems. In addition, students will be able to build skills in using systems thinking that judged from Binkley et al.'s (2012) description, maps onto the CT competencies abstraction, decomposition and data generation and processing. When it comes to attitudes/values/ethics, the CT method will broaden students' horizons as to alternative viewpoints, critical reflection on learning experiences and processes and make them familiar with "unconventional, and innovative solutions to problems and to ways to solve problems [and] ask meaningful questions that clarify various points of view and lead to better solutions" (Binkley et al., 2012, p. 40).

Students' engagement with the novel CT method supports their reflection in relation to competency 3. Learning to learn, metacognition. Students will gain knowledge and understanding of their preferred learning methods when meeting the novel approach. In order to successfully complete the CT activity using the tangible, computational tool, students must work with skills related to "effective self-management of learning" and dedicate time to learning, displaying autonomy, discipline and perseverance (Binkley et al., 2012, p. 43). In terms of attitudes/values/ethics, adaptability, flexibility and the identification of personal biases are required to successfully engage with the activity. Especially personal bias should be the topic of reflection, since the findings of the DBR-study show that some students are reluctant to work with tangible tools and prefer more abstract methods of learning in HE.

The CT method as a way of working

Ways of working comprises the competencies 4. Communication and 5. Collaboration (Teamwork). Communication mainly refers to competencies related to language in mother tongue and additional languages. Also, nonverbal and paraverbal communication is mentioned, as well as skills required to "use aids […] to produce, present, or understand complex texts in written or oral form" (Binkley et al., 2012, p. 45). In addition, the "disposition to approach the opinions and arguments of others with an open mind and engage in constructive and critical dialogue" is mentioned under Attitudes/values/ethics (p. 45). There is little mention of skills needed to use tangible tools in communication. However, the DBR-study shows that a tangible, computational tool can be a powerful means of communication, not only because such tools support the visualisation but also the sharing and discussion of ideas, as well as the abstract concepts and empirical cases that these ideas involve. The group tasks involved in the CT method allow students to work towards competency 5. and enhance their collaboration and teamwork competencies becoming better at interacting effectively with others and in a team, and to respond in an open-minded manner to the ideas and values of others (Binkley et al., 2012).

The CT method as tools for working

Binkley et al's (2012) conceptual diagram of 21st century competencies was published 10 years ago. At the time, the diagram was based on an analysis and synthesis of existing frameworks and was thus quite comprehensive. However, since 2012, much research has been done especially within the category, Binkley et al. has labelled Tools for working. With the rise of CT in educational research and practice, this category must now be revised and expanded. Also, placing the category as an isolated component in the diagram should be questioned. Literacy cuts across other 21st century competencies, as also mentioned by Dohn (2018), and helps us act appropriately in the different aspects of our lives. "'Being literate' […] means being able to participate in a given cultural practice, making use of the cultural resources, artefacts and technologies of that practice" (Dohn, 2018, p. 12).

Two literacies are mentioned in Binkley et al.'s (2012) diagram, namely information literacy and ICT literacy. The latter being more oriented towards the knowledge, skills, attitudes, values and ethics required to successfully make use of ICT tools, and information literacy being oriented towards retrieving, evaluating, using and managing information effectively and doing so using relevant tools. As such, the CT method maps onto these two literacies in the sense that the tasks involved in computing with concepts support students in working with information in the form of abstract concepts and empirical cases from their subject domain. The tangible, computational tool thus becomes an ICT tool that must be mastered in order to successfully compute with concepts. One could also argue that a third literacy should be added to the category of tools for working that presents a better fit with the CT method, namely computational literacy, containing the knowledge, skills, attitudes/values/ethics needed to engage in computational thinking in one's different life situations and using both plugged and unplugged (physical and tangible) technologies to do this.

The CT method is a new way of representing ideas in line with diSessa's (2001) vision for computers. diSessa views literacy as a material intelligence that can be added to "purely mental" intelligence and thus enhances the mind "by allowing appropriate external extensions to the mechanism [the mind], extensions that wind up improving our abilities to represent the world, to remember and reason about it" (2001, p. 5). The tangible, computational tool comprises one such extension. According to DiSessa (2001), literacy is built on three foundational pillars, namely 1. the material pillar that depends on technology and is designed. It includes "external, materially based signs, depictions, or representations" that allow us to “install some aspects of our thinking in stable, reproducible, manipulable, and transportable physical form” (p. 6). 2. The mental or cognitive pillar, i.e. how we couple with the external, materially based representations, and 3. the social pillar which emphasises that literacy is first and foremost social as also outlined in the definition provided above. Computational literacy, then, covers the competencies to represent ideas using computational devices and also includes social factors such as computational participation, collaborative creation, communication and learning (Chongtay, 2018).

21st century competencies for living in the world

The non-STEM CT method constitutes an implicit approach to CT in that students learn with CT and not about CT. However, more explicit approaches adopting a critical pedagogical framing, see explanation below, would allow students to build 21st century competencies such as those listed in Binkley et al.’s (2012) category Living in the world, namely 8. Citizenship - local and global, 9. Life and career and 10. Personal and social responsibility.

The nexus between CT and 21st century competencies is not clear cut and something that can be determined once and for all. The degree of overlap between CT and 21st century competencies is influenced by several different factors which will be discussed below.

Discussion

One factor that influences how CT maps onto 21st century competencies is the learning theoretical standpoint that underpins the integration of CT into curricula and the design of activities. Kafai et al. (2020) introduces three learning theoretical framings of CT in education, namely the cognitive, the social and the critical. The cognitive framing focuses on the individual learner and CT is viewed as the knowledge, skills and competencies of a particular discipline. Computational concepts, such as algorithms and abstraction together with CT practices such as remixing and iteration are the subject content to be learnt, and activities often include computer programming. As such, the cognitive framing first and foremost maps onto the category Ways of thinking.

The situated framing, on the other hand, focuses on communities of practice, activity systems and learning ecologies. CT is understood as practices, participation and preparation for the future and implemented as computational participation and computational making. Therefore, activities are to facilitate students’ meaningful creation of applications, the development of communities and support social interactions and play. Students typically undertake projects, share their work with each other, give and receive feedback, and modify their work accordingly. In this sense, the situated framing is most closely linked to the category Ways of working.

The unit of concern in the critical framing is society and existing power, privilege and opportunity structures relating to, e.g., race, gender, social class and ability. CT is to support students in building awareness of ideologies and support them in developing strategies for social action. Therefore, students are encouraged to develop applications that support the thriving, awareness and activism of citizens in both their local communities as well as on a wider scale. In this framing, CT is conceptualised as computational empowerment (Iversen et al., 2018) and the overall goal is to support students in discussing challenges of a political, moral and ethical nature in relation to digital technologies and artificial intelligence. This means that the critical framework first and foremost supports the acquisition of competencies in the category Living in the world.

The theoretical framing selected when integrating CT in education thus supports the tailoring of activities to a particular category of 21st century competencies. In the case of computing with concepts using tangible, computational tools, this CT method does not fully embrace the social framing. There are collaborative elements in the activity, however, students do not themselves create computational artefacts which is one of the cornerstones in the social framing. The social framing can be embraced by letting students in the humanities create their own computational tools based on the concepts, models, theories etc. of their subject domains. In addition, the CT method can be expanded to include new tasks in which CT and computational problem-solving are taught and discussed explicitly, bringing into play the critical framing and the category Living in the world.

The category Tools for working cuts across all 3 theoretical framings outlined above in that CT activities support students in building literacy depending on the choice of technology and approach. A CT activity does not necessarily involve digital devices. In fact, an unplugged approach using analogue means can help demystify CT and be especially useful for novice learners since digital devices often quickly black box the algorithms and algorithmic processes in play which hinders students in successfully learning CT (Caeli & Yadav, 2020). However, an unplugged approach will mean that students do not engage with digital technology and thus miss the opportunity to build some aspects of literacy. But no matter what technology is used, students will be developing their computational literacy as explained above.

Finally, the actual function of CT in a specific activity will influence what 21st century competencies students can develop. If CT is integrated as content, students will more explicitly work with and have the possibility to develop computational literacy. However, CT can also be integrated as a tool with which to learn another subject in which case the development of computational literacy might be more subtle and implicit.

Concluding remarks

Computing with concepts using tangible, computational tools has been conceptualised as a 21st century competency and mapped unto Binkley et al's (2012) conceptual diagram. This reveals that the CT method has potential to support students in building 21st century competencies within the categories Ways of thinking, Ways of Working and Tools for working.

The CT method can be seen as a novel and rigorous *way of thinking* about complex problems and investigating computational solutions to these. The method provides a novel idea creation technique that supports students in building the 21st century competencies creativity and innovation, critical thinking and problem-solving. The method also challenges students by presenting an unfamiliar way of solving problems that makes unconventional and innovative solutions possible. In addition, students are supported in learning to learn and metacognition when faced with the CT method since they get the opportunity to reflect on their preferred way of learning and examine personal biases. The CT method also connects to Ways of working and facilitate students' acquisition of communication and teamwork competencies. The tangible, computational tool is a means of communication that students must master, and it supports them in developing competencies to engage in constructive and critical subject-related conversations with fellow students and interact effectively.

The four categories of 21st century competencies are depicted as isolated components, however, the category Tools for working, containing information literacy and ICT literacy, should not be isolated but instead cut across the other three categories, since the literacies are important tools for realising the other competencies. It was concluded that the CT method maps onto information literacy since the tasks involved in computing with concepts support students in working with information in the form of abstract concepts and empirical cases from their subject. Furthermore, the tangible, computational tool is an ICT tool that must be mastered to successfully compute with concepts. It was also suggested to expand the category Tools for working to include computational literacy as a better fit with CT since computational literacy is the competency to represent ideas using computational devices.

The CT method in its present form does not map onto the category *Living in the world*, since CT is employed as a tool to learn another subject. Therefore, explicit discussions of CT and its implications with respects to living in the world today are not part of the activity. The function of CT in a given activity influences the degree to which CT and 21st century competencies overlap. Other factors are the learning theoretical standpoint adopted when integrating CT together with the choice of technology and approach.

A first, tentative conclusion is that computing with concepts using tangible, computational tools can provide a relevant way for teachers in the humanities in HE to integrate CT because it supports students in working with the abstract concepts of the subject in question and simultaneously helps students build important 21st century competencies for their future professional lives.

Teaching 21st century competencies

Teachers are faced with competence demands in relation to supporting students' development of 21st century competencies. They must adopt new suitable teaching methods and technologies as well as understand how pedagogy and technology interact because the "new challenges to us as educators […] require fundamental changes in both *what* has to be learned and *how* this learning is to happen" (Voogt et al., 2013, p. 403). Yadav et al. (2016) emphasise the need to align CT and 21st century activities with curricular needs in teachers' specific subject domains. Securing such alignment will help teachers in the humanities make sense of the responsibility allotted to them regarding students' development of 21st century competencies. This article has illustrated how working with 21st century competencies can be more closely aligned with pedagogical challenges and curricular needs in the humanities in HE. I encourage readers to study the design patterns in the appendices for more specific inspiration in relation to the design of CT activities and tools. The design patterns provide a starting point for teachers, educational developers and others who are looking to work with 21st century competencies and want to further investigate how students can be supported in computing with concepts using tangible, computational tools.

Further research should adapt computing with concepts using tangible, computational tools for testing in other contexts and explore how to further develop this CT method to enhance the integration of the social framing – students' creation of computational artefacts - and to bring into play the critical framing with the goal of strengthening students' development of 21st century competencies within the categories *Ways of working* and *Living in the world* respectively.

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Appendices

Appendix 1. Design pattern for the integration of computing with concepts using computational tools in Media Studies

The design pattern below describes how to implement the non-STEM CT method, computing with concepts using tangible computational tools, in courses or modules in the field of media studies.

<table>
<tr><td>Target group</td><td>HE Teachers and students in the field of Media Studies</td></tr>
<tr><td>Context</td><td>Suitable for students' systematic investigation of abstract concepts and for generating, sharing, discussing, providing, and receiving feedback on ideas for papers and projects.</td></tr>
<tr><td>Teaching method and tool</td><td>Situated and embodied learning using a tangible, computational tool. Learning with CT in the humanities in HE. Non-STEM CT method.</td></tr>
<tr><td colspan="2">Learning outcomes
After the activity, students will be able to:
Knowledge goals:
• account for the 3 layers in the model of the media system and its surroundings.
• identify the components of each layer.
Skills goals:
• choose components from the model of the media system and its surroundings and use these for the analysis of specific media systems.
Competency goals:
• analyse cases/problems and assess and discuss what components from the model of the media system and its surroundings apply.
• generate relevant and interesting problems by combining concepts from the three layers of the model: media system levels, media system actors and social macro structures, using the idea generation tool.
• use fellow students as sparring partners in relation to the identification, analysis, assessment and generation of ideas/problems.</td></tr>
<tr><td colspan="2">Materials needed and preparation
Instructions for students, scissors, punch screws, paper board in five different colours, pens and metal clips. Each of the four circles of the idea generation tool are printed on paper board in the relevant number of copies – one for each student. Use a different colour for each circle. Print the selection triangle on dark grey paper board – one per student. Assemble sets of materials for students, see Figure 4 below. Note: to save time, the teacher can cut out the selection triangles and punch holes in the paper board circles and selection triangle, so that students only have to cut out the circles and assemble the idea generation tool. A discussion forum or similar on the institution's learning platform is also needed where students can upload their response to reflection questions and images of their completed idea generation tools. If you think students will be more comfortable uploading their response for the teacher alone, consider using an assignment, journal or similar tool where only the teacher can access students' papers.</td></tr>
</table>

Figure 4. Top left: set of materials for students. Top right and bottom left: how to fasten the disks and marker triangle with the metal clip. Bottom right: the assembled idea generation tool. Illustration from Christensen (2023).

Student preparation Ideally, students should read or reread Vestergaard (2007) to familiarise themselves with his model of media systems and their surroundings. Ask students to think about and make a note of empirical cases that they find interesting in relation to their synopsis.	
Step by step description of activity	
Time	Activity
Introduction (10 minutes)	Introduction by the teacher.
Individual work (20 minutes)	Each student is given a set of materials and instructions. Students cut out the circles and assemble their own idea generation tool. They now write empirical cases they find relevant in the outer white circle and explore what perspectives could be relevant and interesting by turning the three circles of the media systems model. When students arrive at an interesting combination, they make a note of this and then explore further combinations.

Group work, round 1 (20 minutes)	Students work in groups of three. Each group member in turn shares and discusses his/her ideas with the other two group members who ask questions and provide ideas for new perspectives.
Group work, round 2 (20 minutes)	New 3-person groups are formed and students repeat the sharing and discussing mentioned above, exploring, developing and delineating ideas.
Plenary session (15 minutes)	Plenary session facilitated by the teacher where a number of students are asked to share their ideas.
Individual reflection (10 minutes)	Students revise their ideas/problem formulations on the basis of the feedback received from fellow students and the teacher. Students post their responses to reflection questions online together with images of the ideas they developed using the idea generation tools. *Reflection questions* Reflect on your experiences using the idea generation tool by responding to the questions below. • What was easy? How? • What was difficult or challenging? Why? • Did you come to a halt somewhere in the activity? Where and why? • What have you learnt? o About the media system and its surroundings? o About generating problem formulations? o Other? • What is your next step? How do you move on?
Can be provided on request	Teacher intro Instructions for students Template for idea generation tool

Appendix 2. Design pattern for integrating computing with concepts using computational tools in Philosophy

The design pattern below describes how to implement the non-STEM CT method, computing with concepts using tangible computational tools, in modules, courses or workshops that involve idea generation in relation to, e.g., the bachelor project.

Target group	HE Teachers and students in the field of Philosophy
Context	Suitable for students' systematic investigation of abstract concepts and for generating, sharing, discussing, providing, and receiving feedback on ideas for papers and projects.
Teaching method and tool	Situated and embodied learning using a tangible, computational tool. Learning with CT in the humanities in HE. Non-STEM CT method.

Learning outcomes

After the activity, students will be able to:

Knowledge goals:

- identify the components of the good problem formulation.
- explain the type of question words that can be included in a problem formulation.
- list relevant theories and methods.

Skills goals:

- combine topic/problem, question word, theories and methods using the idea generation tool.
- explain what methods are possible in relation to one or more selected theories.

Competency goals:

- generate ideas for problem formulations that delineate topic, relevant theories and feasible methods using the idea generation tool.
- assess what theories and methods are relevant and applicable in relation to a selected topic/problem and question word.
- reflect on own learning, including how one's own learning is supported by tools such as the idea generation tool.
- use fellow students as sparring partners in relation to idea generation and problem formulation.

Materials needed and preparation

Instructions for students, scissors, punch screws, paper board in five different colours, pens and metal clips. Each of the five circles of the idea generation tool are printed on paper board in the relevant number of copies – one for each student. Use a different colour for each type of circle. Print the selection triangle on dark grey paper board – one per student. Assemble sets of materials for students. Note: to save time, the teacher can cut out the selection triangles and punch holes in the paper board circles and selection triangle, so that students only have to cut out the circles and assemble the idea generation tool. A discussion forum or similar on the institution's learning platform is also needed where students can upload their response to reflection questions and images of their completed idea generation tools. If you think students will be more comfortable uploading their response for the teacher alone, consider using an assignment, journal or similar tool in which only the teacher can access students' papers.

Student preparation

Students were asked to prepare as follows:

Form an overview of the theories and methods you have met through your studies

Think of possible topics for your bachelor project

Read the chapter on problem formulations in Rienecker and Jørgensen (2017)

Step by step description of activity	
Time	**Activity**
Introduction (15 minutes)	By the teacher: Introduction to the good problem formulation Review of exemplars explaining the individual components
Group work (30 minutes)	Each student is given a set of materials and instructions. Students cut out the circles and help each other fill in topics/problems of interest, theories and methods.
Individual work (15 minutes)	Students now assemble their own idea generation tool and individually explore possible combinations of concepts from the different disks. When students arrive at an interesting combination, they make a note of this and then explore further combinations.
Group work (15 minutes)	Students work in groups of three. Each group member in turn shares and discusses his/her ideas with the other two group members who ask questions and provide ideas for new perspectives.
Plenary session (15 minutes)	Plenary session facilitated by the teacher where a number of students are asked to share their ideas.

Individual reflection (10 minutes)	Students post their responses to reflection questions online together with the problem formulations developed and images of their completed idea generation tools.
	Reflection questions
	Reflect on your experiences using the idea generation tool by responding to the questions below.
	• What was easy? How?
	• What was difficult or challenging? Why?
	• Did you come to a halt somewhere in the activity? Where and why?
	• What have you learnt?
	    ○ What have you learnt about writing problem formulations and about the components of a good problem formulation?
	    ○ What have you learnt about question words, theories and methods?
	    ○ Other?
	• What is your next step? How do you move on?

Can be provided on request	Teacher intro Instructions for students Template for idea generation tool

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