PhD Thesis

Computing with concepts using tangible, computational tools

Developing design principles and patterns for the integration of computational thinking with computational things in humanistic subjects in higher education

Colophon

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Developing design principles and patterns for the integration of computational thinking with computational things in humanistic subjects in higher education

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Makroniveau
Hele medie-
systemet
Borgere

Organisationer
Teknologi

Contents

English abstract

Computational thinking (CT) is a vital skill today; needed for being a competent employee in the increasingly digital workplace, but also for being a competent individual and citizen in our increasingly digital society. There is thus a need to integrate CT at all educational levels and across all subjects. Current research and implementation efforts have focused on K12 and STEM subjects, and few studies concern the integration of CT in subjects outside STEM in higher education (HE). Therefore, this thesis sets out to investigate how to integrate CT with computational things in humanistic subjects in HE. The thesis contributes theoretical perspectives and principled-practical knowledge regarding how such integration can be approached, as well as methodological insights.

The study reported in this thesis employs a design-based research (DBR) approach and three different humanistic subjects constitute empirical cases. Practitioners were involved as collaboration partners in the design and implementation of interventions.

The overall aim of the thesis is to investigate how CT with computational things can 1) be made relevant and useful to teachers and students in the humanities in HE and 2) support students in acquiring the competences needed for creative problem-solving within their subject. The thesis asks the following main research questions (RQs):

1. *What CT competences are especially relevant for humanistic subjects and how can they contribute to students' professional development?*
2. *How can computational things be made relevant for humanistic subjects in HE?*
3. *What design knowledge (design principles and design patterns) can support the integration of CT with computational things in humanistic subjects?*

The following five publications, that each constitutes a chapter in the thesis, explore and contribute answers to the RQs:

- *CT activities in the humanities in HE: A review of practices and proposals* (Christensen, to be submitted). This publication reviews practices and proposals for integrating CT in the humanities in HE to provide an overview of the current state of the field and identify issues for future research. No consensus was found regarding how to conceptualise or operationalise CT, but additional framings of CT as computational participation, critical CT, and computational literacy, were identified. A number of models for the integration of CT in subjects outside computer science (CS) were located, however, the humanities and HE were

underrepresented in these. For the review of practices and proposals, 19 papers with a total of 23 different CT activities for students in the humanities in HE were identified. Findings show that these were targeted primarily at undergraduates, seven different humanistic subjects were represented, and the majority of activities adopted a CT plugged format and learning CT as learning objective. Future research should work towards broadening the type of tools and approaches used with a particular focus on CT unplugged and the contextualisation of CT within specific humanistic subjects.

- *Integrating computational thinking in humanistic subjects in higher education* (Christensen, 2023b). This publication introduces the DBR-study and describes iteration 1 in detail. CT is defined as algorithmic problem-solving and operationalised as phases and competences. A theory- and challenge-driven approach was employed in which interventions were designed to respond to pedagogical challenges put forward by the practitioners, and designs were underpinned by situated and embodied perspectives on cognition and learning. The pedagogical challenge identified by practitioners was students' difficulties understanding the abstract concepts of their subjects and independently generating ideas for projects and papers. An unplugged CT method involving a tangible, computational thing, an idea generation tool, was developed and tested as a possible solution.

  The findings suggest that the tool developed supports students in systematically investigating possible combinations of abstract concepts, thus generating ideas. In addition, the tool enables students' subject-related conversations and their individual as well as collaborative exploration of subject-related concepts. However, some students reject the tool and explain that they prefer more abstract ways of learning in HE and in connection with their subject.

- *Creating Reusable Design Knowledge in Interdisciplinary Education: Current Methodological Practices and Issues* (Christensen & Markauskaite, 2024). This publication offers methodological insights via a review in which current practices for creating design knowledge in educational innovation are examined. Design knowledge is introduced as principled-practical knowledge that can guide researchers and practitioners in the design of educational interventions. This makes transparency and reusability essential. The review identifies two main pathways for the creation of design knowledge: 1) research first that draws on theories or empirical evidence, and 2) experience first that draws on current design practices, user needs or experiences. The conclusion is that methodological rigour and transparency are lacking which raises critical questions about trustworthiness, reusability, and usefulness.

- *Computing with concepts using tangible, computational tools: a 21st century competency for teachers and students in the humanities* (Christensen, 2023a). This publication introduces and contributes design patterns for the unplugged, non-STEM CT method developed in this study and explains the relevance and usefulness of the method to students in the humanities. The CT phases and associated competences made relevant to students in the method are abstraction, decomposition, data generation, mechanisation (more commonly labelled *automation*) and modelling. The CT method can support students' acquisition of 21st century competencies, since it offers novel, situated and embodied ways of thinking and working as well as new tools for working. It is suggested to further develop the method to also help students build 21st century competencies within the category: Living in the world.

- *Design Principles for Integrating Computational Tools in humanistic subjects* (Christensen, 2024). In the attempt to secure methodological transparency, the final publication explicates the iterative process of formulating and refining design principles while simultaneously undertaking theoretical studies to underpin both design and analysis of interventions. Preliminary as well as refined design principles are presented, and an account is given of the material turn of the study that was triggered by the discovery that some students in HE seem to reject tangible, computational things.

  The material turn consisted of additional, theoretical studies that led to the characterisation of the idea generation tool developed as a manipulative, i.e., a persistent and physically manipulable external representation of abstract concepts within the humanistic subject, it models. When perceived as a useful tool for the cognitive task at hand, the tangible, computational thing can support students' situated, interactive, embedded and embodied cognition and learning. However, the tool can constrain and obstruct students' cognitive work if they do not perceive it as the right tool. *The conclusion is that materiality matters in the integration of tangible, computational things in HE*.

The remaining chapters of the thesis elaborate on the issues of the five publications and report on the results of iteration 2.

The knowledge contributed in this thesis can inform future efforts to integrate CT unplugged in non-STEM domains in HE. To better match expectations with students, two strands of research are suggested: Since the CT method offered involves implicit CT, future research should develop and test activities in which students work with CT in more explicit ways. Likewise, it is suggested to involve students as co-designers to have their perspectives represented from the outset.

Dansk resumé

Computational tænkning (CT) er en vigtig kompetence i dag i relation til at være en kompetent medarbejder, men også i relation til at være kompetent individ og samfundsborger, da arbejdspladser og samfund i stigende grad digitaliseres. Der er således behov for at integrere CT på alle uddannelsesniveauer og i alle fag. Eksisterende forskning og implementeringstiltag har fokuseret på grundskole og ungdomsuddannelser samt STEM-fag, og få studier har beskæftiget sig med integration af CT udenfor STEM på videregående uddannelser. Derfor undersøger denne afhandling, hvordan CT med computationelle ting kan integreres i humanistiske fag på videregående uddannelser. Afhandlingen bidrager med teoretiske perspektiver og designviden i relation til mulige tilgange samt med metodologisk indsigt.

Studiet, der afrapporteres i denne afhandling, anvender en design-based research (DBR) tilgang med tre forskellige humanistiske fag som cases. Undervisere blev involveret som samarbejdspartnere ift. design og implementering af interventioner.

Afhandlingens overordnede mål er at undersøge, hvordan CT med computationelle ting kan 1) gøres relevant og meningsfuld for undervisere og studerende i humanistiske fag på videregående uddannelser og 2) understøtte studerende i at opbygge kompetencer i relation til kreativ problemløsning i deres fag. Afhandlingen stiller følgende overordnede forskningsspørgsmål:

1. *Hvilke CT-kompetencer er særligt relevante for humanistiske fag, og hvordan kan de bidrage til studerendes faglige udvikling?*
2. *Hvordan kan computationelle ting gøres relevante for humanistiske fag på videregående uddannelser?*
3. *Hvilken designviden (designprincipper og designmønstre) kan understøtte integrationen af CT med computationelle ting i humanistiske fag?*

De følgende fem publikationer, som hver udgør et kapitel i afhandlingen, undersøger og bidrager med svar på de tre forskningsspørgsmål:

- *CT activities in the humanities in HE: A review of practices and proposals* (Christensen, indsendes). Gennem et review af eksisterende tilgange og forslag til integration af CT i videregående humanistiske uddannelser, giver denne publikation et overblik over eksisterende forskning og identificerer problemstillinger af relevans for forskningen fremadrettet. Der er ikke konsensus, hvad angår konceptualisering og operationalisering af CT, men yderligere rammesætninger af CT som computationel deltagelse, kritisk CT og computationel literacy blev

identificeret. Der blev fundet flere modeller til integration af CT i fag udenfor datalogi. Imidlertid var humaniora og videregående uddannelser underrepræsenteret i disse. 19 artikler med i alt 23 forskellige CT-aktiviteter blev identificeret til reviewet af tilgange og forslag. Resultaterne viser, at aktiviteterne primært var rettet mod bachelor studerende, at syv forskellige humanistiske fag var repræsenteret, og at størstedelen anvendte et CT plugged (digitalt) format og læring af CT som læringsmål. Ny forskning bør have fokus på bredde i relation til typer af teknologi og tilgange med særligt fokus på CT unplugged (analoge formater) og kontekstualisering af CT i specifikke humanistiske fag.

- *Integrating computational thinking in humanistic subjects in higher education* (Christensen, 2023b). Denne publikation introducerer DBR-studiet og beskriver iteration 1 i detaljer. CT defineres som algoritmisk problemløsning og operationaliseres som faser og kompetencer. Der gøres rede for anvendelsen af en teori- og udfordrings-drevet tilgang, hvor interventioner blev designet som respons på pædagogiske udfordringer identificeret af underviserne, og designs blev underbygget teoretisk ud fra forståelser af kognition og læring, der fremhæver det situerede og betydningen af kroppen og eksterne ressourcer i læringsmiljøet. Den pædagogiske udfordring, som underviserne identificerede, var studerendes problemer i relation til at forstå fagets abstrakte begreber og selvstændigt genere idéer til projekter og opgaver. En CT-metode inklusive en analog, computationel ting, et idégenereringsværktøj, blev udviklet og testet som mulig løsning.

  Resultaterne viser, at det udviklede værktøj understøtter studerende i systematisk at undersøge mulige kombinationer af abstrakte begreber og på den måde generere idéer. Endvidere muliggør værktøjet studerendes faglige samtaler og deres individuelle såvel som kollaborative udforskning af fagbegreber. Imidlertid, afviser enkelte studerende værktøjet og forklarer, at de foretrækker mere abstrakte måder at lære på i deres videregående studier og ifm. deres fag.

- *Creating Reusable Design Knowledge in Interdisciplinary Education: Current Methodological Practices and Issues* (Christensen & Markauskaite, 2024). Denne publikation tilbyder metodologisk indsigt via et review, der undersøger eksisterende praksisser for udvikling af designviden ifm. innovation af undervisning og uddannelser. Designviden introduceres som principiel og praktisk viden, der kan guide forskere og undervisere i design af interventioner i uddannelsessammenhænge. Dette sætter fokus på transparens og genanvendelighed. Reviewet identificerer to overordnede tilgange til udvikling af designviden: 1) forskning først, der trækker på teori eller empirisk evidens, og 2) erfaring først, der trækker på eksisterende designpraksis, brugerbehov og -oplevelser. Konklusionen er, at der mangler metodologisk stringens og transparens, hvilket giver anledning til kritiske spørgsmål om pålidelighed, genanvendelighed og brugbarhed.

- *Computing with concepts using tangible, computational tools: a 21st century competency for teachers and students in the humanities* (Christensen, 2023a). Denne publikation introducerer til og bidrager med designmønstre på den analoge, non-STEM CT-metode, der blev udviklet i dette studie og forklarer dens relevans og brugbarhed for studerende på humaniora. De CT faser og kompetencer, der gøres relevante for studerende gennem metoden, er abstraktion, dekomposition, datagenerering, mekanisering (oftest benævnt automatisering) og modellering. Publikationen forklarer også, hvordan CT-metoden kan understøtte studerende i at erhverve sig kompetencer for livslang læring (21st century skills), da den tilbyder nye, situerede og kropsliggjorte måder at tænke og arbejde på, såvel som en ny type arbejdsværktøj. Det foreslås at videreudvikle metoden, så den også kan understøtte studerende i at erhverve kompetencer indenfor livslang læring-kategorien: ’leve i verden’.

- *Design Principles for Integrating Computational Tools in humanistic subjects* (Christensen, 2024). I et forsøg på at sikre metodologisk transparens gør denne sidste publikation rede for den iterative proces, det har været at formulere og finjustere designprincipper parallelt med teoretiske studier, der havde til formål at underbygge design og analyse af interventioner. Publikationen præsenterer foreløbige og finjusterede designprincipper og forklarer den materielle drejning studiet tog for at søge forklaringer på nogle studerendes afvisning af analoge, computationelle ting.

  Den materielle drejning bestod af yderligere, teoretiske studier som førte til en karakteristik af det udviklede værktøj som et ’manipulativ’, dvs. en blivende og fysisk manipulerbar ekstern repræsentation af abstrakte begreber indenfor det humanistiske fag, det modellerer. Når studerende opfatter værktøjet som brugbart ift. den kognitive opgave i fokus, kan den analoge, computationelle ting understøtte studerendes situerede, interaktive, indlejrede (embedded) og internaliserede (embodied) kognition og læring. Hvis værktøjet imidlertid ikke opfattes som det rigtige, kan det begrænse og obstruere studerendes kognitive arbejde og læring. *Konklusionen er, at materialitet har betydning i relation til integrationen af analoge, computationelle ting i videregående uddannelser.*

Afhandlingens øvrige kapitler uddyber emnerne behandlet i de fem publikationer og rapporterer resultaterne af iteration 2.

Afhandlingen bidrager med viden, der kan kvalificere fremtidige tiltag, der har til formål at integrere CT unplugged i fag udenfor STEM på videregående uddannelser. For at sikre bedre forventningsafstemning med studerende, foreslås to retninger: Eftersom den udviklede CT-metode involverer implicit CT, bør fremtidig forskning udvikle og teste aktiviteter, hvor studerende arbejder mere eksplicit med CT. Endvidere foreslås det at involvere studerende som co-designere, således at deres perspektiver er repræsenteret fra starten.

List of included publications

This section contains bibliographical information on the five publications included in this thesis.

Publication 1

Christensen, I.M. F. (to be submitted). *CT activities in the humanities in HE: A review of practices and proposals*

Publication 2

Christensen, I.-M. F. (2023b). Integrating computational thinking in humanistic subjects in higher education. In M. Specter, B. B. Lockee, & M. D. Childress (Eds.), *Learning, Design, and Technology*. Springer. https://doi.org/10.1007/978-3-319-17727-4_180-1

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Publication 3

Christensen, I.-M. F., & Markauskaite, L. (2024). Creating Reusable Design Knowledge in Interdisciplinary Education: Current Methodological Practices and Issues. In I.-M. F. Christensen, L. Markauskaite, N. B. Dohn, D. Ripley, & R. Hachmann (Eds.), *Creating Design Knowledge in Educational Innovation: Theory, Methods and Practice*. Routledge.

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Publication 4

Christensen, I.-M. F. (2023a). Computing with concepts using tangible, computational tools: a 21st century competency for teachers and students in the humanities. *Tidsskriftet Læring og Medier (LOM)*, *15*(27). https://doi.org/10.7146/lom.v15i27.134149

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Publication 5

Christensen, I.-M. F. (2024). Design Principles for Integrating Computational Tools in humanistic subjects. In I.-M. F. Christensen, L. Markauskaite, N. B. Dohn, D. Ripley, & R. Hachmann (Eds.), *Creating Design Knowledge in Educational Innovation: Theory, Methods and Practice*. Routledge.

1 Introduction

Computational thinking (CT) is an essential skill today; needed for being a competent employee in the increasingly digital workplace, but also for being a competent individual and citizen in our increasingly digital society. CT helps us understand the often hidden and opaque, computational processes involved in our use of apps and devices and can support us in using these on a more informed basis. In addition, CT offers computational methods and models that provide alternative and rigorous approaches to problem-solving and design of new, digital solutions. Therefore, it is suggested that CT be taught at all educational levels and across all subjects. This process is well on its way, especially for K12 (primary and secondary school) and for STEM subjects (science, technology, engineering, and mathematics).

However, CT has not yet gained foothold in subjects outside STEM in higher education (HE). Part of the reason for this may be that many efforts take a computer science (CS) approach to the development of CT learning activities which results in generic courses on programming, e.g. An alternative approach that should be examined is the extrication of CT from computer science (CS), its field of origin, and the contextualisation of CT within non-STEM domains. Approaching the integration of CT from this perspective, it becomes an exercise that, i.a., requires interdisciplinary involvement, rather than an exercise in developing CS education on CT for all.

The problem area in focus in this thesis is the integration of CT with computational things in humanistic subjects in HE, and the thesis contributes theoretical perspectives as well as principled-practical knowledge regarding how such integration can be approached. The study is exploratory and identifies, analyses and discusses opportunities as well as barriers using a design-based research (DBR) approach and three different humanistic subjects as cases. Practitioners are involved as collaboration partners in the design and implementation of interventions, and in a fourth case, students are included as collaboration partners in the investigation of alternative designs. In all cases, participants were recruited from the Faculty of Humanities at the University of Southern Denmark (SDU).

The study is part of a project funded by the Independent Research Fund Denmark *Designing for situated computational thinking with computational things* that investigates the integration of CT at all educational levels from kindergarten to tertiary education. This framing of the present study has brought with it two design constraints that relate to the theoretical underpinnings of interventions. One constraint is the belief that learning is situated and should be conceptualised as participation, hence the approach chosen for the design of interventions is an interdisciplinary one of contextualising CT within specific humanistic subjects. The other constraint is founded in a curiosity regarding how best to support humanities students in learning (with) CT and an interest in exploring embodied perspectives on cognition and learning as possible solutions. This links to the choice of investigating how to integrate CT with *computational things*.

The study focuses on students' and teachers' experiences and perceptions in relation to the integration of CT with computational things in their humanistic subjects. Thus, the study is primarily qualitative and will not report on effects in terms of students' subject-related learning outcomes or development of CT; it is participants' thoughts, experiences, and behaviours (Neuman, 2014) as they unfold in a naturalistic setting (Savenye & Robinson, 2005) that are central to the study.

The study has evolved since its conception in early 2020, as is often the case with DBR in which researcher and practitioners collaborate on the design and testing of interventions. A theory and challenge-driven approach to the design of interventions was adopted which meant that the participating practitioners contributed the subject-related, pedagogical challenges to be solved through design, and the researcher contributed the theoretical perspectives mentioned above of situated and embodied cognition and learning as well as CT. Interventions were thus co-designed and materialised in late 2020/early 2021 followed by a revision of aims and research questions to secure alignment between these and the interventions to be tested.

An important revision was the removal of one of the original aims to support students in decoding digital artefacts. Since interventions were based on CT unplugged, it would not be possible to pursue this aim. Furthermore, two of the four cases mentioned above were added during the study to test tool and activity in a new humanistic setting, and to explore alternative designs. Data collection methods were adjusted after each intervention. In addition, theoretical studies were undertaken to understand and conceptualise the phenomena uncovered during analysis of empirical data (diSessa & Cobb, 2004; Shavelson et al., 2003). The included publication, Christensen (2024), provides details of and reflections on this process.

An unexpected challenge in this study has been the lack of research in relation to the integration of CT with computational things in the humanities in HE. Rather than having a broad foundation on which to base my investigations, I have been working in parallel with other researchers across the world. Therefore, publication 1 (Christensen, to be submitted), a literature review that introduces the field of research, has been ongoing work not completed until spring 2023.

It has been a worthwhile effort, since the number of papers within scope almost doubled from 2019 to 2022.

1.1 Research questions

This thesis investigates how CT with computational things can be integrated in humanistic subjects at SDU in a way that 1) teachers and students experience as relevant and useful and 2) supports students in acquiring the competences needed for creative problem-solving within their subject. The specific purpose is to develop design principles and patterns for the integration of CT with computational things in humanistic subjects in HE. The following overall research questions are investigated:

1. *What CT competences are especially relevant for humanistic subjects and how can they contribute to students' professional development?*
2. *How can computational things be made relevant for humanistic subjects in HE?*
3. *What design knowledge (design principles and design patterns) can support the integration of CT with computational things in humanistic subjects?*

Based on the challenges identified by the participating teachers, the following more specific research questions were formulated to guide the empirical work:

- *How does computational thinking support students' systematic investigation of abstract concepts?*
- *How do computational things enable students' independent idea generation, and is this at all possible?*

1.2 What's in a name?

Key concepts are defined continuously in this summary account and included publications as they are mentioned and discussed in detail. However, the term *computational thing* will be discussed in brief here. Computational things are central in my research as 1) objects of theoretical study in relation to materiality and embodied cognition, and 2) tangible materials that are ideated, prototyped, tested, perceived, experienced, reflected on, and revised by stakeholders. Computational things as a theoretical theme are discussed in sections 7.3 and 7.4. With regards to computational things as an empirical theme, I have noted a proliferation of terms used both by myself and other stakeholders in the effort to capture and articulate our understandings of the tangible, computational things with which we have worked. Thus, in this thesis, the reader will meet a diversity of terms used to denominate what was conceived of and first dubbed the idea generation tool by myself and the participating practitioners. Among other expressions used are the disc, the wheel, and the carboard model, each name bringing to the forefront a particular quality of the tangible, computational thing in question.

The reader should also note the term ‘humanistic subject’ that is used to refer to a subject within the humanities such as philosophy, languages, media studies etc.

1.3 Delimitation

The intervention in iteration 1 at Media Studies consisted of other activities than the task in which students generated ideas using the tangible, computational tool. All in all, there were three rounds of tasks that the practitioner and I labelled the Media Systems Game However, to create a coherent narrative within the space available, only the task and subtasks involving the tool (round 3) is reported in this thesis.

Originally, the aim of the thesis was to contribute design principles, patterns and a HE pedagogy for the integration of CT in the humanities. However, due to the material turn of my research, i.e., the in-depth study of things and materiality, the latter was replaced by a theoretical framework, cf. chapter 7.

1.4 Outline of the thesis

This thesis is an anthology consisting of a summary account and five publications. Rather than presenting the summary account and publications separately, they are intertwined to form a coherent narrative. The following provides an outline of the organisation and contents.

Chapter 2 consists of publication 1 (Christensen, to be submitted) that introduces the field of research: the integration of CT with computational things in humanistic subjects in HE via a literature review. Chapter 3 is made up of publication 2 (Christensen, 2023b) that motivates and provides an introduction to the present DBR-study. It defines and makes operational CT and accounts for research approach and methodology. In addition, it provides definitions of design for learning, design principles and patterns. Furthermore, iteration 1 is described in detail from design, testing and analysis of collected data to revision of interventions.

The remainder of the thesis is divided into three strands that can be read independently of each other. The three strands elaborate on research approach, the theoretical framework and data analysis respectively to secure transparency.

Strand 1 consists of three chapters in which I present, discuss and reflect on the research approach selected, DBR (chapter 4), current strategies for creating reusable design knowledge in educational innovation (chapter 5 that consists of the included publication Christensen & Markauskaite (2024)), and data collection methods employed (chapter 6).

Strand 2 consists of chapter 7 that encapsulates the theoretical framework I contribute for design and analysis of learning activities with CT and tangible, computational things for the humanities in HE. It presents the views I adopt on CT with tangible, computational things, and situated and embodied cognition and learning. Strand 2 further communicates my suggestions regarding how these phenomena can be conceptualised and made relevant and useful to teachers and students in the humanities in HE.

Strand 3 consists of chapter 8. Empirical work and data analysis that provides details of as well as reflections on the data analysis method employed and reports the findings in relation to interventions in iteration 2.

The last chapters of the thesis pull together the three strands. Chapters 9 and 10 present the contributions of this study. Chapter 9 consists of publication 4 (Christensen, 2023a) that introduces a novel CT method for non-STEM domains accompanied by design patterns. Chapter 10 consists of publication 5 (Christensen, 2024) that visualises the theoretical framework and identifies the links between its different components. Chapter 10 also accounts for the design principles developed to inspire practitioners and scholars who work to integrate CT in non-STEM domains and reflects on the process of creating and refining these design principles. In chapter 11, analysis results and contributions are discussed in the light of the theoretical framework and relevant literature, and in chapter 12, conclusions are presented together with recommendations for future research.

2 CT activities in the humanities in HE: A review of practices and proposals

Publication 1. Author: Inger-Marie Falgren Christensen (to be submitted)

Abstract

This paper reviews practices and proposals for integrating computational thinking (CT) in the humanities in higher education (HE) to provide an overview of the current state of the field and identify issues for future research. Initially, already published reviews on CT in HE were examined as were models developed for the integration of CT in subjects outside computer science (CS). Reviews and models revealed that there is no consensus regarding how to conceptualise or operationalise CT. The examination of models provided additional framings of CT as computational participation, critical CT, and computational literacy. The existing reviews pointed out that the humanities and HE were underrepresented in research on CT, and the models studied reflect this tendency. However, in a systematic literature search, the present study identified 19 papers with a total of 23 different CT activities for students in the humanities in HE. Findings from the analysis of these activities show that they were targeted primarily at undergraduates. Universities in 13 different countries were covered in the sample, and seven different humanistic subjects were represented. Almost half of the identified activities were general education for undergraduates. The majority of activities adopted a CT plugged format and learning CT as learning objective. CT was in most cases understood as systematic problem-solving and as a universal skill. Future research should work towards broadening the type of tools and approaches used with a particular focus on CT unplugged. In addition, studies should explore how to realise the interdisciplinary potential by contextualising CT within specific humanistic subjects.

2.1 Introduction

In 1980, Seymour Papert used the term computational thinking (CT) as an aside in his seminal book *Mindstorms - Children, computers and powerful ideas*. Papert had a vision of "educationally powerful computational environments" in which novices could learn from experts in informal settings rather than traditional classrooms. "[S]amba schools for computation", he dubbed them. However, he expressed regret that "[t]heir visions of how to integrate computational thinking into everyday life was insufficiently developed" (Papert, 1980, p. 182). Papert was speaking of people who had experimented with, but failed to start up and run computer clubs and drop-in centers because their experiments were not advanced enough. Papert critised contemporary learning activities with computers for being cases of the “computer programming the child” (Papert, 1980, p. 19). Computers were used for drilling, providing corrective feedback and dispensing information. Papert, adopting a constructivist view on learning, wanted to reverse that practice and have children program computers.

Papert (1980) also envisioned that computers could bridge the fields of humanities and sciences by helping people engage with knowledge in new, interdisciplinary ways. His hope was that it would be possible to “construct intellectual environments in which people who today think of themselves as “humanists” will feel part of, not alienated from, the process of constructing computational cultures” (Papert, 1980, p. 5).

It was Jeanette Wing (2006, 2010) who popularised CT, as term, mindset and activity, when she announced CT as a fundamental and “universally applicable attitude and skill set” for all citizens and professions on par with reading, writing and arithmetic (Wing, 2006, p. 33). Wing further anchored CT firmly in computer science (CS) by stating that “[c]omputational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science” (Wing, 2006, p. 33); i.e., by “thinking like a computer scientist” (Wing, 2006, p. 34).

In a follow-up paper, Wing (2010) defined CT as “the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent” (p. 1). Wing was concerned with attracting more students to CS, and her writings led to a surge of implementation efforts in many countries with a particular focus on K12 education (Curran et al., 2019) and STEM (science, technology, engineering and mathematics) domains (Tang et al., 2020). Subsequently, there have been calls to integrate CT in all domains and at all educational levels (Caspersen et al., 2018); some with a particular focus on the integration of CT in domain-specific undergraduate contexts in higher education (HE) (Tekdal, 2021).

CT is argued to be important for engaging in most aspects of contemporary life, from being a competent citizen in a computational society (Barr & Stephenson, 2011), or a competent employee in the digital workplace (Tikva & Tambouris, 2021) to solving the challenges the globe is facing, such as climate change and shortage of vital resources (Grover & Pea, 2018). However, there is no consensus regarding how to define or operationalise CT and thus yet no consolidation of, or standards in, the field (Kite et al., 2021; Tekdal, 2021).

2.1.1 Research questions

To pave the way for increased research efforts into the implementation of CT in non-STEM domains in HE, this paper uncovers already existing practices and proposals to derive inspiration as to possible conceptualisations and operationalisations of CT, but also identifies issues for future research. Specifically, this paper explores CT in the context of the humanities in HE and asks the research question:

- *What are current practices and proposals for CT activities in the humanities in HE?*

The following sub-questions pin down the scope of and delimit the study:

- *In what contexts, specified as subject domain and level, are CT activities found?*
- *How is CT conceptualised for and operationalised in specific learning activities?*

A literature review was undertaken to examine current practices and proposals and answer the questions posed. This review contributes knowledge at the level of specific CT activities in the humanities in HE. It presents and discusses patterns in relation to how CT is operationalised for students and uncovers the conceptual foundations of existing practices and proposals.

Outline of the article

Initially, the article provides an overview of already published reviews on and models for the implementation of CT in HE with a particular focus on non-STEM domains. Then follows a section on the material and methods employed in the search, screening and analysis of literature for the review performed in this study. Subsequently, the results will be presented and discussed, followed by concluding remarks and recommendations for future research.

2.2 CT in higher education

Even though most research on CT in education has focused on K12, several reviews have been published on different aspects of CT in HE, e.g., Czerkawski and Lyman (2015), de Jong and Jeuring (2020), Lu et al. (2022), Lyon and Magana (2020) and Pérez-Jorge and Martínez-Murciano (2022). The following summarises conclusions from these reviews to provide an update on the field and identify issues of particular interest to non-STEM domains.

A general conclusion across the reviews is that research efforts have, so far, focused on CT in CS and STEM domains or on CT in teacher education within the two fields. Indeed, the review by Lyon and Magana (2020) focused on CT in

STEM domains, which illustrates this tendency. However, de Jong and Jeuring (2020), acknowledging the focus on CS in current research, also found that interventions were developed for a variety of domains and as general education for students not majoring in CS. The authors identified three interventions aimed at humanistic domains (communication, fine arts and music) and found programming assignments to be the main type of CT intervention.

Strands of research that point to strategies for the successful integration of CT outside CS were identified, such as research that endorses game-based learning to teach complex CT skills and research that points to the need for interdisciplinary involvement (Czerkawski & Lyman, 2015). Barriers to the integration of CT in non-STEM domains were also found, i.a., a lack of precision with regards to the meaning of 'computational' outside the domain of CS, and the perception that computational problem-solving is limited and not suited for the type of open-ended questions that are typically investigated in the humanities (Czerkawski & Lyman, 2015).

Lyon and Magana (2020) likewise concluded that definitions are vague and that there is little transparency as to how CT is operationalised in the classroom. The authors emphasised the need for research to address the issue of vague definitions, and to examine how to apply new pedagogies to CT activities and how to implement CT in domain-specific undergraduate education. The call for new pedagogies and implementation models were reflected in most reviews with Czerkawski and Lyman (2015) calling for methods, strategies, examples, and cases of CT, but with a particular focus on non-STEM domains. Whereas Lu et al. (2022) suggested that future research focus on the social component of CT since this aspect is often neglected in CT instruction but is important for the acquisition of CT skills.

With respect to future research, Lyon and Magana (2020) suggested design-based research as a possible way forward since it is a practical methodology, the purpose of which is to develop design principles in domain-specific contexts. In addition, the authors pointed out that current research approaches mainly rely on quantitative data and suggested that future research should make use of qualitative data, as well.

Pérez-Jorge and Martínez-Murciano (2022) took a different approach in their review and examined the use and effect of the applications Scratch and App Inventor, i.e., visual programming languages, in HE. The authors argued that the applications not only support the development of programming skills in students, but also the development of skills and competencies for learning, among which they count computational thinking. Most examples of use identified were in engineering and CS, but examples of the use of Scratch were also found in psychology, the creation of serious games and in humanities students' intercultural, multi-media production. Pérez-Jorge and Martínez-Murciano (2022) concluded in favour of their hypothesis and added that Scratch and App Inventor also support students' problem solving, social interaction and communication. However, they found that the applications were not often used in HE.

Models for the integration of CT in non-STEM domains already exist, and a sample of these are examined below.

2.3 Models for integrating CT in non-STEM domains

This section examines and discusses existing models for the integration of CT in non-STEM domains to identify approaches suggested in existing research. The literature raises several issues for consideration and points to opportunities where the integration of CT in non-STEM domains is concerned. Romero et al. (2017), e.g., argue that CT is a skill that can be transferred to domains outside CS, and that CT can be developed and assessed at all educational levels through solving ill-defined problems. Czerkawski and Lyman (2015) emphasise that CT activities must support the open-ended inquiries pursued in the humanities, and that introductions to CT should be tailored to the domain in question. This is in line with Denning and Tedre (2019) who state that "[c]omputational thinking is powerful, but not universal" (p. 15) and add that knowledge about the subject in which CT is integrated to solve problems is needed for successful application. Other scholars have proposed models for the integration of CT in subjects outside CS. Some of these are examined below to illustrate the diversity of current approaches.

Model 1: Barr and Stephenson (2011) extricated a set of concepts from the CS field for broad implementation in K12 subjects. They were interested in latching on to teachers' existing practices and examining the practical implementation of CT in classrooms. The authors stressed that the integration of CT in domains outside CT should be based on an understanding of problem-solving as algorithmic processes, and the identification of opportunities for using a computer to compute and manipulate data in the subject in question. The aim here was to distinguish problem-solving with CT from problem-solving practices already in use in domains outside CS. The authors defined CT as "an approach to solving problems in a way that can be implemented with a computer" and envisioned students as "tool users" as well as "tool builders" who engage in not only CT but also "computational doing" (Barr & Stephenson, 2011, p. 51). A model of core CT concepts and capabilities was provided together with proposals for integration in the K12 domains of CS, Math, Science, Social Studies and Language Arts (Barr & Stephenson, 2011, p. 52). The core CT concepts and capabilities presented in the model are data collection, data analysis, data representation, problem decomposition, abstraction, algorithms & procedures, automation, parallelisation, and simulation.

Model 2: Dong et al. (2019) developed a practical model to support K12 teachers in integrating CT in existing curricula, viewing CT as an approach that can be used "to facilitate problem solving across all disciplines (p. 908). The authors identified CT concepts that could be understood without students' engaging in coding activities and based on this created a model to help teachers contextualise CT and apply it in support of the learning goals of their subjects, i.e., learning with CT. Dong et al. (2019) singled out parallelisation and automation as two high level concepts that are unsuited for K12 and domains outside CS and proposed the use of a simplified vocabulary and set of skills to demystify CT with reference to Barr and Stephenson (2011). This resulted in the PRADA-model that incorporates the following four elements:

- **Pattern Recognition**: observing and identifying patterns, trends, and regularities in data, processes, or problems
- **Abstraction**: identifying the general principles and properties that are important and relevant to the problem
- **Decomposition**: breaking down data, processes, or problems into meaningful smaller, manageable parts
- **Algorithms**: developing step by step instructions for solving [a problem] and similar problems

(Based on Dong et al., 2019, p. 908)

The authors state that the four concepts can be integrated (on their own or intermixed) in domains outside CS by adapting existing lessons plans, thus establishing a fit with the pedagogical practices already adopted by teachers. Dong et al. (2019) stress that PRADA is "a mindset, not bounded by content area or tools, that helps people solve problems in a systematic and generalizable way" (p. 908). Thus, Dong et al. (2019), unlike Barr and Stephenson (2011), see CT as tool independent, i.e., implementable both with and without computers.

Model 3: A rather different approach that involves perspectives on cognition and learning, specific pedagogical strategies, as well as progression is presented in Piatti et al. (2022). The authors present the CT-cube which is a framework for the design, realisation, analysis as well as assessment of activities for the life-long development of CT skills. Examples in the paper, however, focus on K12. The authors highlight what they assert to be the situated nature of CT when applied to specific tasks, where others focus on CT as internal and individual thinking processes. The CT-cube therefore emphasises social context and artefactual environment and is based on the view that "cognitive activities are embodied, enacted and embedded in a situated cognitive system" (Piatti et al., 2022, p. 2). Subsequently, the authors define CT as a:

> **situated cognitive activity** (individual or collective), **consisting of three (eventually iterative) steps**: (1) setting **a contextualised problem** in such a way that its solution can be computed (**problem setting**), (2) conceiving and representing an algorithm, that should be implemented by an agent (human, artificial and/or virtual agent) in order to solve the problem (**algorithm**), and (3) assessing the quality of the solution with respect to the original problem (**assessment**). (Piatti et al., 2022, p. 2. Authors' original emphasis)

As the quote above illustrates, the authors see algorithms, not computers as necessary for CT, and an example of an unplugged CT activity for K12 is provided in the paper.

The CT-cube is a 3 x 3 x 3 matrix consisting of three dimensions:

1. Type of activity: problem setting, algorithm, and assessment.
2. Artefactual environment in use: embodied, symbolic, and formal.
3. Autonomy of the individual learner: inactive role, non-autonomous active role, and autonomous active role.

(Based on Piatti et al., 2022, p. 3)

The elements of each dimension are understood as consecutive with learners moving from one to the other as they build their knowledge and competences. Young and novice learners first engage with an embodied artefactual environment of, e.g., unplugged activities, then move on to a symbolic and finally a formal, artefactual environment. In this way, learners move from the tangible to the abstract in their development of CT.

The inclusion of perspectives on cognition and learning as well as specific pedagogical strategies in Piatti et al. (2022) is refreshing from the point of view of the learning sciences. Even though a situated perspective is purported, however, the CT-cube dimensions are still viewed from the individual learner. In addition, the benefits of tangible artifacts for embodied cognition seem to be reserved for young children, and thus only seen as beginner steps with respects to CT development.

Model 4: Based on a literature review of CT education initiatives in K12 and the conclusion that CT is most often realised as computer programming activities across subjects, Kite et al. (2021) propose a Computational Pedagogy. They conceptualise CT as an interdisciplinary practice and the purpose of their Computational Pedagogy is to support the integration of CT in subject domains outside CS. Computational Pedagogy is "constructivist in orientation [reference to Papert (1980)], engages students in systems thinking through complex problems, includes extensive work with data, and is built on contexts and [authentic] problems that are personally meaningful to students" (p. 13). The authors endorse the use of CT unplugged to let students build a knowledge foundation before engaging with computational tools.

Model 5: The models and proposals examined above all focus on K12 education, however, Dohn and Nørgård (2022) present a framework for mapping and developing CT activities in HE. The aim is to contribute to the integration of CT across subjects and faculties. Rather than endorsing one particular conceptualisation of CT, the framework provides an overview of different, existing conceptualisations: CT as problem-solving, participation and empowerment. Within conceptualisations of CT as problem-solving, Dohn and Nørgård (2022) further distinguish between three different views on problem-solving: as mental skills focusing on the 'thinking' in CT, i.e., the algorithmic processing of data (with reference to Caeli & Yadav, 2020), as competences-in-use (referring to Shute et al., 2017), and as activities/practices (with reference to Weintrop et al., 2016). In the first view, CT can take place plugged or unplugged, whereas the other two views revolve around classroom practices in relation to computerised problem-solving and data visualisation.

Dohn and Nørgård (2022) further expand conceptualisations of CT to include computational participation, referring to Kafai and Burke (2014), and computational empowerment with reference to Dindler et al. (2020). The goals of computational participation are listed as "creativity, personal expression and collaboration" (Dohn & Nørgård, 2022, p. 68) in a setting of students pursuing open-ended projects of their own choice. Computational empowerment is seen as involving both the "creative participation in computational practices" as well as the "critical assessment of the positive and negative roles of technology in everyday life" (Dohn & Nørgård, 2022, p. 68). There are parallels between the conceptualisations outlined by Dohn and Nørgård (2022) and the three framings of CT (in K12 CS education) suggested by Kafai et al. (2020), namely the cognitive, the situated and the critical.

The framework presented in Dohn and Nørgård (2022) also delimits CT activities from digital activities. The authors argue that digital activities are the use of digital artefacts where users do not engage directly with algorithmic processes, whereas they do in CT activities proper. However, they can do so via both analogue (unplugged) and digital (plugged) formats. Finally, the framework distinguishes between using programs and coding programs, referring to the use-modify-create (Lee et al., 2011) approach often used to scaffold novices' acquisition of programming skills. This leads to a framework of six dimensions (Dohn & Nørgård, 2022, p. 79):

A. Analogue CT
B. Digital CT where students use programs
C. Digital CT where students code programs
D. Digital activities that do not involve CT
E. Computational participation
F. Critical CT

The framework is visualised in Figure 2-13 on p. 52 where it is also explained in more detail.

With regards to algorithmic processes contained in CT, Dohn and Nørgård (2022) list the following as the "aspects [...] usually named as computational thinking" (p. 67):

- decomposition of the problem
- data analysis
- pattern recognition (abstracting patterns in the data)
- modelling (of the problem and of the identified patterns)
- algorithm design (design of step-by-step solution)
- automation of solution (coding and debugging)
- generalisation of solution to other problems

However, with reference to Chongtay and Robering (2016), the authors argue that the automation process is best left out where HE students in the humanities are concerned, since they are typically not interested in learning programming as an end in itself. Furthermore, it is stressed that the best way to engage humanities students in CT is to develop activities in which students work towards goals within their subjects.

One final conceptualisation of CT and a final framework for the integration of CT in non-STEM domains to be mentioned here is computational literacy and the Computational Literacy multi-layered framework.

CT as literacy

The integration of CT in domains outside CS is by some scholars viewed in a bigger perspective, namely CT as part of a new literacy. In the literature, CT is typically denominated as a basic, fundamental or universal skill, a 21st century skill or similar. It is compared to reading, writing and arithmetic as a necessary literacy (Wing, 2006) and described as a "foundational competency for being an informed citizen" (Grover & Pea, 2018, p. 20). It is in the light of this that the call for "CT for all" was launched and continue to drive implementation efforts.

Literacy can be defined as *"a socially widespread patterned deployment of skills and capabilities in a context of material support (that is, an exercise of material intelligence) to achieve valued intellectual ends*" (diSessa, 2001, p. 19, emphasis in original). This material intelligence can be added to purely mental intelligence and improve the mind by enabling relevant external extensions that have the potential to enhance our capabilities to "represent the world, to remember and reason about it" (diSessa, 2001, p. 5). Literacy is constituted by three foundational pillars (diSessa, 2001), namely:

1. The material pillar which is designed and relies on technology. It encompasses "external, materially based signs, depictions, or representations" (p. 6).
2. The mental or cognitive pillar that concerns how we couple with the external, materially based representations that constitute the material pillar.
3. The social pillar which emphasises that literacy is first and foremost social in that literacies are developed on the basis of what already exists and are products of history and culture; and, in addition, represent valued competencies in the latter. An individual can in most cases make use of a literacy on his/her own, the results, however, will most often be shared with others and be the object of discussion, sense-making, negotiation etc.

diSessa (2001) distinguishes between *computer* literacy, the skills to use computer applications, and *computational* literacy, the literacy of interest here. It covers the competencies to use computational devices to represent ideas and as resources for constructing and sharing understanding. Computational literacy includes social aspects such as computational participation, collaborative creation, communication and learning (Chongtay, 2018), cf. the social pillar of literacy mentioned above (diSessa, 2001).

Model 6: Chongtay (2018) proposes a Computational Literacy multi-layered framework. The author understands computational literacy as a skill set to be used in all domains, not only CS, and points to computational participation as a way to learn this computational literacy skill set. The Computational Literacy multi-layered framework builds on experience from programming courses in HE that combine humanistic subjects and ICT. The goal is to learn programming as a tool for other ends, rather than a subject in itself.

The CT concepts decomposition, pattern recognition, algorithm design and generalisation form the first, fundamental layer in the framework proposed by Chongtay (2018). The layer builds on Wing's definition of CT and CT as a problem-solving process and can be taught in any domain using unplugged approaches. After the CT layer, follow layers aligned with the use-modify-create approach (Lee et al., 2011) to learning programming. This is to lower the threshold and ease novices into programming from the use and modification of existing code and/or computational artefacts to the independent creation of computational artefacts. The Computational Literacy multi-layered framework is an example of the code-centric nature of many operationalisations of CT (Kite et al., 2021), however, the incremental approach scaffolds students learning and stresses programming as a tool to reach other ends determined by the subject in question. In addition, the framework contains a progression from unplugged to plugged as was the case in Piatti et al. (2022).

Lessons learned from the examination of models

The six models presented and discussed above are all of a general nature, i.e., aimed broadly at subjects outside CS. Subjects within the humanities are mentioned but are not the sole focus of any model. In addition, four out of the six models focus on K12. The above examination of models highlights the often-reported lack of agreement in relation to how CT should be conceptualised and operationalised when integrated into domains outside CS. However, the collection of approaches, disparate though they may be, also points to several general ideas; one is the extrication of CT from CS to create a more comprehensible vocabulary, and another is the contextualisation of CT within the target subject. A third concerns the conceptualisation of CT as systematic and generalisable problem-solving in relation to contextualised or authentic problems. One of the main points of contention seems to be whether CT requires the use of a computer or can be supported via analogue and unplugged means. CT unplugged refers to learning activities that do not involve computers or other digital devices (Huang & Looi, 2020) and originates in the CS Unplugged movement. CS Unplugged promotes the learning of CS without computers and contributes what is also labelled off-line activities and games for all ages (Bell et al., 1998).

Another point of disagreement to be mentioned concerns the conditions that must be met for something to counts as a CT activity. Can CT be realised by integrating individual elements, such as e.g., pattern recognition or decomposition (this is the position in e.g., Dong et al., 2019), or is CT a process of problem setting, and design, test and evaluation of an algorithm, i.e., sequential problem-solving (as suggested in e.g., Piatti et al., 2022)?

The models examined above also differ in their view on pedagogical strategies for implementing CT in the classroom and which perspectives on cognition and learning to adopt when developing CT activities. E.g., Barr and Stephenson (2011) and Dong et al. (2019) seek to establish models that support teachers in integrating CT in their existing teaching practice. Whereas, e.g., Piatti et al. (2022) suggest new approaches in the classroom based on situated and embodied views on cognition and learning.

2.4 Material and methods

This section describes and reflects on the search, filtering and analysis procedure used for this review.

The search started in December 2019, when I created a Scopus search alert with a query for papers on computational thinking and HE. Using the filters available in Scopus, the search was limited to the subject areas: social sciences, psychology and arts and to English language. I received regular notifications of new publications via emails. Titles in these emails were screened manually. For titles that indicated a match with the search criteria for the present review, abstracts were retrieved and screened manually. Papers that appeared to fit the scope of the review were retrieved and saved for later processing. Papers were also found via Google Scholar searches using keywords such as computational thinking, humanities and higher education, and synonyms for these.

In June 2023, I conducted a systematic database search using ERIC ProQuest, since it is the world's largest education database and provides international coverage. The search matrix shown below in Table 2.1 was used to delimit the search to the scope of the present study but employing synonyms to avoid potential bias. 'Programming' and 'coding' were deliberately excluded from the Topic column in the search matrix to avoid tapping into research on how best to teach programming to humanities students and secure that the focus remained CT.

Table 2.1. Search matrix used for systematic database search

Topic	Focus	Context 1	Context 2
Computational thinking	Teaching	Higher education	Humanit*
CT	Learning	Undergraduate	Art*
Procedural thinking	Activit*	Postgraduate	Philosophy
Algorithmic thinking	Course	College	Media Studies
Computational tools	Module	Tertiary education	Communication Studies
Computational things	Program*		History
CT unplugged			Language*
			Literature
			Design research
			Cultur* studies

In the manual screening, I discovered that 'CT' was not a helpful keyword in this connection, since papers on critical thinking (CT) were recovered. Therefore, it is recommended to add NOT critical thinking to the search string when undertaking similar studies.

In addition to the above, papers were also found via snowballing from, e.g., literature reviews on CT in HE.

Inclusion and exclusion criteria

In the screening process, the following inclusion and exclusion criteria were applied.

Only papers in English were included. Only papers that could be retrieved via open access or the university library were included. Reviews on CT in HE were retrieved to enable snowballing, as described above, and to study the general trends in the area. They were not included in the review itself. In several cases, the activities were stated to be universal or general courses targeting all undergraduate students or all humanities students. In all cases, the paper in question was included in the study. In some cases, the paper reported on the development of platform and tools for the computational scaffolding of students' learning. These papers were likewise included since they fitted the scope of CT for HE humanities students.

Papers dealing with CT activities at other levels than tertiary education were excluded, as were all papers that reported STEM subject as the focus. Papers that more generally presented and discussed the potential application of CT in the humanities and/or HE were excluded.

Search and filtering procedure

PRISMA guidelines (Page et al., 2021) were followed in the identification and screening process. Figure 2-1 below describes the results. References, titles, abstracts and other metadata were imported to the MS Office application Excel for the screening procedure.

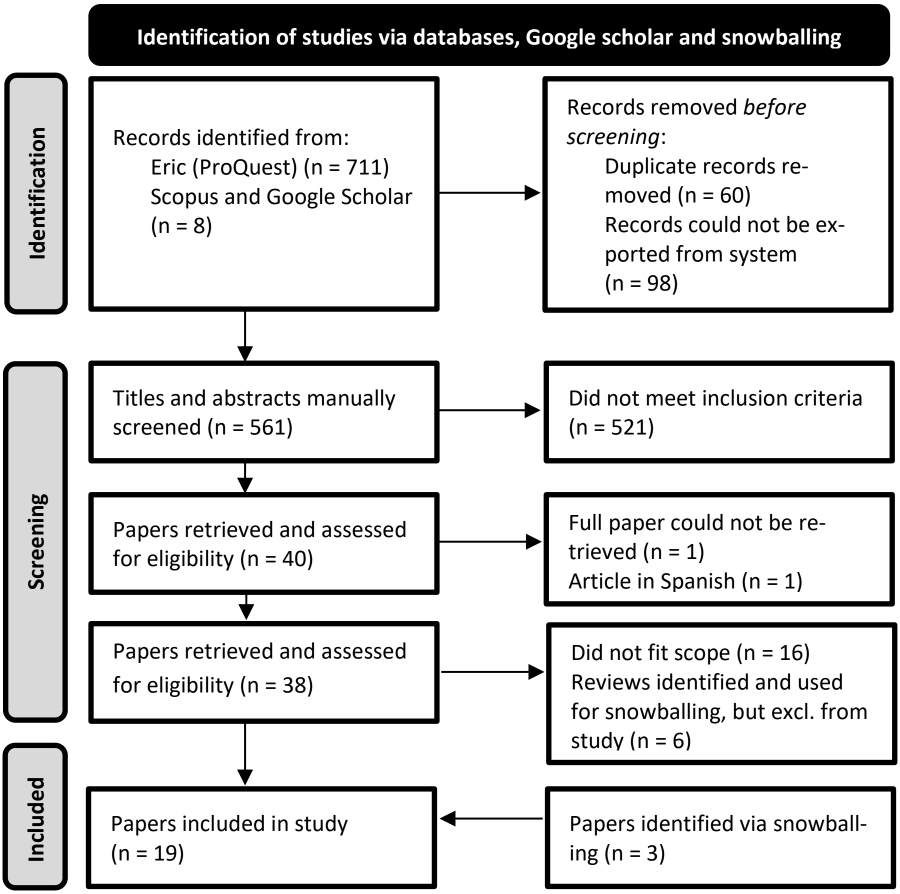

Figure 2-1. Flow diagram of the literature identification and screening process. Based on PRISMA 2020 (Page et al., 2021)

Analysis method

This study is a mapping review that maps out and categorises CT activities reported in research papers by identifying key features (Grant & Booth, 2009). The mapping is to illustrate the humanistic contexts in which CT is integrated and characterise the CT activities identified according to operationalisation and conceptualisation. Therefore, the following key features were targeted for analysis, lending inspiration from the current CT research described and discussed above:

Humanistic context:

- In which humanistic subjects is CT integrated?
- At what level of HE?

- What is the nature of activities? (test of tools, experiments, courses, student projects etc.)

Operationalisation:

- Contextualisation: to which degree is CT intertwined with the subject domain? This is assessed via the learning objective: Do students learn CT or do students learn another subject with CT?
- Format: Which format is used? CT plugged or unplugged?
- Which tools are used?
- Which algorithmic processes are in play and which forms of engagement?
- What pedagogical strategies and learning theoretical perspectives are adopted?

Conceptualisation:

- How do identified activities map onto Dohn and Nørgård's (2022) six-dimensions framework?

With regards to the use of the framework presented in Dohn and Nørgård (2022) for mapping CT activities, the framework helps one distinguish between different types of activities and separate "merely" digital activities from CT activities proper. In addition, the framework contributes a nuanced view regarding potential types of CT activities, illustrating that these can be both analogue and digital in format and can concern both the use and coding of programs. Furthermore, the model highlights computational participation and critical CT as two essential elements in motivating students to engage not only actively, but also critically with computational thinking and devices, and reflect on impacts, opportunities and limitations. As such the framework provides an overview of the CT landscape and will be able to capture the potential diversity found in existing practices and proposals.

An analysis tool was set up in an Excel spreadsheet with a column for each key feature mentioned above, see Table 2.2. This method is inspired by Schirmer (2018) who proposes it as a technique that can be used to identify the key components of papers included in a literature review. Each included paper was listed in a row in the table, and the results of the analysis were added to the appropriate cells. Following this, patterns could be identified and examined.

Table 2.2. Tool for analysis of included literature

Ref.	Year	Title of activity	Nature of activity	Educational level	Programme/ subject	Country	Purpose	Learning objectives
			Development and test of platform and tools Experiment Pilot course Pilot semester course and project Pilot semester project Proposal for a teaching and learning model Semester course Semester course with project Semester project				Overall purpose of activity	Learning CT Learning with CT

Operationalisation of CT/format	Tools	Algorithmic processes and engagement	Learning theory and pedagogy	Conceptualisation of CT
CT plugged CT unplugged		Which processes and what engagement? Use, modify, create	As formulated in the paper	As formulated in the paper

2.5 Presentation of findings

Papers retrieved for screening showed much diversity, from a single-session activity to teach algorithms to university students (Katai, 2020) to a call for decolonial computing, i.e., the critical examination of artificial intelligence (AI) ethics in HE (Zembylas, 2023). Some papers contributed a more general discussion and endorsement of the integration of CT in a specific subject, such as CT and creative coding in art education (Knochel & Patton, 2015). Other papers discussed CT in relation to a specific pedagogy, e.g., CT as facilitator of problem-based learning (Jonasen & Gram-Hansen, 2019). As mentioned above, papers of a more general nature were excluded to focus on the level of concrete learning activities.

In order to give the reader a feel of the body of literature included in this study, this section first provides details in relation to the CT activities identified in terms of geography, publishing year, educational level, subject domains and nature of activities. Subsequently, the CT activities will be mapped and categorised as explained above.

As illustrated in Figure 2-1 above, 19 papers were included in the study. These cover a total of 23 CT activities, since Dierbach et al. (2011) report three relevant activities, while two relevant activities are reported in Møller et al. (2022) as well as in Perković et al. (2010). Geographical dispersion was found in that HE institutions in 13 different countries were involved in the development, testing and/or delivery of CT activities, see Table 2.3 below. Table 2.3 provides an overview of the 19 included papers and the nature and context of the 23 CT activities involved. The papers are listed chronologically which reveals that they cover a timespan from 2006 to 2022 with the major part (14 papers) published between 2016 and 2022. This reflects the general trend in research publications on CT that has experienced exponential growth since 2013 (Tekdal, 2021).

Across the papers, there was no consistency in terms used to describe the nature of activities presented. Terms such as experiment and pilot was used both about trials outside and inside regular courses and classrooms. The reason for this divergence is that authors focused on describing the nature of their research study rather than of the learning activity itself. Therefore, in order to compare the nature of the 23 CT activities, the following terms will be applied in this study, cf. the column Nature of activity in the table below. The term *experiment* is used to denote activities that were tested with students outside of regular course activities and classrooms. The term *pilot* is used to denote activities that were developed and trailed as regular courses. The term *proposal* is used to denote specific suggestions for CT activities that have not been tested with students. *Semester course* or *project* refer to regular course activities that involve CT. The last category is *development of tool* that denotes that the focus is the testing of platform and tools in different stages of development rather than, e.g., implementation in courses.

Table 2.3. Overview of included papers and nature and context of CT activities

No	Author and year	Title of activity and short description	Nature of activity	Educational level	Programme/ Subject domain	Country
1	Liou et al. (2006)	*TOTALrecall platform*: Online English language-learning tools and activities that focus on aspects of reading, writing, and culture. Interacting with an adaptive, intelligent tutoring system, completing written exercises and translations and receiving automated feedback to learn English	Development of platform and tools. Tested on students for formative evaluation of tools	Undergraduate (Intermediate learners)	English learners. English majors and non-English majors	Taiwan
2a	Perković et al. (2010)	*Introduction to game design*. Game analysis and game design	Semester course	Undergraduate	General education, Arts and literature	USA
2b		*3-D modelling*. Introduction to modelling and texturing techniques. Programming 3D objects and scenes for animation and gaming	Semester course	Undergraduate	General education, Arts and literature	USA
3a	Dierbach et al. (2011)	*Everyday computational thinking*. Programming a computational solution to an everyday problem	Pilot semester project	Undergraduate	General education	USA
3b		*Computational thinking in the humanities*. Text-analysis using computational concepts, discussion of limitations, working computationally with a text	Pilot course	Undergraduate	General education, English	USA
3c		*Computational thinking: Creative work with audio and video*. Working computationally with audio and video, reflective writing	Pilot course	Undergraduate	General education, Music	USA

No	Author and year	Title of activity and short description	Nature of activity	Educational level	Programme/ Subject domain	Country
4	Poitras and Lajoie (2014)	*MetaHistoReasoning tool for inquiry-based learning*. Interacting with an adaptive, intelligent tutoring system and receiving corrective, automated feedback to learn about and train skills used in historical inquiries	Development of tool. Tested on students	Undergraduate	History	Canada
5	Evia et al. (2015)	*Creating user documentation*. Working with a structured, automated authoring workflow to create user documentation	Semester course	Undergraduate	Professional writing program	USA
6	Boyle and Hall (2016)	*Reading Don Quixote*. Collaborative translation, digital and computational reading of text, assessment of apps, assessment of physical and digital reading	Semester course	Undergraduate	Spanish majors	USA
7	Feng et al. (2016)	*CyWrite*: Academic writing for nonnative speakers of English. Writing academic English with an automated writing evaluation tool and automated, formative feedback	Development of tool. Tested on student essays to improve system	Undergraduate	English as a second language (ESL)	USA
8	Sáez López et al. (2016)	*Creative coding and intercultural project*. Creating multimedia content using visual, block programming. Interacting and communicating with students from other universities online	Semester project	Postgraduate	European Master in Media Engineering for Education	Japan, Mexico, Spain
9	Pollock et al. (2019)	*Computational thinking in music*. Establishing a joint music vocabulary and terminology basis, creating a computerised corpus, then writing verses algorithmically	Pilot course	Undergraduate	Music	USA

No	Author and year	Title of activity and short description	Nature of activity	Educational level	Programme/ Subject domain	Country
10	Öhman (2019)	*Introduction to language technology*. Working with language technology tools and practicing methods	Semester course with project	Undergraduate	Minors and majors in Linguistics and in Language technology	Finland
11	Katai (2020)	*Six-stage learning session on sorting algorithm*. Watching folk-dance illustrations and animations of the bubble-sort algorithm, reconstructing and orchestrating the algorithm	Experiment	Undergraduate	General education	Romania
12	Byrka et al. (2021)	*A universal five-step sequence of algorithm development adapted for HE*. A proposal for a five-step sequence to follow to develop algorithms for problem-solving in relation to learning and everyday issues	Proposal for model for teaching and learning algorithmic thinking	Not specified	General education for university students outside ICT	Ukraine
13	Lin et al. (2021)	*CT education for humanities students*. Training in CT and visual, block-based programming via Scratch. Designing and implementing an English teaching assistant robot	Pilot semester course and project	Undergraduate	General education for humanities students. Tested on students from the Foreign language department	Taiwan
14	Pipitgool et al. (2021)	*Critical thinking problem-solving activities*. A proposal for a flipped classroom learning management model where students complete analytical problem-solving activities following a six-step model engaging with CS unplugged and programming exercises	Proposal for a flipped classroom learning management model	Undergraduate	General education	Thailand

No	Author and year	Title of activity and short description	Nature of activity	Educational level	Programme/ Subject domain	Country
15	Lai et al. (2022)	*Web programming (web design)*. Using HTML and JavaScript applications to create websites in a flipped learning course	Pilot course	Undergraduate	Department of e-learning design and management	Taiwan
16a	Møller et al. (2022)	*Programming and prototyping* (compulsory). Introduction to concepts. Engaging with training exercises and pair programming. Completing programming project	Semester course with project	Postgraduate	Master's programme in IT, Humanities	Denmark
16b		*Computational thinking* (elective). Lectures, peer discussions, reflections on CT as concepts, practices and perspectives, analysis of technology and software programs	Semester course	Postgraduate	Master's programme in IT, Humanities	Denmark
17	Satavlekar et al. (2022)	*Engage in real-life computational problem-solving scenarios using IoT devices*. Designing computational solutions to real-life problems using IoT devices and utility platforms, and responding to reflection questions from mentor	Experiment	Undergraduate	General education for novice CT learners – tested on Sanskrit students	India
18	Wang et al. (2022)	*Visual AI (artificial intelligence) course*. Introduction to basic knowledge and concepts. Building an AI platform environment, practicing on the platform and engaging in practical exercises	Experiment	Undergraduate	AI curriculum for non-information engineering students	Taiwan
19	Youjun and Xiaomei (2022)	*College English Writing* (compulsory). Non-English majors are guided through five CT-based steps to improve their grammar knowledge and application. Students compute with words	Pilot course	Undergraduate	Non-English majors	China

Educational level, nature of activities and subject domains

The majority of CT activities were developed for undergraduate students, as is illustrated in Table 2.3 above. Pilot courses and semester courses were the most common nature of activities, followed by experiment and development and test of platforms and tools, cf. Figure 2-2 below.

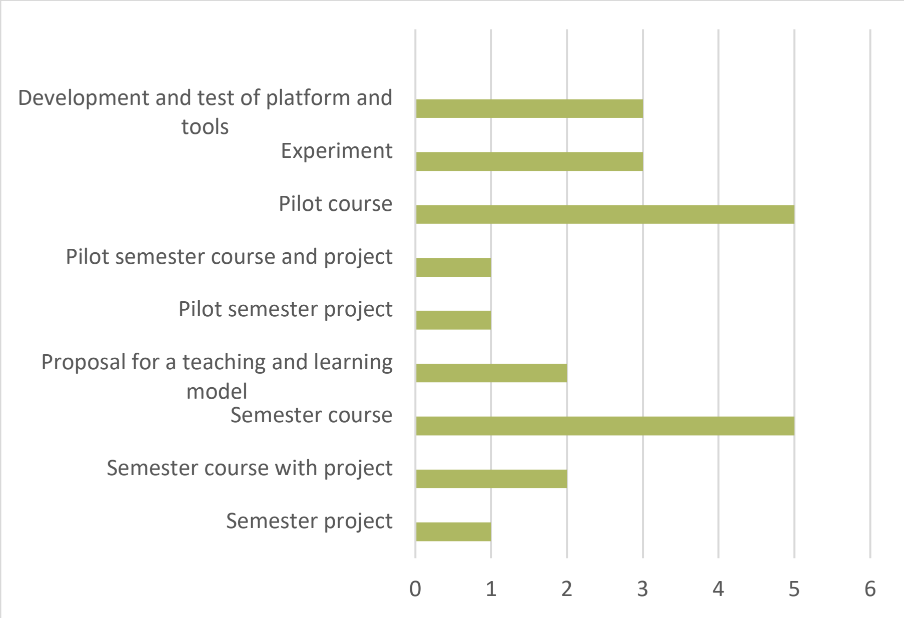

Figure 2-2. Nature of activities represented in this study

Seven different humanistic subjects were represented in the sample of CT activities (Table 2.4), namely education & technology, history, human-centred informatics, languages, linguistics & language technology, music, and writing. Together, these seven subjects comprise 12 of the 23 CT activities with languages being the most dominant. The remaining 11 activities fall within the category of general education for either 1) all undergraduates, 2) novice CT or programming learners, or 3) students within specific subject-disciplines and the humanities in general. Thus, quite a large number of activities seems to respond to the call for CT for all and conceptualises CT as a universal, 21st century skill. This will be explored further below.

Table 2.4. Overview of subjects represented and titles of activities within each subject

Subject domain and title of activity
Education and technology • Creative coding and intercultural project (Sáez López et al., 2016) • Web programming (web design) (Lai et al., 2022)
General undergraduate education *For all undergraduates* • Everyday computational thinking (Dierbach et al., 2011) • Six-stage learning session on sorting algorithm (Katai, 2020) • Critical thinking problem-solving activities (Pipitgool et al., 2021) *For novice CT or programming learners (students outside the CS field)* • A universal five-step sequence of algorithm development adapted for HE (Byrka et al., 2021) • Engage in real-life computational problem-solving scenarios using IoT devices (Satavlekar et al., 2022) • Visual AI (artificial intelligence) course (Wang et al., 2022) *For students within humanistic subjects and the humanities in general* • Introduction to game design (Arts and literature) (Perković et al., 2010) • 3-D modelling (Arts and literature) (Perković et al., 2010) • Computational thinking in the humanities (English) (Dierbach et al., 2011) • Computational thinking: Creative work with audio and video (Music) (Dierbach et al., 2011) • CT education for humanities students (Lin et al., 2021)
History • MetaHistoReasoning tool for inquiry-based learning (Poitras & Lajoie, 2014)
Human-centred informatics • Programming and prototyping (compulsory) (Møller et al., 2022) • Computational thinking (elective) (Møller et al., 2022)
Languages • CyWrite: Academic writing for nonnative speakers of English (Feng et al., 2016) • TOTALrecall platform: Online English language-learning tools and activities that focus on aspects of reading, writing, and culture (Liou et al., 2006) • College English Writing (compulsory) (Youjun & Xiaomei, 2022) • Reading Don Quixote (Spanish) (Boyle & Hall, 2016)
Linguistics and Language technology • Introduction to language technology (Öhman, 2019)
Music • Computational Thinking in Music (Pollock et al., 2019)
Writing • Creating User Documentation (Evia et al., 2015)

Learning objectives and formats

In this section, the approaches adopted in relation to the operationalisation of CT are explicated. The CT activities in the included papers were analysed and categorised according to learning objective: learning CT or learning with CT, and according to format: analogue (CT unplugged) or digital (CT plugged). The matrix in Figure 2-3 below illustrates the resulting distribution of activities. Learning objectives were integrated in Dierbach et al. (2011: Activities a, b and c) and Pollock et al. (2019), so that students were learning CT and simultaneously learning a humanistic subject; hence these references are placed on the right-hand, horizontal bar. In Perković et al. (2010: Activity a), Pipitgool et al. (2021) and Youjun and Xiaomei (2022), both unplugged and plugged formats were used; therefore, these references cross the vertical bar. In Byrka et al. (2021), the learning objective was learning CT, but there was not sufficient information to determine whether the approach was plugged or unplugged, both approaches seem possible with the activity proposed. Therefore, this reference has been placed across the horizontal bar but followed by a question mark. References have been colour-coded in the matrix below to uncover any connection between subject domain, learning objective and format.

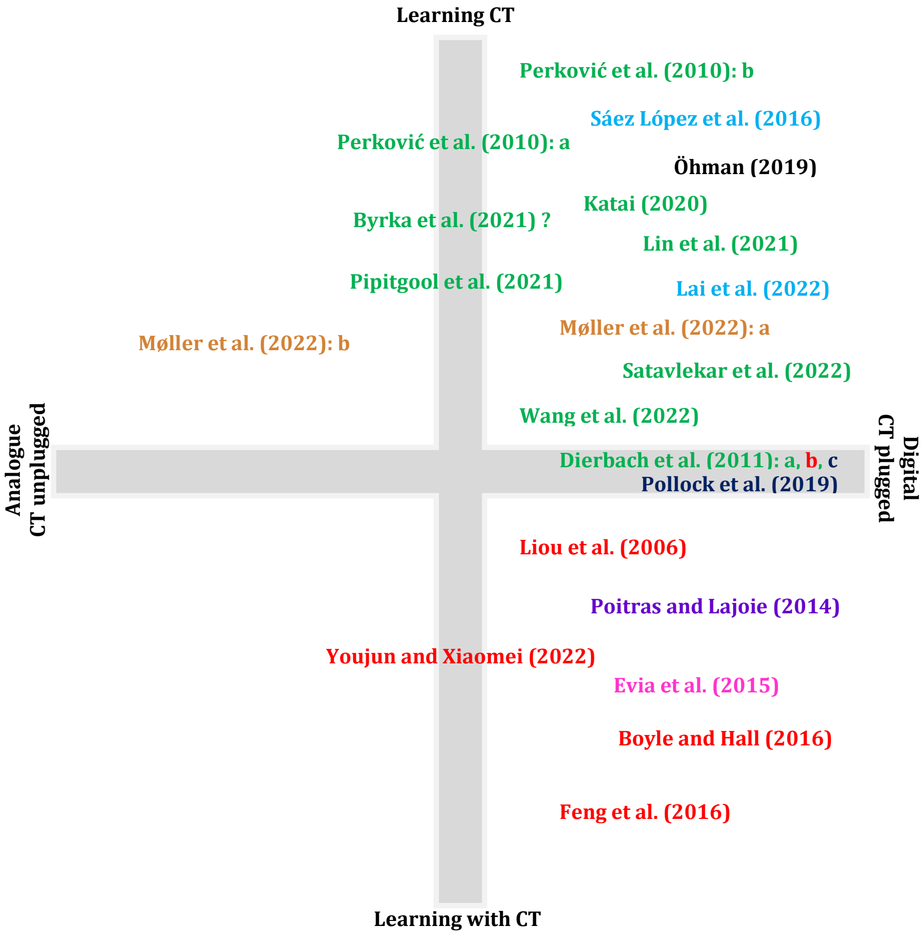

Figure 2-3. Distribution in relation to operationalisation. Colour-coding: see legend in Table 2.5

Table 2.5. Explanation of colour-coding of references in Figure 2-3

Colour-coding legend
Education and technology
General education
History
Human-centred informatics
Languages
Linguistics and Language technology
Music
Writing

Figure 2-3 reveals that activities cluster in the upper, right-hand corner of the matrix: learning CT using CT plugged. In four out of 23 activities, an analogue, unplugged format was adopted; in three of these, it was in combination with a plugged format. Only one activity appeared to be entirely analogue (Møller et al., 2022: Activity b). However, technology and software programs were integrated as analysis objects, cf. Figure 2-4 below. Thus, efforts to implement CT in humanistic subjects in HE seem to be as code-centric as Kite et al. (2021) found efforts to be in K12.

16b (Møller et al., 2022)

In the elective course *Computational thinking*, students attended traditional lectures with peer discussions via Zoom due to COVID-19. The course revolved around students' reflections on three dimensions of CT: concept, practices and perspectives and sought to build students' computational understanding and empowerment. Students completed three assignments in which they were to analyse a technology or a software program (Denmark)

Figure 2-4. Short description of analogue CT activity

It is interesting to note that in some activities learning objectives are integrated, combining the learning of CT with learning a humanistic subject. It is also a point of interest that most of the recent papers are to be found in the upper, right-hand corner of the matrix, adopting a learning CT/CT plugged approach.

Subject domain, learning objective and format

The colour-coding of references to illustrate the distribution of subjects in the matrix in Figure 2-3, reveals that most of the general education activities are located in the upper, right-hand corner as learning CT via plugged formats. This is also where we find subjects that integrate technology in humanistic courses and study programmes. The only exception is Møller et al. (2022: Activity b) that adopt an unplugged approach.

Activities that stand out here are Dierbach et al. (2011) and Pollock et al. (2019) who intertwine learning objectives so that students are learning CT in the context of their humanistic subject. This was one of the recommendations gleaned from the examination of models above.

Implicit and explicit CT

Figure 2-3 provides a good overview of the distribution of activities in relation to learning objective, format and subject. However, it does not uncover the degree to which CT is made explicit to students or not, and activities do differ on this point. In some cases, CT is very implicit to students as in Evia et al. (2015) where CT is embedded in the course design as five layers of abstraction. These layers decompose the palette of skills and competences to be mastered and help students gain mastery at one level before progressing to the next: "The multiple layers of abstractions allow processing (computationally) some layers without concerns about the details to be encountered at other layers" (Evia et al., 2015, p. 331). In Youjun and Xiaomei (2022), on the other hand, CT is made very explicit and used as a mediating tool to scaffold Chinese students' grammar learning. In effect, students process words as one would data or code. The vignettes in Figure 2-5 below provide a short description of these two different approaches.

The following provides a more detailed analysis of the ways in which CT was operationalised in the identified activities. First, findings in relation to type of activity, tools used, algorithmic processes and forms of engagement, pedagogical strategies, and learning theoretical perspectives will be presented. Then follows findings in relation to conceptualisation of CT.

5 (Evia et al., 2015)

Students on the course *Creating user documentation* engaged with assignments and reflection exercises on each of five layers of abstraction: 1) Developing quality documentation, 2) Separating content from design, 3) Authoring granular content with XML, 4) Authoring and linking Component Content Management modules with DITA (Darwin Information Typing Architecture), and 5) Single-sourcing and content reuse. The purpose was to combine computational abstraction with students' existing genre knowledge to facilitate their adoption of the DITA tool (USA)

19 (Youjun & Xiaomei, 2022)

In the compulsory course *College English Writing*, instructors guide non-English majors through five CT-based steps to improve their grammar knowledge and application, and enhance their learning agency and engagement: 1) data analysis of selected sentences, 2) pattern recognition: recognising grammar patterns, 3) abstraction: key issues concerned with EFL grammar (English as a foreign language) are abstracted from patterns, 4) decomposition of the abstracted issues, and 5) parallelisation: constructing network diagrams of grammar learning. Students apply CT as a thinking pattern and process words as they would numbers or code (China)

Figure 2-5. Implicit approach to CT (left) and explicit approach to CT (right)

Activity types, tools and engagement with algorithms

Table 2.6 below provides an overview of the activity types found across the identified CT activities and the types of engagement with algorithms identified. Type of activity (left hand column in the table below) is based on the learning objective of the activity in an attempt to capture the gist of the activity, so to speak. In Öhman (2019), e.g., students work computationally with texts, but the learning objective is for students to learn to apply language technology tools, cf. the vignette in Figure 2-6 below, hence this activity is categorised as Practicing use of language technology tools. Thus, the categorisation ignores that several types of activity may be present in a single CT activity. Programming, e.g., is involved in many of the 23 activities and was considered to be the main activity in eight as illustrated in Table 2.6.

Even when using this, perhaps conservative approach to categorisation, programming comes out as the main type of activity with more than a third of the identified activities adopting it. However, three different programming approaches were identified, namely programming with Java or HTML, visual (block) programming and programming computational things, cf. Table 2.6. The computational things employed were Zenbo robots (Lin et al., 2021), micro:bit kits (Møller et al., 2022: Activity A) and IoT devices (Satavlekar et al., 2022). In the visual (block) programming category, Scratch was used in two activities (Lin et al., 2021; Sáez López et al., 2016), while an AI platform with a visual interface was used in one activity (Wang et al., 2022). These findings mirror Tikva and Tambouris' (2021) identification of an upward trend in the use of visual programming as well as computational things in CT through programming activities in HE.

It is also worth noting that three instances of interacting with an intelligent tutor and automated feedback were identified, since such activities integrate computational processes in hidden or opaque ways, e.g., in the form of NLP and machine learning. Above, I have labelled this implicit CT. Below, it will be discussed how such activities can be mapped against the conceptualisations of CT in the framework presented in Dohn and Nørgård (2022).

Table 2.6. CT activities distributed on activity type and type of engagement with algorithms

Activity type	Reference/CT activity	Forms of engagement identified
Authoring with structured, automated workflow	5 Evia et al. (2015)	Use, modify, create
Computational reading and text-analysis	6 Boyle and Hall (2016)	Use, critique
	3b Dierbach et al. (2011)	Create, critique
Computing with words	19 Youjun and Xiaomei (2022)	Follow and use
Game analysis and design	2a Perković et al. (2010)	Use, modify, create, critique
Interacting with intelligent tutor and automated feedback	1 Liou et al. (2006)	Follow
	4 Poitras and Lajoie (2014)	Follow
	7 Feng et al. (2016)	Follow
Practicing use of language technology tools	10 Öhman (2019)	Use, modify
Problem-solving using a step-based model	12 Byrka et al. (2021)	Follow to create
	14 Pipitgool et al. (2021)	Follow to create
Programming: Java, HTML, e.g.	2b Perković et al. (2010)	Create
	3a Dierbach et al. (2011)	Create, critique
	15 Lai et al. (2022)	Create
Programming: Visual/block	8 Sáez López et al. (2016)	Create
	18 Wang et al. (2022)	Create
	13 Lin et al. (2021)	Create
Programming with computational things		Create
	16a Møller et al. (2022)	Create
	17 Satavlekar et al. (2022)	Create
Reflections on CT and analysis of technology	16b Møller et al. (2022)	Critique
Watching, reconstructing & orchestrating algorithms	11 Katai (2020)	Follow and recreate
Working computationally with music	9 Pollock et al. (2019)	Use
	3c Dierbach et al. (2011)	Create, critique

10 (Öhman, 2019)

In the blended learning course *Introduction to language technology*, students engaged with language technology and practiced the methods taught through assignments and voluntary computer lab sessions. Students used Python, AntConc, TagAnt, Grep, Sed, Latex and a CSC server. The teacher employed a use-modify approach to coding and students were provided with step-by-step instructions. After having submitted an assignment, students got access to YouTube screen capture videos that illustrated how it could have been completed. Quizzes on the content of the course textbook were available online. The aim was to "future proof" students and to teach all humanities students computational literacy (Finland)

Figure 2-6. Short description of CT activity 10

With respects to tool usage, information was missing in several descriptions of activities. Scratch, computerised corpora and visual (block) programming tools were mentioned in three papers each, while Python, Google apps, NLP tools and digital humanities tools were mentioned in 2 papers each. Other tools were mentioned in one paper only. Therefore, it is difficult to identify any patterns in tool usage in relation to CT activities for students in the humanities in HE.

When looking at the algorithmic processes in play in the identified CT activities, abstraction is the most frequently adopted algorithmic process followed by automation, decomposition, design and debugging. The third most frequent algorithmic processes are pattern recognition and evaluation. See the word cloud in Figure 2-7 below for illustration. When creating the word cloud below, words were put in the same word class to more accurately reflect the number of times the algorithmic process was adopted. E.g., evaluating was changed to evaluation and automating to automation. In addition, different constellations of design, e.g., algorithm design, designing etc. were all changed to design.

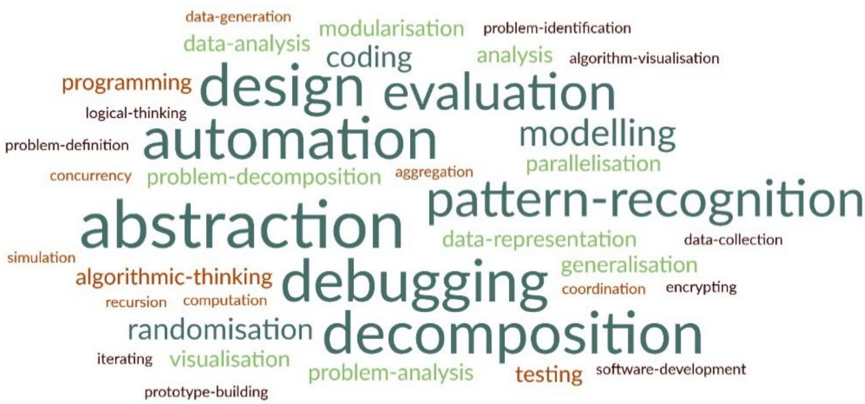

Figure 2-7. Algorithmic processes in play in the identified CT activities

Table 2.6 above shows the forms of engagement with algorithmic processes that were adopted across the 23 CT activities. All engagement forms that could be gleaned from the description of activities have been included to capture the diversity that unfolds in practice. This means that additional forms have been added to the use-modify-create collection, namely ‘follow’, ‘follow to recreate or create’, and ‘critique’. ‘Follow’ was added to describe activities where students do not use code to program something, but instead follow or observe an algorithm as it unfolds. An interesting example of ‘follow to recreate’ was found in Katai (2020), while Byrka et al. (2021) and Pipitgool et al. (2021) represent examples of following an algorithm to develop an algorithm, i.e., ‘follow to create’. The two different forms of engagement are described in Figure 2-8 below.

11 (Katai, 2020) In the *Six-stage learning session on the sorting algorithm*, students were introduced to CT, algorithms, and the e-learning session itself. Following this, they completed the six stages using the AlgoRythmics environment containing videotaped dance-performances and interactive, computer-based animations. Students watched folk-dance illustrations and animations of the bubble-sort algorithm, then reconstructed and orchestrated the algorithm using different interactive tools in the e-learning environment. The overall purpose was to promote CT for all through contextualised computing education (Romania)	12 (Byrka et al., 2021) The *Universal, five-step sequence of algorithm development adapted for HE* is a proposal for a method to teach university students problem-solving in relation to learning and everyday life issues. The method consists of following a universal five-step sequence of algorithm development to design, test, and debug algorithms. The aim is to prepare students for their future work life in the information society by forming and developing their algorithmic thinking skills (Ukraine)

Figure 2-8. Forms of engagement with algorithms. Follow to recreate on the left and follow to create on the right

‘Critique’ was added to denote a form of engagement with algorithms of a more analytical and/or reflective nature, where, e.g., technology and devices are the object of analysis and/or where students discuss the limits of computation. Critique was found in six activities and was the most dominant form in Møller et al. (2022: Activity b), see Figure 2-4 above. Critique as form of engagement was also in play in, e.g., Dierbach et al. (2011) and Boyle and Hall (2016), cf. Figure 2-9 below.

3a (Dierbach et al., 2011)

In *Everyday computational thinking*, students chose a problem to work with during a semester project. The problem had to be an everyday problem that benefitted from a computational approach and not an inherently computational one. Students analysed the problem, designed, and evaluated a computational solution and discussed the limits of computation. The overall purpose was to integrate CT in undergraduate, general education as a fundamental skill for all students (USA)

6 (Boyle & Hall, 2016)

In *Reading Don Quixote*, students engaged in collaborative translation (Spanish-English), and digital and computational reading of the novel using Voyant tools, online corpora, Google docs, iPad apps and objects on campus. Students searched for, retrieved, and assessed apps using the search word Don Quixote and the Spanish equivalent. Students compared physical and digital devices/objects for reading a book. The aim was to optimise students' engagement with the narrative and the material culture of Don Quixote and to create a student-centred environment that invigorated textual analysis and supported students in refining their close-reading skills (USA)

Figure 2-9. CT activities with critique as form of engagement, i.a.

It is worth noting that ‘create’ is adopted in around half of the CT activities, and this fits well with many authors reporting to adopt a student-centred, active learning or hands-on approach. This will be elaborated below. Surprisingly, the full use-modify-create approach was only found in a few activities. Since many of the included papers report CT activities for novice learners, one might have expected the approach to be more prevalent and also to be explicitly mentioned.

Pedagogical practice and learning theoretical foundations

A wide variety of pedagogical strategies and learning theoretical perspectives were adopted in the design of the 23 CT activities. A few patterns emerged when looking across these strategies. There is broad agreement about the usefulness of creating opportunities for authentic learning by, e.g., engaging students in problem-solving in relation to real-life problems, rather than having students work with abstract ones. Lin et al. (2021) recommended to tailor materials and examples to humanities students, and Wang et al. (2022) recommended using real-life examples when explaining CT.

Scaffolding is mentioned in four papers, with or without reference to Vygotsky’s socio-cultural theory and zone of proximal development. It is, however, operationalised in different ways. In Youjun and Xiaomei (2022), CT is a “social mediation tool” that scaffolds students’ learning of English grammar. In Møller et al. (2022), students are scaffolded in building computational empowerment by reflecting on CT as concepts, practices and perspectives and through analyses of technology and software programs. Öhman (2019), in an attempt to deal with students’ technophobia, scaffolds her students’ learning by first establishing a baseline of knowledge and then moving on to more difficult tasks in a use-modify approach. The MetaHistoReasoning tool uses computerised processes and pedagogical agents to scaffold students' self-regulated inquiry-based learning (Poitras & Lajoie, 2014). And finally, the TOTALrecall platform is to support students' autonomous learning by offering a learning trajectory from computational scaffolding to full participation in an English language community (Liou et al., 2006). The two latter activities are illustrated in Figure 2-10

1 (Liou et al., 2006) On the *TOTALrecall platform*, students can access English learning tasks (i.a. written exercises and translations) to improve their English reading, writing, vocabulary, and overall English abilities. The platform provides adaptive, computational scaffolding and feedback via NLP tools and access to real life, bilingual corpora for culture-based English learning. "An anytime English tutor that 'understands' what learners say to it" (p. 90). The purpose is to support English language learners in reaching higher levels of proficiency when engaging in CALL (computer-assisted language learning) tasks (Taiwan)	4 (Poitras & Lajoie, 2014) The *MetaHistoReasoning tool* is an open-ended, computer-based learning environment for scaffolding students' self-regulated learning of the skills used in historical inquiries. The tool has a training module where students are introduced to the skills, and an inquiry module where students can practice their skills. Both modules contain exercises, and the tool provides corrective feedback. The tool is to support students in completing ill-structured and complex tasks using disciplinary-based strategies and to help students gain self-regulated learning skills in the domain (USA)

Figure 2-10. CT activities that offer computational scaffolds

In yet another paper, scaffolding is mentioned together with situated learning, embodied cognition and the adoption of a constructionist approach; Satavlekar et al. (2022) uses IoT devices to provide novice CT-learners with embodied scaffolds (see Figure 2-11). The activity also includes reflection spots to lead students towards discoveries and multiple real-time problem-solving pathways. Situated learning, as active participation in a learning community, is also mentioned in Sáez López et al. (2016) who describe how students collaborate online to create multimedia projects using Scratch and in a multi-cultural setting.

17 (Satavlekar et al., 2022)

The aim of the *Real-life computational problem-solving scenarios* was to provide novice CT learners with embodied scaffolds. Students attended a three-hour session with a familiarisation phase (demonstration and guided problem-solving) and an unguided problem-solving phase (completing 3 tasks). Sample task: configure a smart light bulb such that it automatically switches on at the start of the evening and switches off before a predefined bedtime. A mentor intervened in the unguided phase and asked questions to create reflection spots. Students used Internet of Things (IoT) devices and utility platforms such as IFTTT, Google Home and Alexa to complete the tasks (India)

Figure 2-11. CT activity offering embodied scaffolds

The importance of using visual programming tools, when integrating CT in non-STEM contexts is mentioned in several papers, namely Lin et al. (2021), Sáez López et al. (2016) and Wang et al. (2022). Katai (2020) also mentions the importance of visualisation and explains how algorithm visualisation can make algorithms more tangible to learners.

Computer-assisted language learning (CALL) is mentioned in Liou et al. (2006) and Feng et al. (2016) that both account for digital platforms to support students' language learning. Active learning, collaborative learning, experiential learning, student-centred learning environments and hands-on approaches are also mentioned, as is project pedagogy and object-based learning. Two papers investigated flipped learning as an approach to teaching CT, namely Pipitgool et al. (2021) and Lai et al. (2022). A few papers do not go into detail about pedagogical strategies but report to have revised courses and made CT more explicit (CT was mapped onto specific disciplines), or to have infused CT in undergraduate education to support all in acquiring computational competences.

In the section below, findings in relation to conceptualisations of CT in the included papers are presented.

Conceptualisations of CT in current practices and proposals

As is often reported (e.g., in Tekdal, 2021), no consensus was found regarding definitions and conceptualisations of CT across the papers included in the present study. Furthermore, the level of detail in relation to articulating definitions and/or conceptualisations differed. Lai et al. (2022), e.g., focused on developing a flipped learning approach that integrates design thinking, i.a., and merely stated, but did not develop or discuss, the adoption of the five dimensions on the Computational thinking scale developed by Korkmaz et al. (2017), namely creativity, cooperation, algorithmic thinking, critical thinking, and problem-solving. In contrast, Møller et al. (2022) elaborated on their implementation of CT as computational empowerment referring to Dindler et al. (2020) and

Iversen et al. (2018). However, where the operationalisation of CT is concerned, Møller et al. (2022) did not go into detail but used terms such as CT concepts, practices and perspectives and software-development, programming and prototype building. This lack of transparency around definitions and/or conceptualisation of CT is in line with the findings in Tikva and Tambouris (2021).

Conceptualisations of CT in the included papers were often embedded in CS and seen as requiring a computer. This explains the fact that a plugged format was used in the majority of CT activities, cf. Figure 2-3. In addition, many papers conceptualised CT as a 21st-century and/or universal competence, i.e., a literacy which accounts for the many CT activities that fall into the category of general undergraduate education. Below, the 23 identified CT activities are mapped onto the framework for CT activities in HE presented in Dohn and Nørgård (2022), see Figure 2-13. First, a more detailed explanation of the framework itself is provided.

The framework for CT activities in HE distinguishes between the use of CT for constructing something (the brown shape in Figure 2-13) and critical CT, i.e., critical reflection on the roles that algorithms and IT play in different aspects of our lives (the brace at the top of the figure). In addition, the framework distinguishes between analogue and digital forms of CT activities, i.e., the CT plugged and unplugged formats mentioned above (indicated by the vertical, black bar in Figure 2-13). It also distinguishes between using and coding programs (indicated by the horizontal, black bar), cf. the account above of forms of engagement with algorithmic processes. Furthermore, the framework delimits CT activities from digital activities, but acknowledges an overlap between these. Digital activities are contained in the shape with the dotted green line in Figure 2-13. Finally, the framework illustrates computational participation, as a digital, CT activity that involves using or coding programs to construct something (the green circle in the figure). This brings about six different dimensions (Dohn & Nørgård, 2022) that help create transparency in relation to possible conceptualisations and operationalisations. I.e., on which understanding of CT are activities based (computational thinking, computational participation or critical CT) and how is CT operationalised in the classroom (unplugged or plugged, constructing or critiquing, using or coding programs)? The six dimensions are (cf. p. 25):

A. Analogue CT
B. Digital CT where students use programs
C. Digital CT where students code programs
D. Digital activities that do not involve CT
E. Computational participation
F. Critical CT
G. Computational scaffolding

On the background of the findings in this study, computational scaffolding has been added as a seventh dimension, G. to the list above. In computational scaffolding, CT is in play implicitly, as intelligent tutors, or explicitly, as step-by-step sequences to scaffold students' learning. With the rapid growth of pretrained text generators, such as ChatGPT based on NLP and machine learning, computational scaffolding will be an increasing factor in students' learning, hence my suggestion to add it to the model. This is discussed further below.

Figure 2-13 below illustrates the mapping of the identified 23 CT activities. All seven dimensions were covered, and the figure shows how some of the 23 activities move through several dimensions. E.g., activity 2b (see Figure 2-12 for a short description) starts in dimension F with students critiquing computer games, then moves to A with students analysing games, to end in E with students developing their own game ideas. Overall, it is interesting to note that a fair number of activities fall within the critical CT dimension.

2a (Perković et al., 2010)

In *Introduction to game design*, students studied computer games as 1) examples of media that can be analysed and critiqued, 2) as complex software artifacts, and 3) as cultural artifacts. Students studied the process of game development and the principles of game design, analysed existing games, and developed their own game ideas. The purpose was to implement Wing's vision of CT as a basic skill for all in undergraduate education (USA)

Figure 2-12. Example of CT activity in which several dimensions of CT are in play

The activities located in dimension E in Figure 2-13 are activities where students work on problems or projects of their own choice, thus realising their computational participation. While it is beneficial to see that so many activities adopt this approach, there are also many instances of students working on problems posed by the teacher (activities in A, B and C), even though these problems are purported to be real-life or authentic problems. Students in the three identified experiments (Katai, 2020; Satavlekar et al., 2022; Wang et al., 2022) work with teacher-posed problems, but this approach is also adopted in some of the semester courses. This could be due to control-states in relation to the experiments, and for the semester courses, it might be due to CT being integrated into courses without considerations concerning changes to pedagogical strategy.

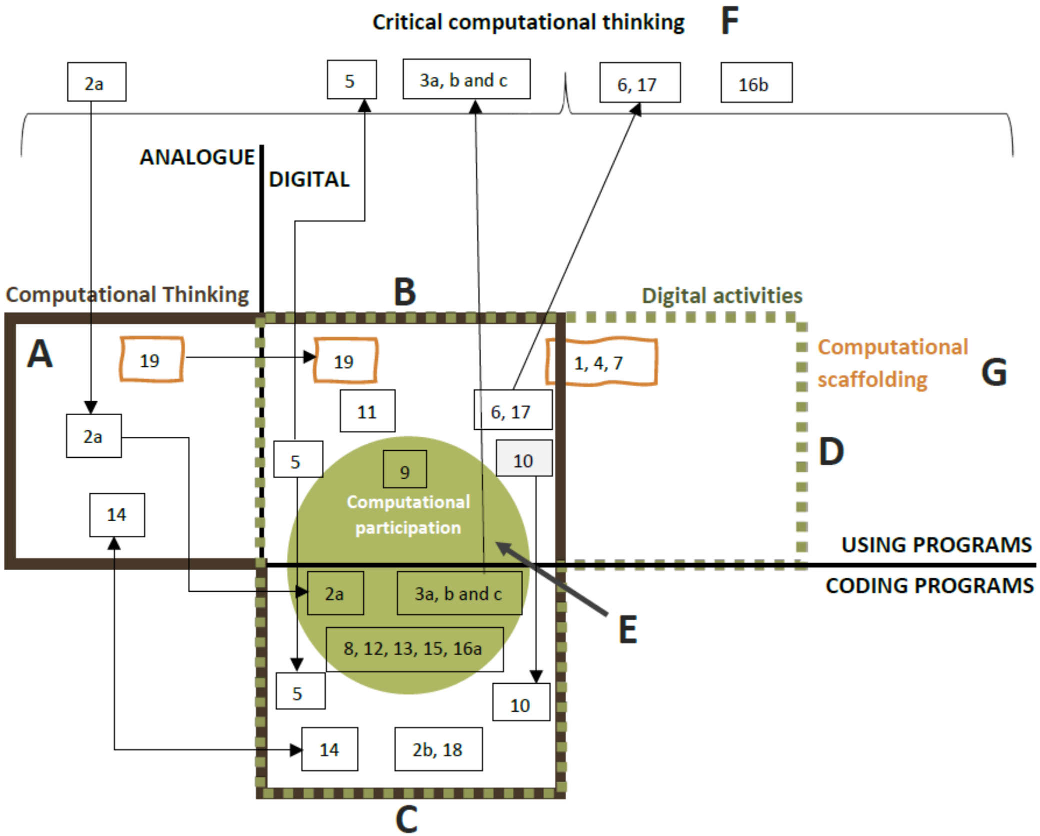

Figure 2-13. CT activities mapped against adapted version of Dohn and Nørgård's (2022) framework. Figure elements are explained above. Arrows show how an activity moves from one dimension to another

With regards to the activities mapped to dimension B, it should be noted that the mapping has been undertaken on the basis of the information it was possible to glean from the papers. Descriptions regarding how programs were actually used were typically not detailed and sometimes entirely missing. Therefore, some of the activities should perhaps be placed in D instead. This especially goes for the three activities (1, 4 and 7) that involve digital platforms where students interact with intelligent tutors and received automated feedback.

In the section below, the findings will be discussed followed by conclusions and suggestions for future research

2.6 Discussion

It is encouraging to see the diversity in activity types and tools used across the 23 CT activities analysed in this study. However, it is problematic that most of the activities cluster around learning CT using a plugged approach. With regards to format, there is little diversity. Using unplugged approaches, on their own or as a precursor to plugged approaches, might make CT more accessible (Huang & Looi, 2020) to humanities students and provide new ways of integrating CT with subject topics and learning objectives. CT unplugged is reported as a useful approach for developing students' CT skills (Chen et al., 2023; Li et al., 2022), and especially when integrated in interdisciplinary courses (Li et al., 2022). However, most studies on CT unplugged have been carried out in K12, and thus knowledge is lacking on the impact with regards to students in HE.

The above analysis of CT activities evidences that researchers are working to develop and test new methods for integrating CT in non-STEM domains. However, many efforts seem to reinvent the wheel rather than looking to existing models, such as those examined in section 2.3 above, for inspiration. E.g., several of the included papers report on the task of identifying the elements of CT that should be included in an activity and appear to be adopting disjointed strategies in which they focus on separate CT elements, as in Barr and Stephenson (2011) and Dong et al. (2019). The question is whether it is sufficient to integrate one or a couple of CT elements in an activity to be able to call it a CT activity or whether CT elements must be integrated as (iterative) steps as suggested in Piatti et al. (2022). Of course, the answer, i.a., depends on the conceptualisation of CT adopted in a given context. A way forward could be to adopt a discourse of CT as different types of engagement with algorithmic processes. In Dohn et al. (2022), 'engagement with algorithmic processes' is suggested as the defining feature of a CT activity. However, it must be determined what constitutes sufficient engagement and likewise how to label different forms of engagement. Programming education has brought us the well-known sequence of use-modify-create (Lee et al., 2011) and the present study has identified additional forms, namely 'follow', 'follow to recreate or create', and 'critique'.

The findings presented above show a rather strong focus on the learning objective, learning CT. This means that few adopt the approach suggested in the literature of contextualising CT within the humanistic subject in question. The interdisciplinary involvement needed for implementation of CT in non-STEM domains (Czerkawski & Lyman, 2015) seems not to be realised. However, Pollock et al. (2019) as well as Dierbach et al. (2011) should be singled out for providing specific examples both of contextualising CT and of supporting interdisciplinary involvement. E.g., Pollock et al. (2019) explain how summer schools are carried out to support teachers in gaining CT competences and planning the integration of CT in their subjects with employees from the CS department available for support. In many cases, however, the development of CT activities seems to be a question of simplifying rather than contextualising CT for students in the humanities.

The contextualisation of CT within the humanities also involves development of the open-ended type of tasks that characterises the domain (Czerkawski & Lyman, 2015). But whereas there was broad agreement across the analysed papers that real-life or authentic problems should be posed to students, tasks were not entirely open-ended. In several cases, the teacher assigned specific tasks to students to which there might be different solutions, but where the scope of the project to be completed was delimited. One example of this is Perković et al. (2010: Activity b) where students in a 3-D modelling course at the Arts and literature department were asked to develop and submit a 3D model and a rendered image of a finished warehouse space. Another can be found in Satavlekar et al. (2022) where students are asked to configure a smart light bulb to automatically switch on when it gets dark and switch off before bedtime, see Figure 2-11 above.

However, Satavlekar et al. (2022) also offer an example of approaches based on more explicitly articulated perspectives on cognition and learning. Referring to situated learning, embodied cognition and the constructionist approach, the authors account for their hypothesis that embodied scaffolds using tangible, computational things, such as IoT devices, can support novice CT learners in solving authentic, computational problems.

The learning theoretical perspective found to be most frequently present (explicitly or implicitly) in the analysed papers is that of socio-cultural theory together with the notions of zone of proximal development and scaffolding. This, of course, fits well with programming activities (that made up a large proportion of the examined CT activities) and the use-modify-create approach, the purpose of which is exactly to scaffold the learning process of students new to programming (Lee et al., 2011). A very interesting type of scaffolding, namely computational scaffolding, is mentioned in Liou et al. (2006) who developed tools to support English language learners in "moving from computational scaffolding to full participation in the English-speaking discourse community" with the end goal of achieving learner autonomy (p. 91). This computational scaffolding is an intelligent tutoring system that offers feedback, automated error correction and tasks adapted to the level of the learner. Examples of computational scaffolding were also found in Poitras and Lajoie (2014) and Feng et al. (2016); though not labelled so in the latter.

The type of computational scaffolding described above constitutes implicit CT, i.e., black-boxed computational processes. However, an example of computational scaffolding with explicit CT was found in Youjun and Xiaomei (2022) who explain how non-English majors improve their English grammar by computing with words from English sentences that they are analysing. They do so by following five CT-based steps guided by their instructor; the first step is to analyse the data and transform each word to a predefined numeric code. These numeric codes are then used in the subsequent computing, see short description of the activity in Figure 2-5. The activity seems to combine the unplugged and plugged approaches. The authors concluded that the students seemed more confident working with numbers than words, which indicate the positive impact of the computational scaffold put in place for students.

Computational scaffolding involves learner interaction with more or less black-boxed, computational processes, implicit and explicit CT, that provide output that presumably impacts student learning. I argue that it is important to highlight the role of such computational processes in learning and to put transparency on the agenda to work towards informed and competent use on the part of the learner, and teachers as well. Otherwise, we risk experiencing what Papert (1980) warned against, namely the computer programming the learner. Computational literacy (diSessa, 2001) as well as algorithmic Bildung (Gerdes, 2021) might form part of the solution.

The question is also whether to characterise activities that involve computational scaffolding as CT or digital activities, and whether that distinction is feasible today. Most digital activities involve applications that use algorithms. As I am writing this, a new feature in my MS Word application is suggesting the next word(s) to add. It is surprisingly tempting to just accept the suggestions. Algorithms decide what I view in my Facebook feed and what recommendations I get when I open my Netflix app to be entertained. Computational processes and algorithms are ubiquitous, therefore I suggest to add computational scaffolding as a seventh dimension in the framework for CT activities in HE proposed by Dohn and Nørgård (2022), see Figure 2-13 on p. 52. Computational scaffolding is suggested incorporated into the framework to create awareness about the implicit way that computational processes are present in many of our digital activities today.

A final point to be discussed here is conceptualisations of CT. In the analysed papers, CT was most often conceptualised as problem-solving and with reference to Wing. Literacies (code literacy, computer literacy, as well as computational literacy) were mentioned, but without reference to, e.g., diSessa (2001). In addition, computational empowerment (Dindler et al., 2020; Iversen et al., 2018) as well as AI empowerment were mentioned, but the latter was not elaborated. All in all, many of the included papers did not attempt to position themselves in relation to conceptualisations of CT. Indeed, the focal point differed across papers with some being more concerned with learning theoretical perspectives and pedagogical strategies, than with conceptualisations of CT. Such lack of transparency makes it difficult to accumulate knowledge in the field and to pursue further research because it may not be clear on which foundation existing efforts rest.

A framework such as that for CT activities in HE presented in Dohn and Nørgård (2022) could form a starting point with respects to establishing a common base of knowledge regarding the different ways in which CT can be conceptualised and operationalised. However, such a framework must remain open to revision, such as adding new dimensions like computational scaffolding suggested in this paper, so that it incorporates new conceptualisations or operationalisations as these are developed and identified. Likewise, it should be considered what demarcations it makes sense to uphold, whether it is one between CT and digital activities or rather one between different forms of engagement with algorithmic processes covering both implicit and explicit forms.

2.7 Conclusions and future research

Dohn and Nørgård (2022) state that "integrating computational thinking within higher education is still in its infancy" (p. 65). However, the present study shows that progress is being made, albeit there is still room for development. In this section, conclusions are outlined and recommendations for future research are made.

The study reported here asked the question: what are existing practices and proposals for CT activities in the humanities in HE? In a literature search, 19 papers with a total of 23 CT activities were identified and analysed to provide a response. These 23 CT activities were mapped and categorised against key features inspired by existing research in the field. The findings revealed that existing practices and proposals are primarily targeted at undergraduates in HE. Universities from 13 different countries were represented in the sample of CT activities and seven different humanistic domains were covered, namely education & technology, history, human-centred informatics, languages, linguistics & language technology, music, and writing. However, CT activities identified as general education for undergraduates made up almost half of the sample. The CT activities in this category could be further split into general education for either all undergraduates, novice CT learners or undergraduates within the humanities.

The majority of activities adopted a CT plugged format and learning CT as learning objective. Only 4 activities from two different papers were found to intertwine CT and learning objectives and topics from the subject domain, i.e., contextualise CT within the humanistic subject in question. CT was most often conceptualised as systematic problem-solving and as a universal skill. In some cases, conceptualisation or operationalisation was not explicitly articulated.

Wide variety was uncovered with regards to how CT was operationalised in the classroom, but a few patterns could be discerned. Programming was the main activity type, followed by computational scaffolding. About one third of the programming activities involved visual or block-based programming, and another third involved the programming of computational things. The most frequently adopted algorithmic processes were abstraction, automation, decomposition, design and debugging followed by pattern recognition and evaluation. With regards to forms of engagement with algorithmic processes, new forms were identified and added to the well-known use-modify-create sequence, which in itself was only fully present in a couple of CT activities. The new forms added are ‘follow’, ‘follow to recreate or create’ and ‘critique’.

Diversity was also found in the learning theoretical perspectives and pedagogical approaches adopted with a few papers investigating the benefits of a flipped learning approach and one paper investigating how to provide students with embodied scaffolds involving the use of computational things in programming exercises, e.g.

The 23 CT activities were mapped against the framework presented in Dohn and Nørgård (2022). This illustrated that together, the 23 activities cover the six dimensions contained in the framework with the following four dimensions dominating: digital CT where students use programs, digital CT where students code programs, computational participation, and critical CT. For the mapping exercise, computational scaffolding was added to the framework as a new dimension, and it was argued that the dimension, digital activities, may be obsolete today since most of our digital activities involve more or less hidden, but powerful, algorithmic processes. Focusing on learner engagement with algorithmic processes and presence of CT from implicit to explicit may be a way forward.

It is problematic that CT activities are often based on opaque or unarticulated conceptualisations, since it decreases the chances of consolidating the field, establishing a joint vocabulary and advancing knowledge. Further research is needed regarding how to operationalise and conceptualise CT for students in the humanities in HE. It is especially important to broaden the type of tools and approaches used and examine how CT unplugged can be integrated in humanistic subjects in HE. In addition, studies should explore how to more fully realise the interdisciplinary potential by contextualising CT within specific humanistic subjects.

2.8 Limitations

Only peer-reviewed papers in English were retrieved which means that potentially relevant CT activities described in other languages were not identified. The above analysis of the 23 identified CT activities is based on the information it was possible to glean from the included papers. Sometimes, descriptions were not very explicit in which cases educated guesses had to be made to establish a best fit with the key features employed in the mapping and categorisation of activities.

3 CT with computational things in Philosophy and Media Studies

Integrating Computational Thinking in Humanistic Subjects in Higher Education

Publication 2. Author: Inger-Marie Falgren Christensen (2023b)

Abstract

This chapter describes and discusses a study that has as its focus the theory-driven and collaborative design of interventions in higher education using a design- based research approach. The study investigates how to integrate computational thinking (CT) with computational things in the context of two case studies involving teachers and students from Media Studies and Philosophy. The theoretical framework consists of CT, computational things, situated and embodied cognition and learning, and design for learning. This framework has informed the preliminary general-substantive and general-procedural design principles that have guided the design of interventions. The interventions designed consist of computational things in the form of idea generation tools that support students in decomposing core models and provide students with tangible representations of abstract subject concepts. Furthermore, the tools require students to engage with algorithmic processes and compute with concepts. Results from the first iteration show there is potential in the tangible representations of abstractions and in the decomposition of core models. However, some students are unfamiliar with working at this level of decomposition and abandon algorithmic processing to engage in abstract discussion. Thus, the most promising potential is the computational thing as conversation tool and object to think with and secondarily the computational thing as idea generation tool.

Keywords

Computational thinking · Computational things · Humanities · Higher education · Situated learning · Embodied cognition · Design-based research

3.1 Introduction

This chapter describes and discusses a study that has as its focus the theory-driven and collaborative design of interventions in higher education (HE) using a design-based research (DBR) approach. The first half of the chapter is devoted to the presentation of the theoretical framework of the study including definitions of core concepts and an account of the DBR approach and the data collection and analysis methods employed, whereas the last half of the chapter will provide details of the design process, the interventions designed as well as the findings from the first iteration and plans for the second.

The study is an ongoing research project the purpose of which is to investigate how Computational Thinking (CT) with computational things can be integrated in humanistic subjects in HE in a way that (1) teachers and students experience as meaningful and that (2) supports students in achieving the competences needed to engage in creative problem-solving within the subject area in question. The specific purpose is to develop design principles, design patterns, and an outline of a HE pedagogy for the integration of CT with computational things in humanistic subjects not only to inspire practitioners but also to identify and discuss the challenges and implications.

The term computational thinking was first used by Seymour Papert in 1980 and defined by computer scientist Jeannette Wing in 2010 as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information- processing agent" (Wing, 2010, p. 1). This agent can be either human or machine or a combination of the two. In this sense, CT is viewed as sequential problem-solving and can be analogue or digital as well as physical and bodily mediated.

Problem-solving and problem-solving methods have been the object of much research. Polanyi describes problem-solving as the process of first recognizing a situation as problematic and then engaging in intelligent action to find a solution (Polanyi, 1957). A well-known problem-solving model is based on Pólya's work. In his study of mathematical thinking and productive thinking, Pólya devised a framework for the problem-solving process consisting of four phases: understanding the problem, devising a plan, carrying out the plan, and looking back and checking the solution (Schoenfeld, 1987). Thus, problem-solving is not unique to CT but also plays a central role in, e.g., mathematical, engineering, and design thinking. There are not only overlaps between the different types of thinking, but also important differences that lie in the specific application of the type of thinking in its own domain (Shute et al., 2017).

An important difference between CT, engineering, and design thinking is that the focus in the latter two domains is on product specifications and constraints posed by users and physical settings. CT, on the contrary, "is not limited by physical constraints, enabling people to solve theoretical as well as practical problems" (Shute et al., 2017, p. 146). Furthermore, the CT approach to problem-solving is unique in that it revolves around the design and testing of algorithms. Therefore, this definition that brings out the unique focus of CT will be applied: CT is "*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 both Wing and Shute et al.'s definitions, a possible end goal of automation is implied, highlighting CT as the use of computational tools to handle tasks that we consider valuable. In this sense, CT is "designing computations that get computers to do jobs for us" (Denning & Tedre, 2021, p. 365), where the problem-solving or parts of it are computerized. The concept of algorithms is further explained in the section on the theoretical framework.

Already in 2006, Wing proclaimed that CT "is a fundamental skill for everyone, not just for computer scientists" (Wing, 2006, p. 33) and suggested that CT be given the same status as reading, writing, and arithmetic. Wing poses the argument that CT has already affected and created breakthroughs within, e.g., statistics and biology, among other fields, due to the possibility to compute large amounts of data, and she predicts that CT "will be part of the skill set of not only other scientists but of everyone else" (Wing, 2006, p. 34). Grover and Pea (2018) also view CT as a basic requirement for being a competent citizen and for obtaining success within STEM subjects. They emphasize that CT is a competence that has much potential in relation to problem-solving and innovation within all other domains as well. Furthermore, CT is seen as "especially relevant as a widely applicable thinking competency along with other critical thinking needed to solve the challenges posed in this century throughout various domains" (Grover & Pea, 2018, p. 22).

There is thus a wish to focus on CT outside STEM, but the question is how to integrate CT in a way that is meaningful to students and teachers outside STEM and that supports students' learning of non-STEM subjects. The study reported in this chapter explores possible answers to this question focusing on the integration of CT in humanistic subjects. The purpose is to explore CT from inside specific, humanistic subjects, collaborating with teachers to analyze their subjects and identify possibilities for integrating CT in a manner that is both relevant and meaningful from the point of view of students, teachers, and the subject area. CT activities are designed to link to specific subject content rather than appearing as isolated activities.

In the study, cognition and learning are understood as situated and embodied; therefore, computational things rather than computers, where students merely interact with a screen interface, will be part of the interventions designed. Computational things are "reprogrammable physical artefacts that are programmed in a specific, step by step way and work towards a clearly defined purpose" (Mikkonen & Fyhn, 2021, p. 311. My translation). These computational things thus support the situated and embodied engagement with algorithmic processes, computing inputs to arrive at a solution: a specific output.

Rather than testing predefined hypotheses, this study is an open exploration to uncover the potentials and challenges of employing CT and computational things to support student learning in humanistic subjects in HE. This leads to the following research questions:

3.1.1 Research Questions

- *What CT competences are especially relevant for humanistic subjects and how can they contribute to students' professional development?*
- *How can computational things be meaningfully integrated in humanistic subjects in HE?*
- *What design tools (design principles and design patterns) can support the integration of CT with computational things in humanistic subjects?*

Chapter Outline

Initially, the two case studies that have commenced in spring 2021 will be presented: (1) CT with computational things in the subject Media institutions, industries, and systems at the Master's degree program in Media Studies; and (2) CT with computational things in relation to generating ideas for bachelor projects at Philosophy. Next, the theoretical framework employed in the study to support the theory-driven design of interventions will be elucidated, core design concepts will be defined, and the preliminary design principles derived from the theoretical framework will be presented. Following this, an account of the DBR approach employed will be given together with details of data collection and analysis. Then, an account of the design process and the designed interventions will be given. In addition, the analysis of data collected in the first iteration of interventions will be presented and discussed. The chapter concludes by accounting for the plans for the second iteration of interventions and by summarizing the uncovered potentials and challenges of employing CT and computational things to support student learning in humanistic subjects in HE.

3.2 Presentation of the Cases

In this section, the two cases that are involved in the study are presented to give the reader insight into the particular humanistic contexts that form the setting of the study. The presentation includes a description of the aims, contents, typical teaching and learning activities, assessment, and a brief outline of the subject-related challenges that constitute the point of departure for the design of interventions. An account of the design process and the designed interventions will be given in the last half of the chapter.

The researcher has a background as an e-learning consultant at the University of Southern Denmark, the context of the study. She has more than 12 years' experience working together with practitioners, supporting them in developing their teaching and their teaching competences with a particular focus on technology enhanced learning. The teachers participating in the study are well-known to the researcher who has collaborated with both teachers before and know them to be interested in developing their teaching as well as their teaching competences. A relation of mutual trust and respect has been established which is essential for a close and successful collaboration when it comes to the design and carrying out of interventions that have an impact on both the practitioners' teaching and the learning outcome of their students.

Case One: CT with Computational Things and Media Studies

Case one involves the integration of CT with computational things in the 10 ECTS (European Credit Transfer System) subject *Media institutions, industries and systems* at the second semester of the Master's degree program in Media Studies at the University of Southern Denmark (SDU). The learning outcomes of the subject are listed in Table 3.1 below.

The overall purpose of the course is to give students a thorough academic and research-based introduction to different types of media institutions, industries, and systems. The course is assessed via a 10-page, individual synopsis and an oral examination. The synopsis must include an introduction, a relevant empirical and theoretical problem formulation, an overview of methods that will be applied in relation to data collection and analysis, theories and definition of concepts, topics that will be presented at the exam, possible points for discussion, and a list of references.

Students have three weekly lessons, and teaching and learning activities typically include independent studies of literature, lectures, guest lectures from and visits to media institutions, students' roundtable presentations and dialogue, and students' blogging on the subject and commenting on each other's blog posts. Furthermore, students can book a supervision session with the teacher in relation to their synopsis.

In the spring 2021 semester, 32 students were enrolled in the course.

Challenges

The teacher, an experienced teacher having taught the course several times, reported that students typically have difficulties understanding the concepts of the subject. In their undergraduate studies, students have worked with media from a media product and consumption perspective and are usually well versed in the analysis of different types of media products. In the course *Media* *institutions, industries and systems*, students are required to take the perspective of media institutions and to also work with topics such as media law and policy. This is very foreign to students, and according to the teacher, many students do not fully understand what a media institution or a media system is until the end of the course. In addition, students often consult the teacher when they start working on their synopsis, asking whether she can provide them with ideas for problem formulations. The teacher hopes that an intervention can support students in getting an understanding of the core concepts of the course earlier on and in generating their own synopsis ideas.

Table 3.1. Learning outcomes of Media institutions, industries, and systems

Level of learning	Learning outcomes
Knowledge	At the end of the semester, students should have acquired: Knowledge on central theories on media institutions, industries, and systems Knowledge on theories and methods for the analysis of media institutions, industries, and systems, including relevant actors and their relations Knowledge on relevant media law, including international copyright and related issues Knowledge on central ethical discussions regarding media and related theories Knowledge on the historical dimensions in relation to central media institutions, e.g., public service
Skills	At the end of the semester, students should: Be able to give a comprehensive account of theories on media institutions, industries, and systems in a national and international context and critically discuss these Be able to critically analyze specific media institutions and industries, their internal structures and external functions, in a political, legislative, ethical, and cultural perspective Be able to analyze and explain the communication and media strategies of institutions
Competences	At the end of the semester, students should: Be able to formulate and communicate a relevant empirical and theoretical problem in relation to the analysis of media institutions, industries, and systems Be able to perform a high-level literature search and write a literature review related to a self-elected topic and case within the scope of the subject

Case Two: CT with Computational Things and Philosophy

Case two concerns the integration of CT with computational things in a workshop series for undergraduate Philosophy students on their fourth semester at SDU. The aim of the workshop series is to prepare students for and support them in getting an early start on their bachelor projects, something which has posed a problem in the past. The more specific aim is to facilitate students' independent generation of project ideas and creation of problem formulations.

The series consists of four workshops that are spaced out during the spring semester with one workshop of 3 h per month from February to May. At the beginning of the workshop series, the teacher stresses that he will not be teaching but expects students to take the floor working actively with the generation of ideas, possible problem formulations, and getting an understanding of the bachelor project genre. Typically, the workshops consist of short presentations by the teacher followed by group discussions where students reflect on the issues presented and possible directions for their own bachelor projects. Students' assessment and discussion of exemplars is also an important component of the workshops as are students' presentations of and peer feedback on their ideas and plans for the bachelor project. The teacher follows up on group discussions and work in plenary sessions. There is no formal curriculum for the workshop series, but students are encouraged to prepare for each workshop by reading relevant papers.

In spring 2021, 18 students were enrolled in the workshop series. Table 3.2 below provides details of the typical workshop contents.

The workshop series runs in parallel with students finding a topic for their bachelor project, writing a problem formulation, and finding a supervisor. In May, students are to submit a contract and a petitum signed by their supervisor. Supervision begins in August, and students are to submit their bachelor projects on 1 December. The oral defense is midend December.

Challenges

From the perspective of the teacher, the challenge is that students' discussions on possible topics and generation of ideas for their bachelor projects are often superficial and lack substance which makes it difficult to realize the aim of facilitating students' independent idea generation and problem formulation. Furthermore, the teacher wants to train students in giving and receiving peer feedback. Students have a tendency to attach more weight to feedback from the teacher and to receive this feedback uncritically. However, according to the teacher, the best feedback comes from peers. Assessing other students' work and giving and receiving peer feedback present good learning opportunities. This goes hand in hand with the teacher's wish to take the role of facilitator during the workshop series rather than subject supervisor, the latter role to be filled by other colleagues depending on the individual student's choice of topic. The teacher hopes that an intervention can make the process of creating a problem formulation more tangible for students and support students in having specific rather than general discussions when generating ideas for their bachelor projects.

Table 3.2. Contents of the workshop series for philosophy students

Workshop	Contents
Workshop one February	Introduction, topic, and process Introduction to the series of workshops, choice of topic for the bachelor project and reflections on what constitutes a (good) topic, topic in relation to problem formulation, student discussion on topics of interest, literature search, referencing, the work process, and the petitum
Workshop two March	The problem formulation Follow-up: what has happened in relation to your bachelor projects since the first workshop The aim of the problem formulation. The problem formulation in relation to domain and topic. What does a problem formulation look like? Finding the gap in the literature. Problem character in relation to type of assignment
Workshop three April	The outline Follow-up: what has happened in relation to your bachelor projects since the second workshop The purpose of the outline. Standard outline for philosophy assignments. Outline in relation to problem formulation and type of assignments. Outline as continuous work. Meta communication in relation to the outline. Outline as the structure of the assignment and as work process
Workshop four May	Argumentation and the writing of assignments Follow-up: what has happened in relation to your bachelor projects since the third workshop How do you write an argument? How do you argue? Concluding remarks and next steps regarding your bachelor project

3.2.1 Specific Research Questions

Based on the challenges identified by the participating teachers, the following more specific research questions were formulated to guide the design of interventions:

- *How can computational thinking support students' systematic investigation of abstract concepts?*
- *How can computational things automate and facilitate students' idea generation, and is this at all possible?*

3.3 Theoretical Framework and Definition of Concepts

In this section, the components that make up the theoretical framework will be elucidated. Establishing a theoretical framework will make it possible to undertake theory-driven design of interventions, and from each component in the framework, preliminary design principles will be inferred. These will inform the design of interventions and will be tested and adjusted on the background of data collection and analysis following each iteration. The concepts of design for learning, learning design, design principles, and design patterns will also be presented in this section that concludes with a presentation of the inferred preliminary design principles.

The first part of the theoretical framework is CT and computational things in HE. It provides a brief overview of previous studies and research interests in the field, operationalizes CT for use in the present context, and discusses how best to design learning activities with CT and computational things.

3.3.1 CT and Computational Things in HE

CT is linked to research in many disciplines, and a wide array of existing subjects now have computational branches. Studies show that the primary focus has been the implementation of CT in primary and secondary school both in Denmark and globally speaking (Caspersen et al., 2018; Curran et al., 2019; Lyon & Magana, 2020).

In 2015, Czerkawski og Lyman conducted a literature review to examine issues in relation to CT in HE and determined that there has been less interest and research in the potential of CT outside STEM. Research in CT is primarily undertaken in computer science at bachelor level, and the critical and even transformative power of CT in relation to STEM subjects is widely acknowledged. The authors conclude that yet there are no cross-institutional or cross-disciplinary initiatives to integrate CT as a basic set of skills, and among the reasons for this, they state that computation is understood as limited, i.e., some problems are computable, some are not.

Via a literature review, Lyon and Magana (2020) mapped empirical studies dealing with CT in HE teaching. The purpose was to identify efficient and topical methods for the integration of CT in undergraduate teaching with a particular focus on STEM. However, the authors also identified studies that dealt with the integration of CT in subjects outside STEM, e.g., the use of CT in a writing course for professionals. The studies display much variation and illustrate how CT is utilized as a framework for structuring teaching, for the design of specific activities and contents and for the design of assessment. This diversity of approaches makes it difficult to establish standards regarding how CT is taught and assessed. Lyon and Magana conclude that consensus is needed on a specific and operational definition of CT together with research regarding what pedagogical methods are efficient at the undergraduate level. In relational to the latter, the authors propose design-based research as the approach to knowledge development.

Particular attention should be paid to the work of Pollock et al. (2019) who aim to “develop, pilot, and evaluate a model for infusing computational thinking into undergraduate curricula across a variety of disciplines” (2019, p. 435). The authors use multiple methods, including faculty professional development and undergraduate peer mentors, with a view to supporting faculty in integrating CT into their already existing courses and report on successful integrations of CT in sociology and music, among other subjects.

Furthermore, in a scoping literature review of interventions used to teach CT in HE, de Jong and Jeuring (2020) identified studies that explore the integration of CT in STEM subjects as well as a range of subjects in the humanities and social sciences. However, the authors conclude that the majority of interventions take place within computer science and teacher education. Tang et al. (2020) performed a content analysis of CT research and identified studies on CT in the context of arts, languages, and music but conclude that STEM subjects are still the main area for CT efforts. Therefore, further studies are needed to uncover and contribute examples that illustrate how CT can enrich humanistic subjects. This study is a contribution to the spread of CT via integration into existing subjects and focuses on the most underexposed part of the education system in this connection, namely, HE and humanistic subjects.

CT Made Operational

CT is not confined to machines or the human brain but also is understood as bodily processes (sensorimotor movements) and extrabodily processes (interaction with the environment, including other persons and objects) acknowledging that CT can be analogue, digital, and physical as well as bodily mediated (Dohn, 2021). Dohn's characterization of the competences involved in CT is utilized to operationalize CT; see Table 3.3 below. The first column contains CT phases, and the second column lists the competences involved in each of these phases. Some of these competences are part of several phases.

The table below depicts phases and competences for sequential problem-solving. All phases and competences are not necessarily realized or needed in a given CT activity, and the question also remains whether people do solve problems sequentially. According to Dohn, an iterative process in which one moves back and forth between several phases, e.g., modeling, algorithm design, and automation, seems likely since it allows for the continuous debugging and testing in practice; perhaps several phases take place simultaneously.

According to Dohn et al. (2022), engagement with algorithmic processes is a defining feature of a CT activity. This engagement can be the informed use of existing programs, the critical assessment of algorithmic processes and artifacts, and/or the construction and testing of algorithms. An algorithm is a step-by-step action sequence, a procedure to accomplish a specific task which is done by the algorithm taking "any of the possible input instances and [transforming] it to the desired output" (Skiena, 2020, p. 3). Algorithms, algorithm design, and algorithmic processing are essential components of CT since an algorithm manifests a possible solution to a specific problem and the algorithmic processing is the execution and testing of this solution.

Table 3.3. Characterization of competences involved in CT. Based on Dohn (2021, p. 41. My translation)

Phases	Competences
Problem formulation	Abstracting the problem from the specific situation Decomposing the problem into small, manageable parts
Data generation and processing	Creating and collecting data, preparing data for analysis Decomposing data, i.e., logical data analysis and organization
Modeling	Abstracting certain traits/data as the most significant Recognizing/creating patterns on the basis of these traits Model creation – analogue, bodily, and computer visualized
Algorithm design	Writing step-by-step instructions/action sequences
Automation	Coding the algorithm for automatic processing, in program or IT-artifact Debugging and iterative testing
Generalization	Abstracting pattern for problem-solving Generalizing and transferring the problem-solving pattern to other domains

The list of phases and competences will be drawn on in the formulation of design principles and the development of interventions. Particular attention will be given to designing activities and tools that can support students' engagement with algorithmic processes.

Designing Learning Activities with CT and Computational Things

An important distinction to make is between teaching and learning CT, i.e., CT as a subject, and teaching and learning *with* CT, i.e., using CT as a tool to learn other subjects (Dohn et al., 2021). In this study, the latter is in focus.

The design of computational things for the interventions is inspired by Papert's (1980) concept "objects to think with." The computational things are to facilitate students' situated activity and embodied cognition to make possible an investigation of students' learning with CT under these conditions. Inspiration is derived from CT unplugged, i.e., nondigital approaches to human problem-solving (Caeli & Yadav, 2020). Computation was a human task long before automatic computers and digital devices were invented, and people relied on analogue and manual devices to support their memory and make computations faster (Denning & Tedre, 2021).

The challenge of using digital devices is that the algorithms and algorithmic processes involved quickly become black boxed and nontransparent which can obstruct students' learning of or with CT. Furthermore, CT unplugged is a good approach with groups of learners who might feel intimidated by digital devices.

The idea is to avoid that any digital device and the students' efforts to master it become the center of attention and overshadow the subject-related problem, students are working with.

Valente and Marchetti (2020) have coined the concept of paper computing machines and experimented with the use of simple paper-based artifacts for the design, execution, testing, and debugging of algorithms. The intention is to "support lively and playful forms of shared sense-making" (2020, p. 180), and one of the conclusions is that tangible materials support the active engagement of and dialogue between groups of learners better than computers. Valente and Marchetti have investigated the use of paper computing machines in primary schools and non-scholastic institutions, but as you will see in this case, the concept can be adapted to higher education as well.

A very early example of the unplugged approach to problem-solving is Ramon Llull's (around 1232–1316) idea of the "ars magna" which was to contain the principles of all individual sciences and thus be able to answer any conceivable question. Llull's designs were mechanical devices based on Aristotelean syllogistics, and the devices were to assist scientists in discovering new truths and validating existing truths. Llull's primary goal 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).

Llull is believed to have inspired interest in, among others, the idea that logical reasoning is computation, the idea 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 idea that mechanical devices can be utilized for the combinatorial manipulation of symbols and for generating lists of combinations (Bonet, 2011; Sales, 1997). Llull, himself, among other things, constructed manually operated, mechanical devices, some in the shape of concentric circles that were placed on top of and could be manipulated independently of each other and thus allowed for the generation and testing of combinations (Sales, 1997). Thus, these devices allowed for logical computations and have been labeled logical wheels by Bonet (2011); see Figure 3-1. Today, we would call Llull's devices computational things, and what is unique about them is that they allow for the computation of concepts rather than numbers (Uckelman, 2010), an idea that was abandoned with the invention and implementation of the binary system. This makes the devices particularly interesting as computational things in relation to humanistic subjects, and as will become apparent later, Llull's devices have been a great source of inspiration for the computational things designed in this study.

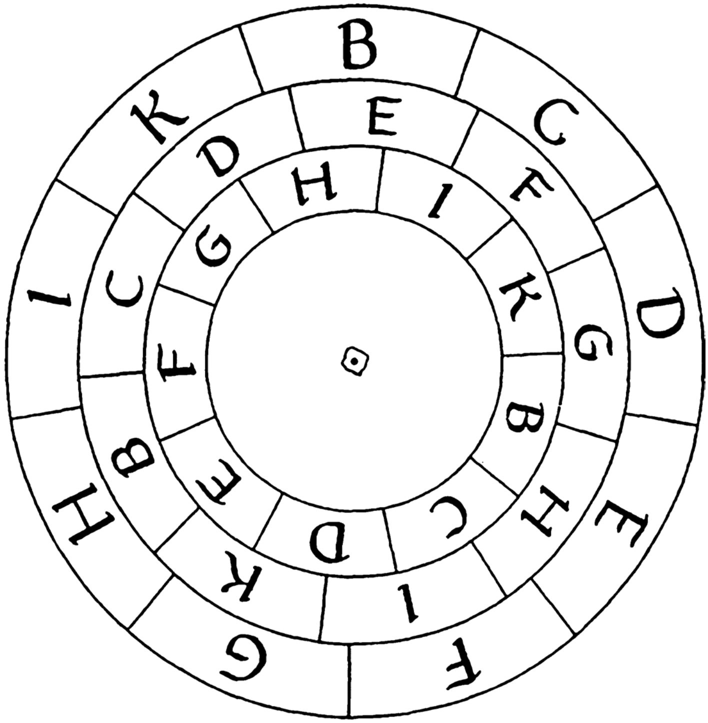

Figure 3-1. One of Llull's logical wheels. (Reprinted with permission from the author Bonet, 2011, p. 101)

The next part of the theoretical framework accounts for the learning theoretical foundation of the study, namely, situated and embodied cognition and learning, and explains how these concepts inform the present study.

3.3.2 Situated and Embodied Cognition and Learning

Proponents of CT such as Wing (2006) and Grover and Pea (2018) assume that CT skills can simply be transferred from one domain, namely, computer science, its domain of origin, to another. However, the transfer of abstracted forms of reasoning has been shown to be problematic. Situated learning, in particular, views learning as an integrated and inseparable aspect of social practice; the social practice, i.e., the specific context in which the learning takes place, shaping and adding content to what is learnt (Lave & Wenger, 1991). Not only learning, but also knowledge is situated, since knowledge, to a certain degree, is a product of the activity, context, and culture, in which it is developed and used. Thus, activity and context are not neutral or subordinate elements, but an integral part of what is learnt (Brown et al., 1989). Learning is therefore viewed as a participation process, a situated activity that spans "mind, body, activity and culturally organized setting (which include other actors)" (Lave, 1988, p. 1).

This study investigates how CT learning activities with computational things can be situated in specific, humanistic subjects in a way that is experienced as meaningful and contributes to the professional development of students. The situatedness is thus of a subject-related kind, the purpose of which is to anchor and support students' sensemaking of the CT learning activities so that these are perceived as integrated parts of the subject in question rather than decontextualized concepts that lack meaning. "[A]bstract representations are meaningless unless they can be made specific to the situation at hand" (Lave & Wenger, 1991, p. 33). Thus, learning and knowledge are understood as relational to a given context and social practice.

The use of computational things, in the shape of, e.g., tangible artifacts, is viewed in this study, as an important aspect of situatedness. Through the manipulation of artifacts, the students get the opportunity to interact actively with and in the learning context. This embodiment, the students' sensorimotor movements in relation to the computational things, and the specific aim of the activity contribute to situate and support students' learning of abstract concepts (Abrahamson & Bakker, 2016).

The design domain involved in this study is *design for learning* which consequently makes up the third part of the theoretical framework. Design for learning together with the design tools (design patterns and design principles) used in this study will be defined and explicated below.

3.3.3 Design for Learning

When designing interventions in this study, the researcher and teachers are working within the domain of *design for learning* which "is the field of 'giving form' to technologies that open learning possibilities" (Dohn & Hansen, 2018, p. 29). This encompasses the giving of form to resources, learning environments, and learning activities, including student and teacher roles together with forms of interaction, e.g., students' interaction with resources, the learning environment, with fellow students, the teacher, etc. Technology is not confined to digital devices but is understood as any method, practice, and/or device used by a culture to make things work (Arthur, 2009). This is a definition that includes unplugged computational things, which is essential in this study, cf. above.

There is a growing focus on design for learning both in educational research and practice since, today, teachers are faced with a multitude of choices when organizing teaching and learning tasks and selecting learning resources. The many new possibilities for reshaping learning activities emphasize the importance of *designing* for students' learning, the term *design* both connoting "a distinctive form, a process of forming and a lack of determinism as to the precise outcome" (Dohn et al., 2020, p. 161). The term *learning design* is used to denote a plan or prototype for a specific teaching and learning activity that is to support students in achieving set learning objectives (Dohn et al., 2020).

3.3.4 Design Principles

In this study, the formulation of design principles on the background of the components in the theoretical framework ensures a theory-driven approach to the design of interventions. Design principles are used in practical domains to support design, development, creation, or implementation, and they "guide the design process or [.. .] support an intervention in practice" (Dohn et al., 2020, p. 162). Design principles are not rigid rules but should be adapted to the context in question and can serve different functions. Design principles can be a useful way of communicating a learning design to practitioners and disseminate good and/or innovative practice within a domain. In addition, design principles can:

1. be guidelines for handling or developing a practice and for creating a solution in a complex environment;
2. constitute a language for reflecting on and communicating about the handling or development of a practice; and,
3. articulate norms or values for evaluating a practice. (Based on Dohn et al., 2020, p. 162)

Design principles can be categorized as *substantive*, i.e., principles that describe the characteristics of the end result of an intervention, and as *procedural*, i.e., principles that are formulated as guidelines and provide methods for developing the intervention (van den Akker, 1999). In addition, design principles can be *specific* if formulated for specific learning designs anchored in specific contexts, or they can be *general* if formulated for use across different domains and learning contexts (Dohn et al., 2020). These four forms of design principles are brought together in Figure 3-2 below which produces "four paradigmatic forms of design principles, distinguished by the scope of their contribution to practice (specific or general) and by their function (substantive or procedural)" (Dohn et al., 2020, p. 163). The model below and Dohn, Hansen, and Goodyear's approach to the formulation of design principles have inspired the formulation of preliminary design principles in this case study.

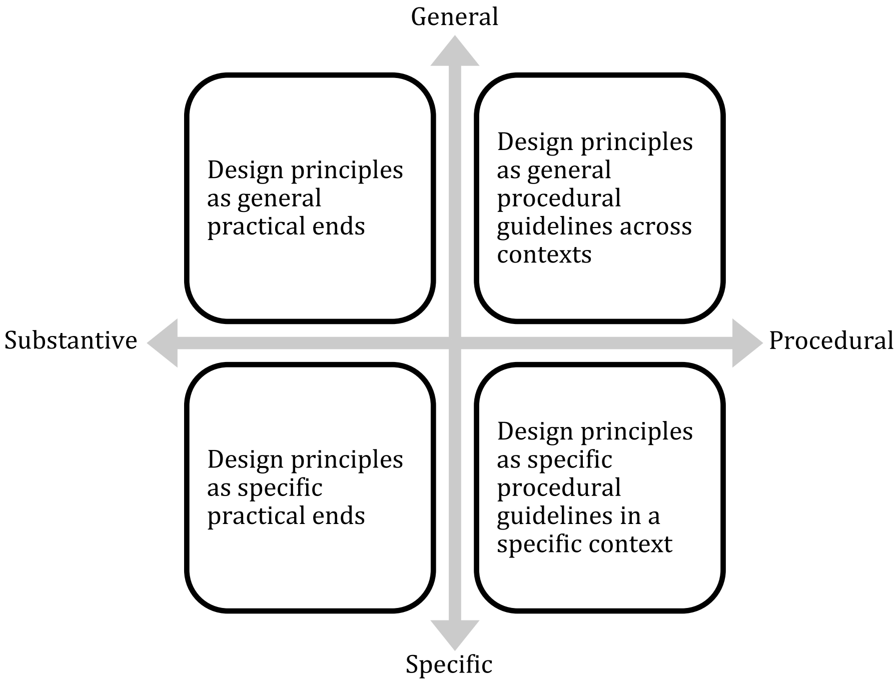

Figure 3-2. Four types of design principles. Based on Dohn et al. (2020, p. 163)

3.3.5 Design Patterns

Design patterns are the systematic descriptions of learning designs that make possible the "encoding, sharing and using knowledge for educational design" (Goodyear, 2005, p. 87). Thus, design patterns are a means of documenting a learning design with the purpose, among others, of inspiring practitioners and providing instructions and resources for new/innovative teaching and learning activities within a given learning context and domain. Consequently, there are similarities between the concept of design pattern and the *specific* design principles. However, a design pattern will often include both the practical ends and procedural guidelines of a given intervention, thus resembling both *substantive* and *procedural* design principles. Furthermore, the design pattern will pose a solution to a specific challenge related to teaching and learning in a specific context.

The three components of the theoretical framework, the integration of CT with computational things in HE, situated and embodied cognition and learning, and design for learning, have now been presented, and this section concludes with an account of the preliminary design principles inferred from this theoretical framework.

3.3.6 Preliminary Design Principles

On the basis of the theoretical framework above, the following preliminary design principles were formulated to be used as guidelines for the design of interventions for Media Studies and Philosophy. Note that the preliminary design principles are of a general nature. When designing interventions for Media Studies and Philosophy, it will be possible to formulate design principles of a specific nature informed by the subject and the teacher as the subject-matter expert.

General-Substantive Design Principles

These are the general practical goals of students engaging with a learning design for the *situated* and *embodied* cognition and learning with *CT* and *computational things*:

- Students can employ CT competences to gain an in-depth understanding of core questions or concepts related to the specific subject they are studying.
- Students can make use of computational things to gain an in-depth understanding of core questions or concepts related to the specific subject they are studying.
- Students can employ CT competences to identify, formulate, and solve subject- related problems.
- Students can make use of computational things to identify, formulate, and solve subject-related problems.
- Students can participate in situated learning, making use of mind, body, fellow participants, activity, and cultural setting in their learning process.
- Students can reflect on their learning from engaging with alternative learning activities and tools.

General-Procedural Design Principles

These are the procedural guidelines that inform the design of interventions:

- Design tasks that address core questions or concepts in the specific subject.
- Facilitate students' use of select CT competences as tools to explore these subject- related questions or concepts.
- Facilitate students' use of computational things to explore the subject-related questions or concepts. Investigate how to create tangible and manipulable representations of these abstractions.

- Iterate between items 1–3 above, until tasks that allow students to work in a situated and embodied manner with subject-related questions or concepts using CT and computational things as tools have been arrived at.

The next section of the chapter provides a description and discussion of the DBR approach utilized in the study covering the phases, the design aspect of DBR as well as points of attention. The section ends with an outline of data collection and analysis methods and a brief note on ethics.

3.4 Research Design and Methods

3.4.1 Design-Based Research

Since the purpose of this research project is to investigate the meaningful integration of CT with computational things in humanistic subjects in HE from the point of view of teachers and students, to develop design principles that can inspire practice, to arrive at theoretically informed and empirically tested design patterns, and to develop an outline of a HE pedagogy, an educational research approach that connects theory and practice is called for. DBR is an approach that emphasizes this connection; it serves both an applied and a theory-building purpose and is under-taken in the wild, in actual classrooms, or in other authentic learning contexts (Reimann, 2011). This fits with the conceptualization of cognition and learning as situated and embodied as described above.

One of the main motivations for making use of DBR is to make learning research more relevant for practice since much research conducted in lab settings is unknown to practitioners and only in few cases affects teaching practices or educational policies. Reimann argues that “teachers find it difficult to implement learning innovations, as the lab setting where the learning innovation has been established is too different from the demands and constraints of the classroom” (Reimann, 2011, p. 38). A further challenge in relation to implementing learning innovations from lab settings is the need for practitioners to adjust the lab tasks to fit their own teaching context with the resources available. DBR was chosen for this study to overcome the challenges mentioned above; by working with practitioners across several iterations, empirically testing and then improving tools and activities, the hope is to arrive at design principles and patterns that teachers in the humanities will find useful and easily applicable.

DBR is defined as:

> a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers

> and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories. (Wang & Hannafin, 2005, p. 6)

The point of departure is the development of a solution to a specific challenge in relation to a domain-specific learning process (Cobb et al., 2003). By conducting cycles of design, development, testing, and revision, the researcher can test and improve the design in specific contexts and across contexts. This process informs the development of design principles and of a coherent theory. In this study, the research process is organized as a four-phased DBR-model inspired by Reeves (2006) and illustrated in Figure 3-3.

Phase 1. Analysis took place in winter 2020/2021; the researcher and practitioners collaborated to investigate the subjects in question and uncover practical problems that might serve as objects of interventions and to identify possibilities for the integration of CT with computational things as possible solutions to the problems uncovered.

Phase 2. Design, early spring 2021, involved the informed development of interventions, i.e., specific design patterns in collaboration with the practitioners. This phase also included the development of preliminary design principles and an interpretative framework for data analysis.

The third phase, Intervention, is comprised of two iterations in which the interventions are carried out, data are collected and analyzed, the results are scrutinized and discussed with practitioners, and suggestions for improvements in relation to the next iteration are identified and recorded. The first iteration was conducted in spring 2021, and the second iteration is currently being conducted (spring 2022).

In the fourth and final phase, Reflection, autumn 2022/spring 2023, the robustness and validity of design patterns are assessed, and final design principles, design patterns, and an outline of a HE pedagogy are developed.

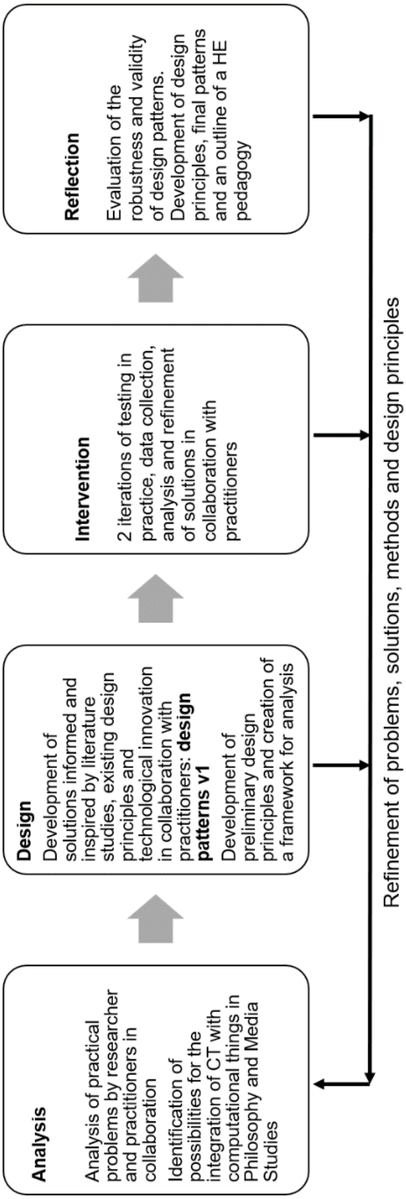

Figure 3-3. The DBR phases of the present study

Points of Attention in DBR

Among other things, DBR is criticized for lack of transparency in that it is not always clear what has been involved in a specific intervention or how it has been carried out in practice. At the same time, the realized design will often be different from the intended since DBR takes place in the wild and is not confined to controlled experiments in the laboratory as explained above.

However, transparency can be increased if researchers "lay open and problematize the completed design and resultant implementation in a way that provides insight into the local dynamics [.. .] sharing rich descriptions of context" (Barab & Squire, 2004, p. 8). Such rich descriptions are provided in the second half of this chapter.

Dede claims that some DBR studies are "under-conceptualized and over-methodologized" (Dede, 2004, p. 107) and emphasizes the importance of a solid, theoretical framework for the development of interventions together with a focus on the generation of results that can contribute to the refinement and development of theory. An account of the theoretical framework of this study was provided in the first half of the chapter.

3.4.2 Data Collection and Analysis

Case Type and Selection

This section describes the methods utilized in the study for the collection and analysis of data. Since this is an exploratory study with the purpose of investigating how CT with computational things can be integrated in humanistic subjects in HE, a qualitative approach involving multiple cases (Creswell et al., 2007) is utilized. Two cases have been selected to make possible the in-depth investigation of the integration of CT with computational things in two different humanistic contexts. Each case consists of a specific course with a teacher and students as described above, the unit of analysis being the interventions, both the design and the actual unfolding of these in a situated context. The use of cases makes it possible to capture the contextual conditions which is essential in relation to the phenomenon being studied (Yin, 2003).

The two cases chosen for this case study are paradigmatic cases, the purpose of which is "to develop a paradigmatic example, a prototype or a metaphor for the domain concerned" (Flyvbjerg, 2010, p. 475. My translation).

Already in the planning phase of the present study, practitioners from the two study programs at the Faculty of Humanities at SDU were contacted to inquire whether they would participate as cases in the project, and they agreed. The practitioners contacted are known for their interest in course, curriculum, and/or continued professional development within pedagogy and technology-enhanced learning since this was seen as an important prerequisite for completing the study. Below is given an outline of data collection methods and purposes.

Data Collection

Data are collected after each of the two iterations and on several levels, which is a characteristic of DBR (Reimann, 2011). The purpose is to:

- Document the design-process and the learning process of the researcher. The researcher keeps a log for each case where all minutes from planning meetings with the teachers are recorded, as well as design ideas and reflections that are generated at and in between meetings.
- Study how the interventions unfold, i.e., how students engage with the activities and tools designed. Video observations of the interventions are carried out, the researcher takes field notes, and students' products and reflections are collected.
- Evaluate the learning designs to be able to improve these for the second iteration. Semistructured interviews with the teachers and some students are conducted. An evaluation questionnaire is used to collect both qualitative and quantitative data on students' experiences and perceived outcome.

The following data were collected in the first iteration, spring 2021:

Media Studies: Video recordings from five groups of three students (n = 15). Reflections collected from 11 students. Field notes. Four semistructured interviews conducted and recorded via Zoom: The teacher and three students.

Philosophy: Video recordings from five groups of three students (n = 15). Reflections collected from 8 students. Field notes. Four responses on evaluation questionnaire. Four semistructured interviews conducted and recorded via Zoom: The teacher and three students.

Due to the fairly low response rate on evaluation questionnaires that were administered outside of class via the learning platform, it was decided to discontinue this data collection format and instead rely on the collection of students' responses to reflection questions at the end of interventions. Questionnaire responses were, however, used to inform improvements made to activities and tools in preparation for the second iteration.

An account of analysis methods is given below, and the interventions designed are explained in detail in the last part of the chapter.

Data Analysis

The data analysis strategy is to describe the case, the identified themes of the case as well as themes identified across cases (Creswell et al., 2007). A rich description of the contextual conditions plays a central role (Yin, 2003). The purpose is to arrive at an in-depth, contextual understanding of what happens when humanistic students are to learn with CT and computational things and how you can design for such learning. In the data analysis, the researcher's log was used to provide a rigorous description and documentation of the design process to make this as transparent as possible. See the section "Development of Interventions".

The video recordings worked as "a lens with which to focus on selected aspects of classroom activity" (Clarke & Chan, 2018, p. 6), more specifically students' engagement with the designed activities and tools with a view to determine whether and how the interventions designed support students' situated, embodied, and subject-related cognition and learning with CT and computational things. According to Snelson et al. (2021), a methodological challenge in any video study is determining what to look for in the video content and establishing a procedure for the documentation and analysis of what is observed. Video recordings contain rich data making it necessary to focus attention on aspects of relevance to the research questions. To secure this focus, the video recordings were analyzed using the following approach based on Snelson et al. (2021): Observation, memoing, and coding. Observation: Each recording was viewed looking for phenomena of interest: students' strategies for engaging with and completing the activities, students' tool usage, and dialogue and interaction around tasks and tool(s). During observations, videos were indexed developing a content log with time codes and descriptions of video content. Based on these indexes, memos were created, adding transcriptions of audio and visual content to relevant clips and student products to the indexes. The memos were then coded using thematic analysis.

The researcher's field notes, student products and reflections, and evaluation questionnaire results as well as the interviews with teachers and students were likewise coded using thematic analysis, and patterns were identified across the cases. Again, the focus was on capturing students' engagement with the activities, tools, and each other.

The thematic analysis conducted was partly analyst-driven (Braun & Clarke, 2006) with a particular focus on coding for the individual components in the theoretical framework described above and partly data-driven to also capture participants' views and allowing their perceptions and experiences to be voiced. Thus, deductive and inductive coding were combined in a hybrid approach to thematic analysis (Xu & Zammit, 2020). To validate codes, categories, themes, and interpretations, data sessions were held with colleagues in which data extracts were studied and discussed. Furthermore, as part of the data analysis, the interventions were evaluated, identifying successful components as well as possible improvements. The possible improvements were discussed and negotiated with the teachers, and the researcher subsequently implemented the agreed improvements before the second iteration.

The second iteration of interventions is currently taking place (spring 2022). The data collected will undergo the same analysis as described above. Then follows the final reflection phase in which the lessons learned from the two cases will be extracted and used to refine the design principles and patterns for the integration of CT with computational things in humanistic subjects in HE.

Ethics

Since the interventions at both Philosophy and Media Studies were an integral part of the course, all students who were present were asked to engage in the activities. However, each student had the opportunity to decline to participate in the study. A few students used this option and were not recorded on video. A practical solution was found in which the students who did not want to be video recorded were placed in the same group.

3.5 Development of Interventions

In this section, a detailed account of the design process and the resulting interventions will be given. Furthermore, it will be explicated how CT has been integrated into these interventions.

3.5.1 Development of Intervention for Media Studies

The planning started in December 2020, when the teacher and researcher met online for a first discussion of the subject and identification of challenges experienced that could form the basis for an intervention. The planning meeting started with the researcher introducing the theoretical framework for the intervention to be developed to establish common ground. As mentioned in the initial presentation of the case studies above, the challenges are that students have difficulties understanding the concepts of the subject, adopting the perspective of media institutions, trades, and systems and independently generating ideas for their synopsis.

In relation to students' understanding of the core concepts, the teacher pointed to a model which is central to the subject, namely, *Media, actors and macro structures of the media system* (Vestergaard, 2007), depicted below (Figure 3-4).

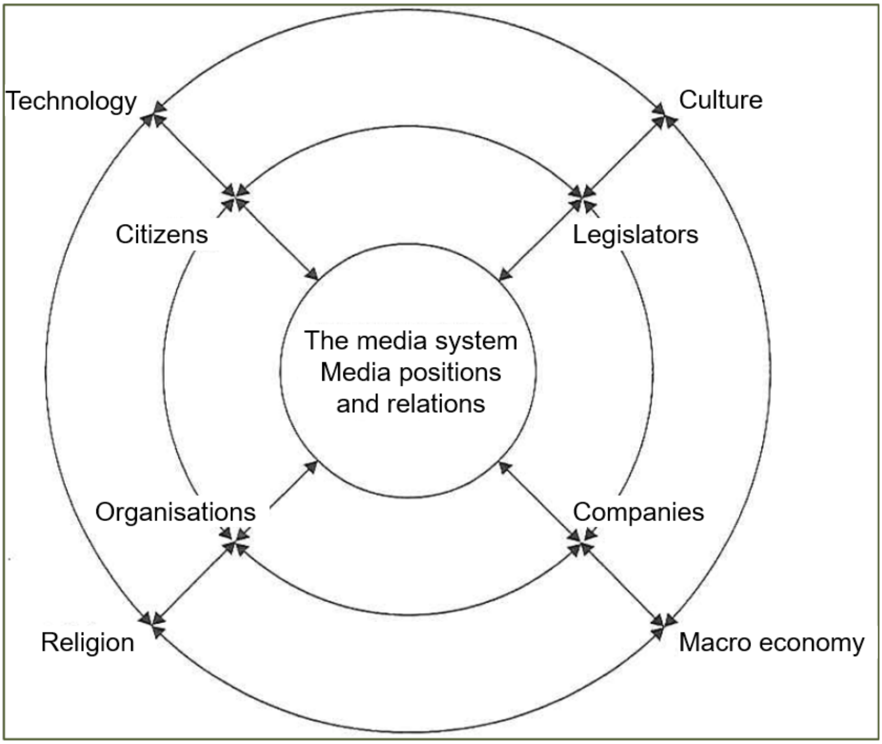

Figure 3-4. Media, actors, and macro structures of the media system. (Vestergaard, 2007, p. 70. My translation)

Ideas for the intervention were explored and negotiated in the course of three planning meetings with the teacher. In between the meetings, the researcher studied the lesson plan and the subject-related resources (Jensen, 2018; Vestergaard, 2007) provided by the teacher and generated ideas for the integration of CT and the development of computational things for the context, working with the design principles derived from the theoretical framework as a foundation. In addition, the idea generation was inspired by the design of interventions for Philosophy in which the researcher was also engaged during the same period of time, cf. below.

A first prototype for a computational thing that was to support students in generating ideas for their exam synopses was produced by the researcher and discussed and negotiated with the teacher. Following this, the researcher made the agreed changes which resulted in the prototype that was tested with students. This prototype included learning outcomes, instructions for students, a plan for facilitation, and a computational thing for generating ideas. Together these elements constitute a design pattern, version 1. See description of the idea generation tool for Media Studies students and the related activity in Table 3.4.

Table 3.4. Outline of the Media Studies intervention

Step	Activity
Materials for the face-to-face version	Instructions for students, scissors, punch screws, paper board in five different colors, pens, and metal clips. Each of the four circles of the idea generation tool is printed on paper board in the relevant number of copies – one for each student. Use a different color for each circle. Print the selection triangle on a dark gray or black paper board – one per student. Assemble sets of materials for students. Note: to save time, the teacher or researcher 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 on the institution's learning platform is also needed where students can upload their response to reflection questions and their completed idea generation tools
Introduction (10 min)	Introduction by the teacher
Individual work (20 min)	Each student is given a set of materials and instructions Students cut out the circles and assemble their own idea generation tool. See illustration in Figure 3-5. They now write topics 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 (35 min)	Students work in groups of three. Each group member in turn shares and discusses their ideas with the other two group members who ask questions and provide ideas for new perspectives
Plenary session (15 min)	Plenary session facilitated by the teacher where students share their ideas
Individual reflection (10 min)	Students post their responses to reflection questions online together with images of their idea generation tools

In Figure 3-5, you see the following illustrated: top left: set of materials for students; top right and bottom left: the four circles of the tool and the selection triangle are fastened with a metal clip which allows students to turn each circle independently; and bottom right: the assembled idea generation tool.

Figure 3-5. The idea generation tool for Media Studies

The intervention was timed to match the lesson plan and contents of the course, and it was therefore scheduled for the last teaching session to give students the opportunity to explore and delimit ideas for their synopsis.

The CT in the Idea Generation Tool for Media Studies

Using the idea generation tool requires students to *engage with algorithmic processes and compute with concepts.* The core model of the subject lends itself easily to Llull's concept of a logical wheel in that it consists of three concentric circles. A fourth circle has been added to the idea generation tool to allow student input in the form of cases or problems that students find of interest in relation to their synopsis. Furthermore, a marker triangle has been added to enclose the theoretical perspectives selected by students for further scrutiny. This results in the logical wheel, *the idea generation tool*, shown in Figure 3-6. The circles in the wheel will be referred to from the outside-in, so that the outer circle is circle one and the inner circle is circle four.

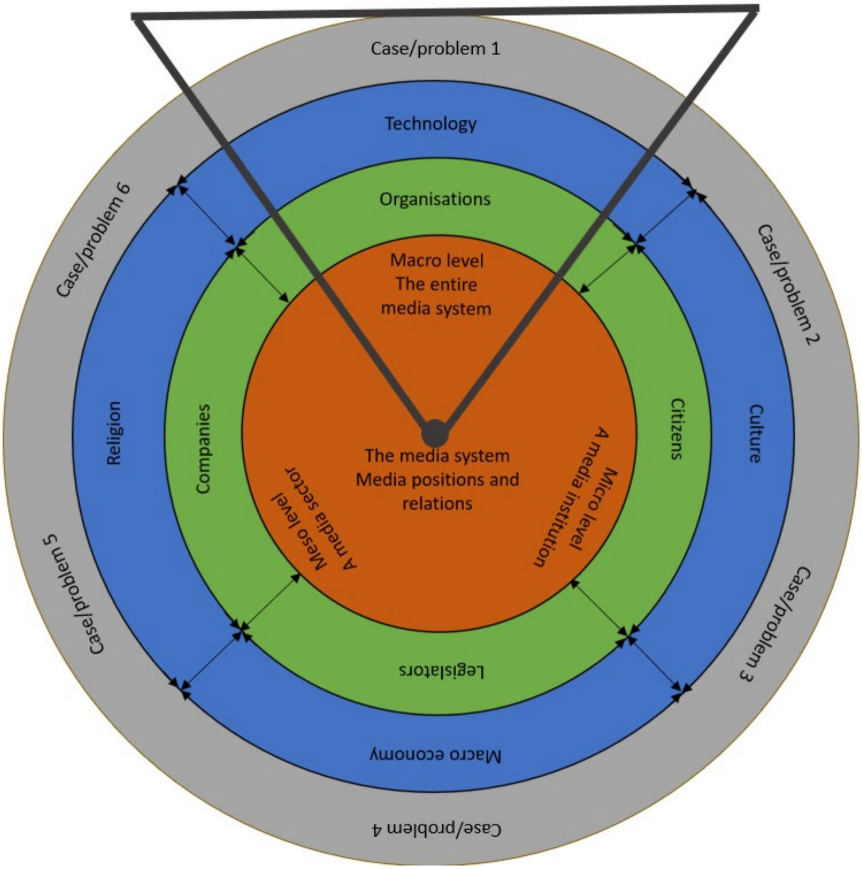

Figure 3-6. The idea generation tool for Media Studies

Students are asked to start anywhere in the tool they please. If, e.g., a student would like to investigate technology in their synopsis, the student turns the second circle to place technology within the selection triangle. The student can now explore what other perspectives to integrate into the synopsis by turning circle four and assessing the relevance of each of the media system levels and by turning circle three and assessing the relevance of each of the media systemic actors. Once students have made selections on all three circles and have arrived at a combination, they can reflect on specific cases or problems that are contained in this combination. Students are asked to write down the combinations they have explored, and the specific ideas generated, and then explore other combinations. In this way, the tool allows for students' systematic exploration of all possible combinations of macro structure variables (circle two), media systemic actors (circle three), and media system levels (circle four); see overview in Table 3.5. A systematic exploration would not be possible without the tool since for each case or problem, students are interested in, there are 48 possible ternary combinations if students choose a perspective from each of the three circles of the model (circles two to four) and 40 binary combinations if students choose a perspective from only two of the circles.

Table 3.5. Overview of the perspectives students can choose between and combine when generating synopsis ideas

Circle one Cases/problems of interest to the student	Circle two Macro structure variables	Circle three Media systemic actors	Circle four Media system levels
Data generated by students	Technology	Legislators	One media institution (micro level)
...	Culture	Companies	A media sector (meso-level)
...	Macro economy	Organizations	The entire media system (macro level)
...	Religion	Citizens	

The teacher explains that binary combinations are those most commonly found in students' synopses. These typically involve a component from circle four and a component from circle two or three. Students can also choose to select two components from circle two or three and combine these with a component from circle four. The tool is thus a computational thing in that it allows students to engage with algorithmic processes in the computation of concepts.

The idea generation tool contains all the possible perspectives that students can work with in their synopsis, thus framing the idea generation firmly and situating it within the subject. The idea generation tool becomes an object to think with in Papert's terms, an object with which to think about theoretical perspectives related to the analysis of media systems. When using the tool, 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 on the outer disk in the form of topics and cases they find interesting. They can then explore and select perspectives from the other three disks that they find relevant for these topics or cases.
- 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 for students to arrive at a problem statement.

Below, the design process and resulting intervention for Philosophy is explicated.

3.5.2 Development of Intervention for Philosophy

The researcher's contact at Philosophy was the Head of Studies who had promised to facilitate contact to teachers. Consequently, the researcher was invited to pitch her study at a teachers' meeting in mid-November 2020. The pitch included an outline of the study, including the research questions, an introduction to the theoretical framework, an example of a possible intervention, and questions and answers, and concluded with the researcher encouraging interested teachers to contact her. The teacher of the bachelor project workshop series reached out, and an agreement was made to explore possible interventions in this context focusing on the challenge outlined above of facilitating students' independent generation and specific discussions of project ideas and problem formulations.

Ideas for interventions were explored and negotiated in the course of four planning meetings with the teacher. Again, the design process was informed by the resources provided by the teacher (Lippert-Rasmussen et al., 2020; Rienecker & Jørgensen, 2017) in an iterative negotiation between the contents of the resources and the requirements of the theoretical framework. In addition, prototypes were shared with the teacher from Media Studies who gave her feedback and input for improvements. The good problem formulation quickly became the center of attention for the design process together with possible ways of encouraging students to consider, reflect on, and further develop ideas. The solution arrived at was to support students in investigating the components of the good problem formulation, in generating ideas, and in systematically investigating possible problem formulations. The overall goal was to make the process of creating a problem formulation more tangible for students and to support students' specific rather than general discussions of ideas and constructive peer feedback.

A first prototype of an idea generation tool was developed by the researcher and negotiated with the teacher in an iterative process. After each negotiation session, the researcher made the agreed changes which resulted in the prototype that was tested with students. In addition, learning outcomes, instructions for students, and a plan for facilitating the activity were formulated. Together with the idea generation tool, these elements constitute a design pattern, version 1. See Figure 3-7 for an illustration of the idea generation tool, and see Table 3.6 for an outline of the intervention. Since the intervention aligned with the contents of the second workshop of the bachelor project workshop series, it was decided that the intervention be carried out on that workshop. This intervention had to be carried out online via MS Teams due to the corona lockdown, and therefore the idea generation tool was developed in an online version in PowerPoint that allowed students to input data and turn each of the circles.

Below follows an explanation regarding how CT is embedded in the activity.

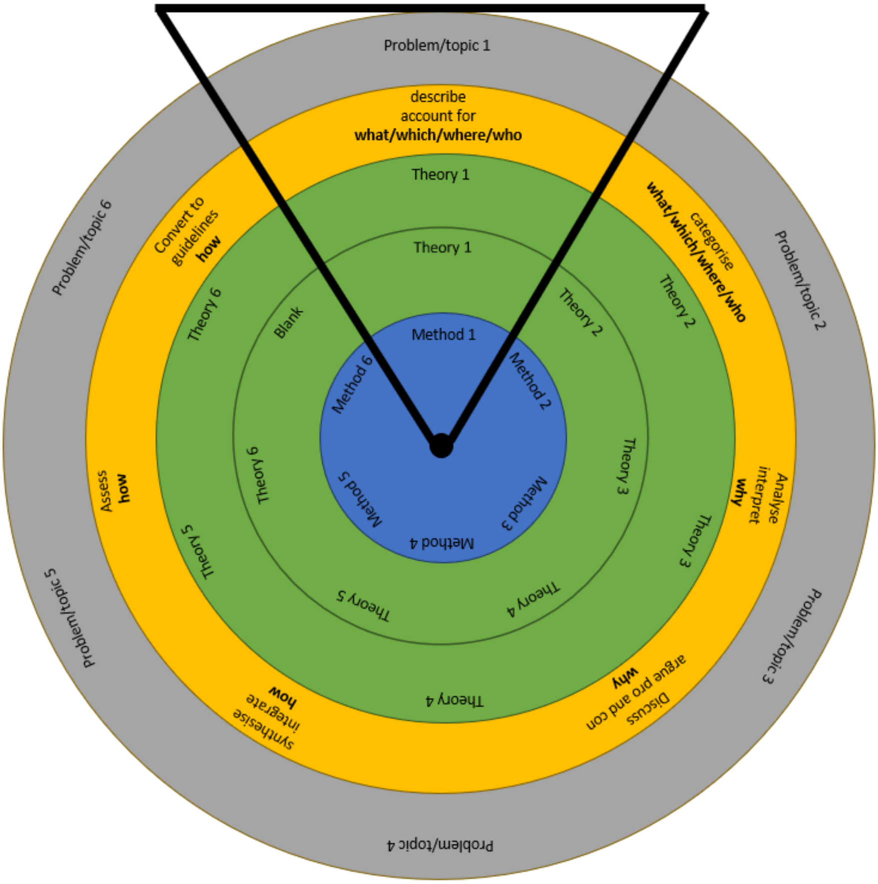

Figure 3-7. The idea generation tool for Philosophy

Table 3.6. Outline of the Philosophy intervention

Step	Activity
Student preparation	Students were asked to prepare as follows: Try to decide on one or two possible topics for your bachelor project Consider the possible wording of your problem formulation Consider who would be relevant as your supervisor (and perhaps contact that person) Begin a tentative literature search Read the chapter on problem formulations in Rienecker and Jørgensen (2017). Students had read Lippert-Rasmussen et al. (2020) for workshop one
Materials for the online version	Instructions for students. Online version of the idea generation tool for download. Reflection questions. Discussion forum on institution learning platform where students can post their response to reflection questions and their completed idea generation tools
Introduction (45 min)	Introduction to project by researcher and obtaining consent from students with respect to data collection. Formation of groups Introduction to the good project formulation by teacher Demonstration of the idea generation tool by teacher
Group work (45 min)	Students work in groups of three. Each group member in turn shares his/her screen, displays, and works with the downloaded tool inputting topics, theories, and methods and investigating possible question words. The other group members act as sparring partners giving feedback, asking questions, and providing new perspectives/combinations. After 15 min, the next student takes over the screen
Plenary session (20 min)	Plenary session where students share experiences, comments, and questions. Facilitated by teacher
Individual reflection (20 min)	Students reflect on and post their responses to reflection questions online together with images of their completed idea generation tools

The CT in the Idea Generation Tool for Philosophy

There are similarities between the idea generation tool for Philosophy and the tool for Media Studies. Both tools require students to *engage with algorithmic processes and compute with concepts*. However, the idea generation tool for Philosophy has been modeled on the components of the good problem formulation and constitutes a decomposed and tangible representation of this abstraction. Circle one is for topics, circle two contains possible question words, circles three and four are for theories, and circle five for methods; see Figure 3-7. The circles in the wheel are referred to from the outside-in, so that the outer circle is circle one and the inner circle is circle five. A selection triangle is also added to this tool to enclose combinations selected by students for further scrutiny.

The purpose of the idea generation tool is to support students in *decomposing* the good problem formulation and in working with the individual component parts before combining and exploring specific instances of each component.

Students are to *generate data* themselves when using the tool. They must input topics they find interesting together with relevant theories and methods. Students explore solutions, which in this case are potential problem formulations, by turning the circles and creating combinations of data that they have inserted into circle one and circles three to five and the already existing data (question words) in circle two. Students are required to engage in algorithmic processing as illustrated in pseudo code below:

Generating data:

1. Start with circle 1.

   Input topic of interest in box 1.

2. Proceed to the next box in circle 1 and input topic of interest.

   Repeat until the list of interesting topics is exhausted.

3. Go to circle 3.

   Input relevant theory in box 1.

4. Proceed to the next box in circle 3 and input relevant theory.

   Repeat until the list of relevant theories is exhausted.

5. Repeat for circle 4.
6. Go to circle 5.

   Input relevant method in box 1.

7. Proceed to the next box in circle 5 and input relevant method.

   Repeat until the list of relevant methods is exhausted.

Exploring combinations:

1. Go to circle one and choose a topic to explore. Place within selection triangle.
2. Go to circle two and choose question word to explore. Place within selection triangle.
3. Go to circle three and choose theory to explore. Place within selection triangle.
4. If comparing or contrasting theories, then go to circle four and turn to desired theory. Place within selection triangle. If you only work with one theory, then turn circle four to blank.
5. Go to circle five and choose method to explore. Place within selection triangle.
6. Consider chosen combination and write down possible problem formulation.
7. Repeat steps 1–6 to explore other combinations.

The tool was meant as an aid for students' systematic exploration of project ideas with students not necessarily starting with circle one and moving inward but working with the elements of the tool that seem relevant and meaningful. Table 3.7 below aligns the CT in the idea generation tools and the related activities with the overview of CT phases and competences presented in the theoretical framework above.

3.5.3 The CT in the Idea Generation Tools Aligned with CT Phases and Competences

Table 3.7. The CT in the idea generation tools and related activities aligned with the overview of CT phases and competences

Phases	Competences	Media studies	Philosophy
Problem formulation	Abstracting the problem from the specific situation Decomposing the problem into small, manageable parts	The media systems model is in itself an abstraction The circles of the tool constitute a decomposed version of the media system and its surroundings	The tool constitutes a decomposed version of the abstract concept of the good problem formulation, each circle equaling a component
Data generation and processing	Creating and collecting data, preparing data for analysis Decomposing data, i.e., logical data analysis and organization	Students generate and input topics or cases in the outer circle of the tool	Students discuss, generate, and input topics, theories, and methods that they find relevant and interesting
Modeling	Abstracting certain traits/data as the most significant Recognizing/ creating patterns on the basis of these traits Model creation – analogue, bodily, and computer visualized	Students engage in analogue and embodied modeling 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 decide which circle to compute first, and how to proceed; the action sequences unfold in the moment	Students discuss and decide which circle to compute first, and how to proceed. The action sequences are negotiated and unfold in the Moment

<table>
<tr><td rowspan="3">Automation</td><td rowspan="3">Coding the algorithm for automatic processing, in program or IT-artifact
Debugging and iterative testing</td><td colspan="2">The tool represents the coded algorithm for partly automatic processing</td></tr>
<tr><td>Each circle contains the possible states of a variable, and the student then manually processes each variable selecting and combining the preferred states</td><td>Each of the completed circles contains the possible states of a variable, and the student then manually processes each variable selecting and combining the preferred states</td></tr>
<tr><td colspan="2">Debugging and iterative testing: students share, discuss, and challenge each other's ideas</td></tr>
<tr><td>Generalization</td><td>Abstracting pattern for problem-solving
Generalizing and</td><td colspan="2">Students can use the same pattern for their different ideas and support fellow students in applying the pattern to their ideas</td></tr>
</table>

After this account of the design process and the resulting interventions, the findings from the analysis of data collected in the first iteration will be presented and discussed.

3.6 Findings from the First Iteration

In this section, the findings from the first iteration are presented starting with the themes from the theoretical, deductive analysis, and then follow the themes from the data-driven, inductive analysis. Each theme will be elaborated and illustrated with quotes that exemplify the experiences of respondents. The quotes have been selected because they represent the experiences of several respondents or because they incorporate different or particular facets of these experiences. The focus is on securing an equal representation of the data.

3.6.1 Themes from the Deductive Analysis

In the deductive analysis, the data were approached with the theoretical framework in mind to find instances of CT in use: problem-solving, decomposition, automation, and algorithmic processing, i.e., computing with concepts. Furthermore, the data were coded for situated and embodied aspects in relation to the use of the idea generation tool – the computational thing.

Problem-Solving: What Is the Problem?

The tool and activity were to help students investigate abstract concepts and to partly automate and facilitate students' idea generation. The problem-solving in focus was therefore related to understanding the abstract concepts of the subject in question and generating specific ideas and problem formulations for exam papers and bachelor projects. However, several students pointed to another problem which the tool helped them solve, namely, that of identifying the bounds of their subject. What perspectives were within the bounds and which were outside? One Media Studies student who was interviewed said that the tool helped frame his idea generation, locating it securely within the bounds of the subject. Thus, the tool became an object for situated and subject-related thinking and exploration of possible ideas. According to the student, the tool helped answer his question regarding what possible perspectives he could integrate in his synopsis. If the tool had not provided these answers, I would have probably asked the teacher, he said.

> Often, generally, university subjects can be very open and very abstract in their framework, and this is often because you learn a lot of different things very quickly or with a little too much distance, perhaps. You learn about one thing and then connect it to something else half a year later. And then you're like, what is the framework around what I am sitting and doing? And if it doesn't like click right from the start. And, as a matter of fact, I didn't think it did in Media Institutions. There, I was a bit insecure as to the framework of the subject. So, it [the tool] was such a good insight in, ok, these are the things, we have talked about. This is how you can look at it, and that thing about being able to like play with the setup: how broadly will I look at it? What aspects, can you look at? (Excerpt from interview 3 with student from Media Studies. My translation)

Another student used the word template to describe how she used the tool and how the tool framed her thinking within the bounds of the subject:

> At any rate, I think it was a nice template for like, well again, this thing about getting something physical in your hand because it has all been online. So, I just feel it [the tool] was good at like providing some thoughts eh, because you like had to relate to all those different eh, well things that are contained in the [media system]. (Excerpt from interview 2 with student from Media Studies. My translation)

A student from Media Studies pointed to a possible explanation for the challenge perceived by the teachers that students have difficulties generating ideas. She explained that she usually finds it intimidating to generate ideas, but found it manageable using the idea generation tool and getting feedback from fellow students. Thus, she produced an idea during the intervention that she pursued in her synopsis.

> I think it can be super-stressful sometimes to have to come up with some brilliant problem formulation [...] For me it became

> possible [using the tool] to arrive at a problem formulation for my exam – quite specifically (laughs) [...] Because, it is something that I can find difficult to do, or something that I can find very difficult to manage, to have to generate ideas. (Excerpt from interview 1 with student from Media Studies. My translation)

The Media Studies teacher, who had individual supervision sessions with students after the intervention, reported that many students brought their completed idea generation tool for and/or referred to it during the supervision, and that no students approached her to ask whether she could provide them with an idea.

Algorithmic Processing: Computing with Concepts

Some Philosophy students reached the computing with concepts phase as did all the Media Studies students. Some students describe the process as intuitive, one student talks about trying to find that [components in the wheel] which matched what she had thought about beforehand, and another student explains how the tool presents three steps that she can use to arrive at her idea, selecting one [component] from each circle. These responses all point to students' systematic investigation of possible combinations.

> I think, as mentioned, I already had an idea that I wanted to do something on [anonymised] public service. So, I wrote it on [the disk] right away. And then, I really just started looking at the different things, and thinking about what is it the different things, the different spaces, like, involve? And then, I don't know, very simply, like almost intuitively, I just started turning, yes. Well, perhaps it doesn't fit into, what is it called, the organisation part. Well, then you just try another one. And then you think, could it fit in here, and how big an, eh, what is it called, aspect are you under, are you under those meso and the like? And then like, I don't know, but it was very intuitive, the thing about you, like, going down the row and saying, where does it fit in. And if there were more, I just went through it again. (Excerpt from interview 3 with student from Media Studies. My translation)

> So, in that way, I actually think it [the tool] helped nicely to like create some ideas like: well, what media institution would you like to look at, eh? Well, I would like to look at DR. You know, so that I like, all, so that I could like use the three steps to arrive at my idea. [.. .] So, you can sort of build it up in the way, that is, choose one from each circle. (Excerpt from interview 2 with student from Media Studies. My translation)

It is interesting to note that some students point to the tool as a support for exploring different ideas or different angles in relation to the same topic. This indicates that the tool can support divergent thinking and helps students compute with concepts.

> There were some of the combinations, I hadn't considered, of eh positions. Also, because, when you are to fill it in [add topics, theories and methods to the wheel], you want to, I thought that I wanted to fill in as much as possible. So, I also started to search, you know. Think about different positions that I had not considered, and that then eh resulted in some combinations that I had not considered either. (Excerpt from interview 1 with student from Philosophy. My translation)

> It made one think about, ok, perhaps there are actually some of these parts that you had envisioned, these building blocks, you had planned to build your assignment on, that should perhaps be exchanged for something altogether different. (Excerpt from interview 3 with student from Philosophy. My translation)

However, one student was overwhelmed by the many possibilities the tool pointed to which could make it difficult to make decisions on the direction to take:

> I feel that there was a lot that was possible with the tool. And actually, that could perhaps also be difficult for me, like, eh. Because there were perhaps several things that could fit my topic like. I had to like figure out, eh, what angle. Ehm, no, I wouldn't say that some things are not possible with it. I felt that there were quite a lot of possibilities. Which can also be difficult (laughs). (Excerpt from interview 1 with student from Media Studies. My translation)

Using a Computational Thing: A Tangible Tool

In the phase where students worked to generate and explore ideas, many possible angles were identified, and several students pointed to the significance of having a physical tool.

> But this thing that you can see it. Visualise it in one way or other and have a concrete tool. Instead of you sitting eh. I know that it is difficult for me if it is all just up in my head, and you have to sit and try to keep track of your ideas. And there are endless possibilities as to how you can angle a specific, like, subject. So, you have to like concretise it some way. And I felt that the tool, like,

> helped me visualise it better and I could. This thing about having something, right. (Excerpt from interview 1 with student from Media Studies. My translation)

> But, it is easier because you're sitting with something physical in your hand, and you are sort of in that way eh to actively go in (laughs) and choose these different aspects of the [media system], you know, and are to sort of to get the 3, what can I say, circles to fit like with this, that thing in the middle that you could turn [.. .] So, I just thought that was really cool, because if it had been online, then I think perhaps that it would have been more, like, superficial, you know. Like, but then I'll choose that and such. I feel that when you are there physically then and have something in your hands and, then I just feel that you learn it in a better way, or that you remember it better, too. (Excerpt from interview 1 with student from Media Studies. My translation)

Students thus pointed to the computational thing helping them individually not only to keep track of ideas, but also to learn and remember better, indicating benefits of embodied cognition. As will become apparent in the next section on the themes from the inductive analysis, the tangible computational thing also supported dialogue between students and social learning.

What Is Automated?

The data were examined to find out how students perceived the distribution of tasks between themselves and the tool. As explained above in the section on problem-solving, some students indicated that the tool handled the task of representing the perspectives that fall within the bounds of the subject. In this way, the different categories of variables and their possible states depicted on the different circles of the tool all represented valid choices that could be incorporated in a specific idea or problem formulation. The Media Studies tool could thus provide an automated and comprehensive answer to the question: What theoretical perspectives can I include, whereas the Philosophy tool could answer the question: what components do I have to consider to create a good problem formulation? A couple of students pointed out that the tool did not automatically choose a perspective, generate an idea, or create a problem formulation for you. These tasks had to be undertaken by the students themselves:

> It [the tool] is kind of a framing which is still open enough for you to not feel, well, ok I have just been given my synopsis here. Because I was not. You see, I had to create my synopsis myself on the basis of it. I just got the opportunity to see what could be involved

> in the synopsis. (Excerpt from interview 3 with student from Media Studies. My translation)

> Well, those I have talked to about the idea generation tool in more general terms, it has been like. Well, I think it has been a sort of general misunderstanding that they like thought, the tool would spit out an assignment for them or a problem formulation, right? Eh, where my impression was more that it is the work with the tool that makes it possible for you to get closer to your problem formulation and the like. (Excerpt from interview 1 with student from Philosophy. My translation)

As will be illustrated below, the dialogue with fellow students was quite important for convergent thinking, i.e., for the choice of perspective and the delimitation of ideas.

3.6.2 Themes from the Inductive Analysis

In the inductive analysis, open coding was used to give voice to students' perceptions and experiences in order to uncover unexpected themes that could inform the evaluation and further development of the activity and tool. In this phase, important discoveries were made in the form of two themes; one pointing to an unexpected, but seemingly powerful potential, namely, the tool as a conversation tool, and the other pointing to a significant challenge, namely, the rejection of tangible tools for HE. Both themes will be elaborated below.

A Conversation Tool: A Tool for Visualizing, Sharing, and Discussing Ideas

The tangibility of the tool and the possibility to visualize one's ideas were important prerequisites for students' sharing and discussing specific ideas. This was found to be an important theme across the datasets but only realized when students had first computed with the tool, selecting a concept from each circle and combining these using the marker triangle to frame the output. The interviewed students used words like foundation, base, and cornerstone to describe the function of the tool in relation to their sharing and discussing ideas:

> Well, it sort of laid the foundation for eh the discussion. Eh, we had set up some frames for ourselves, or not actual frames, because they were up for discussion, eh. But you could sort of angle a bit and then you could throw the ball up to your fellow students and say: this here is what I have currently set it [the tool] to. And this is what I currently think, and then the rest of us would give all we had in terms of input for that. (Excerpt from interview 1 with student from Media Studies. My translation)

> I think we used it more as a base eh for conversation rather than. We did perhaps not use it so much during the conversation, but we used it a lot as a base for conversation, because like, I have had the following thoughts and then set it up against the thoughts you have. And then you can like adjust after yourself and then maybe. Well, we used it more in that way, I feel. Like a kind of cornerstone for the thoughts. [.. .] Yes, a cornerstone and like a kind of foundation for my thoughts and how can I perhaps take the things, I am told [by fellow students] and adjust that foundation. Yes. (Excerpt from interview 3 with student from Media Studies. My translation)

> We used a lot of time talking each other's ideas through. Eh, and like provide inputs regarding how our classmates could like angle their ideas and how you could sort of eh. Because there were many who gave ideas that were sort of general, and then we could spar with each other which like resulted in you delimiting yourself a bit more or the like. (Excerpt from interview 1 with student from Media Studies. My translation)

The tangibility also seemed to work in the online setting of the intervention at Philosophy:

> So, it was like a kind of starting-point for the discussion, eh. But, well, the tool itself, it was like very quickly forgotten. But not in a bad way. It just sort of fell into the background. It is easier just to talk about it instead. (Excerpt from interview 3 with student from Philosophy. My translation)

> Well, it made it more concrete, I think. That thing about what one, what I should contribute with for the others. What they were to help me with. Eh, especially in such an online format, then it made it easier to see what it was I could say to them. But I imagine that it had also been an advantage if you were sitting in a classroom. (Excerpt from interview 2 with student from Philosophy. My translation)

A tangible tool for exploring abstract concepts together: The observations showed that even if students did not engage in algorithmic processing and generated ideas using the tool, it still had the ability to support their joint exploration of abstract concepts. At Media Studies, the abstract concepts were present in the idea generation tool, and in Philosophy the names of the components contained in the good problem formulation were represented. This gave students a framework for their dialogue and negotiation of meaning as is illustrated by the quote from a Philosophy student in the section below.

Rejection of Tangible Tools for HE

During the intervention at Philosophy, where students were required to use the idea generation tool based on the components of the good problem formulation, an interesting phenomenon was observed. The students worked in groups of three, and in some groups, students took turns sharing their screen, inputting data, creating combinations, and discussing these with and getting feedback from their fellow students. In these groups, students helped each other generate data in terms of identifying relevant theories and methods. Thus, students worked algorithmically, computing with concepts, as intended. However, other groups tried to work algorithmically, following the sequence of steps, but quickly got stuck. This happened in the data generation phase, where students asked: What constitutes an idea? What are relevant theories and what are relevant models? Students made an attempt at working algorithmically, but without answers to their questions, they could not proceed to the next phase of creating and exploring combinations and therefore engaged in a free sharing and discussion of ideas for their bachelor projects instead.

> It [the tool] was also met with much frustration, eh, that is, we really wanted to like just. Ok. We would like to try to execute, like, the task and use the tool, like in the way it is described. Then we kept running into this wall by starting to discuss things like method and the like, and then it was really more like frustration that came out of it. So, it was more like in frustration, we said, hey, let's forget it and then try, like, to discuss some of those ideas that, like the tool easily brings up. (Excerpt from interview 3 with student from Philosophy. My translation)

The data were examined to identify any such instances of nonuse of the tool, and the theme *rejection of tangible tools in HE* began to form. It is not observed with many groups or mentioned by many students in interviews, but nevertheless the apparent rejection of tangible artifacts is significant in that it concerns the type of analogue, computational thing tested in this study. The rejection, however, takes multiple forms. A few students perceive a mismatch or explain that they can see how their fellow students would perceive a mismatch, between the analogue technology, the materials, and processes, on the one hand, and expectations or personal preferences in relation to learning at university, on the other hand.

> And then I also think, well, that there are some that have, well that are better at, like, at using such tools like these than others. Well,

> I know that I am not so good at like at all at using tools in general. I know I like to sit and think or something like that. I know that I am not that hands-on in that way there. (Excerpt from interview 3 with student from Philosophy. My translation)

> I'm originally from eh, the dramaturgy study programme at university [anonymised], so cutting, gluing and play that is the university for me (laughs). [.. .] I can well understand if some would perhaps think it is childish, but I don't know. I just think it was a really nice way, because you get it in your hand, and then you also get. I don't know. It is therapeutic. You get the opportunity to, I did, at least, while I cut [out the tool] to quietly and peacefully read what was on [the disks]. (Excerpt from interview 3 with student from Media Studies. My translation)

In the dataset from the Philosophy intervention, a few students reject the tool and activity due to: Timing: I am not far enough or too far in the process of finding a topic and generating an idea/a problem formulation. Topic: It is difficult to see how I can use the tool with the topic I have chosen or with Philosophy in general. Perhaps it works with other topics and subjects.

> And then we were to sit with the idea generation tool, like, try to stuff some of the, like ideas, some topics in and then some different things into this tool. And then try to use and turn it etc. Well, it was actually rather quick, like one of the reasons that we did not use the tool especially much because it actually dawned on us that, like, eh within Philosophy, it is actually rather difficult to split up, like the subject, like in these very like delimited and these, like, very specific fields. (Excerpt from interview 3 with student from Philosophy. My translation)

The idea generation tool required students to work with idea generation and problem formulations at a level of decomposition that some students did not find meaningful in relation to the subject area of philosophy. According to the teacher, however, the goal of supporting students' more substantial discussions of ideas, anchoring these more firmly in Philosophy, and supporting peer feedback was realized.

Several students at Media Studies, however, pointed to the timing being absolutely right because they were just to embark on the exam synopsis.

In the next section, the findings presented above are discussed, and the implications and plans for the next iteration outlined.

3.7 Discussion

In this section, the potentials and challenges uncovered by the analysis are discussed with a particular view to determining if and how students' systematic investigation of abstract concepts was supported and how their idea generation was automated and facilitated.

The analysis of data from the first iteration reveals that it is not first and foremost the function of idea generation tool that is realized when students engage with the tool and activity. The tool does in some cases support idea generation and can help students systematically consider possible alternatives, thus supporting the computation of concepts and divergent thinking. However, the tool is, in all cases, realized as a tool for the individual investigation of abstract concepts. Many students mention the tool's ability to show them the bounds of their subject and to guide them as to what specific concepts or components should be considered. There is thus evidence that the idea generation tool works as a domain-specific external representation, the domain being the humanistic subject in question. This external representation makes the abstract concepts studied "tangible, manipulable, and available for thought, action and imagination" (Pande, 2021, p. 464). The tool can help solve the problem of identifying what constitutes valid concepts and components to include in an idea or problem formulation. However, computational things not only support individual students' tangible computing of concepts, but, when used in group activities, also make possible the sharing of ideas and the negotiation of understanding. It provides a foundation for students' dialogue and joint exploration of ideas and abstract concepts.

The Media Studies tool seems to be more firmly situated in the subject in that the tool is a tangible representation of the core model. Furthermore, the activity and tool were introduced at the optimal time since the teaching was ending and students were ready to focus on the exam. The Philosophy students had to generate a lot of data before they could start generating ideas. This led to more general, but still fruitful and relevant discussions as to the components in a good problem formulation.

The algorithmic processing seemed to be intuitive, and students appreciated the marker triangle that could hold the items selected on the different circles. This points to the design of the tool being helpful with respects to computing with concepts.

The fact that the tool helps decompose a humanistic subject, visualizing individual abstract concepts and combinations of these, makes it a powerful conversation tool. However, there are also challenges that must be considered and further examined. Before students can start computing with concepts using the tool, several processes must be successfully completed. Students must understand the concepts on the different circles. They must understand the algorithm, i.e., how to do the algorithmic processing of concepts: inputting, selecting, and combining. In addition, they must understand how the different tasks involved in generating ideas and creating problem formulations are distributed between themselves, the tool, and fellow students. Finally, students must understand the purpose of algorithmic processing, i.e., find it meaningful to engage in the tangible computation of abstract concepts using an analogue computational tool. This latter point is exactly where some students experience a mismatch between the tool and appropriate technology and activities for learning at university. An important focal point going forward is therefore how to better match expectations to overcome some students' view that learning activities involving cardboard and scissors do not belong at university. It is exactly the potential of the tool to make abstract concepts and the computing of these tangible and concrete that is rejected here in favor of the abstract and intangible. This finding, furthermore, has implications for the assumptions in the theoretical framework that cognition and learning are situated and embodied. Whereas most students can appreciate and use the external representation of abstract concepts as a situated, subject-related starting point or frame for dialogue, not all students appreciate the possibility to engage in embodied cognition and learning, indeed rejecting this form of learning as not suitable for HE.

On a different note, the tool seems to respond to a more widespread challenge regarding understanding abstract concepts and generating ideas. Furthermore, it is flexible and can easily be adapted to fit other subjects and contexts. In addition to the two cases reported in this study, the tool has also been adapted and tested in the subject Design Research 1 at the Master program in IT product design. Furthermore, students doing a Professional apprenticeship project at the same master program developed and tested alternative designs for a tangible tool to support the understanding of and dialogue on abstract concepts. In interviews with teachers and students, some have pointed to new areas of usage and/or new circles that could be added to allow for the computation of other relevant elements. In the second iteration at Philosophy, a student suggested to add a disk for philosophers/great thinkers or key concepts. The teacher suggested to adapt the tool for the history of philosophy with, among other things, a circle showing periods of time.

The tool thus has potential broadly speaking, but the framing and the matching of expectations is important for successful implementation. Next, the plans for the second iteration are outlined.

3.7.1 Improvements of Tool and Activity for the Second Iteration

Minor improvement points were noted in relation to Media Studies where some students found they had too much time for discussions since they had more or less chosen the same idea. Furthermore, several students lost their responses on the reflection questions, when they inserted an image of their tool in the same post.

An important point for consideration is how to better support students at Philosophy in generating data and working at the level of decomposition required when using the idea generation tool. A possible improvement to the Philosophy intervention could be to add an initial activity in which the components of the good problem formulation are explained with examples from Philosophy to more firmly situate the tool in the subject. See Table 3.8 for an overview of problems identified and planned improvements.

Table 3.8. Problems identified and planned improvements for the second iteration

<table>
<tr><th>Case</th><th>Problems encountered</th><th>Adjustments made in the following iteration</th></tr>
<tr><td>Media studies</td><td>If students in a group have similar ideas, discussion quickly ceases</td><td>A second round of sharing ideas will be added in which students gather in new groups to share and discuss ideas</td></tr>
<tr><td></td><td>Some students lost the reflections they had typed into a post in the discussion forum on the learning platform when they uploaded the image of their idea generation tool</td><td>Create word-document with reflection questions that students can download from the learning platform, complete, and upload</td></tr>
<tr><td>Philosophy</td><td>Students have difficulties deciding what constitutes topics, theories, and methods and thus cannot generate data for the different disks of the tool</td><td rowspan="3">New element included in the activity. The teacher starts out by presenting examples of problem statements in philosophy outlining what constitute the topic, theories, methods, and concepts</td></tr>
<tr><td></td><td>Tool not useful for topic chosen or philosophy as such</td></tr>
<tr><td></td><td>Timing: too soon or too late in the process of generating ideas and writing problem formulations</td></tr>
</table>

The chapter concludes by summarizing the initial lessons learnt with respect to the integration of CT with computational things in HE.

3.8 Concluding Remarks and Implications for Further Research

CT unplugged as partly automated problem-solving with analogue computational things has been implemented at BA in Philosophy and MA in Media

Studies. The computational things were developed as subject-specific idea generation tools in cardboard. After the first iteration of empirical testing, data collection, and analysis, the following answers can be given to the overarching research questions. The findings indicate that computational things that constitute tangible representations of abstract subject concepts can be meaningfully integrated in humanistic subjects in higher education. These tangible representations provide automated answers as to what concepts are within the bounds of the subject, and thus the tools display what are valid concepts for students' subject-related discussions and valid choices when generating ideas and problem statements. The students used the computational things as objects to think with or frames within which to think.

The computational things designed are manipulable and allow students to compute with concepts. This supported students in the systematic exploration of many different possible directions and combinations of theoretical perspectives for their exam synopses and bachelor projects, i.e., supported divergent thinking. In this way, the original intention of the tool to function as an idea generation tool was realized. However, some students never reached the idea generation stage, for different reasons, but used the tool as a base for abstract discussion as described above.

The tangible tool helped students visualize and physically model their ideas, which could then easily be shared with and explained to fellow students who, in turn, felt comfortable suggesting new angles or perspectives. Thus, students challenged and supported each other in exploring ideas and directions. Students, furthermore, helped each other delimit ideas. In this way, the tools proved, first and foremost, to be powerful conversation starters, contributing a foundation for student dialogue and peer feedback. Therefore, the conclusion is that the most promising use of the tool is as a conversation tool.

The CT competences: decomposition, modeling, and algorithmic processing, i.e., computing with concepts appears to be especially relevant for humanistic subjects and for students' professional development. The tools designed are decomposed versions of the media system and the good problem formulation, respectively. This focuses students' attention on and supports them in investigating core concepts on their own and with fellow students. In this way, the tools support students' subject- related and situated cognition and learning. The tangible and manipulable aspects of the tool support students in the physical and embodied modeling of their own ideas onto the theoretical framework of the subject. The algorithmic processing allows divergent thinking via the systematic exploration of possible alternatives.

However, the findings also point to challenges that must be dealt with to achieve successful implementation, namely, that (1) some students have difficulties generating data and never get to the idea generation stage, (2) some students are not willing to engage in algorithmic processing in a humanistic subject, and (3) a few students reject the idea of tangible tools in HE. In these areas, further research is needed to uncover how to better support students' learning with CT and computational things and how to better match expectations around this.

With respect to design tools (design principles and design patterns) that can support the integration of CT with computational things in humanistic subjects, it can be concluded that the preliminary design principles presented in this chapter have proven to constitute a helpful design space that secured the anchoring of the interventions in the theoretical framework. However, the design principles and patterns did not address students' personal preferences for learning or general ideas about learning activities and technology in higher education. These aspects must be added to guide future practice and research. In addition, specific design principles can now be formulated that describe exactly what CT competences should be considered and what type of computational things can support the learning of students in humanistic subject in HE.

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4 Design-based research

This chapter examines the research approach adopted in more detail, starting with the origins of DBR, then the notion of *design*, and finally the collaboration with practitioners and the role of the researcher.

4.1 Origins of DBR

The term *design-based research* can be traced back to the Design-Based Research Collective' s paper from 2003 "Design-based research: An emerging paradigm for educational inquiry". DBR focuses on the challenge of connecting theory and practice in educational research (Reimann, 2011). Brown (1992) and Collins (1992) are often mentioned as seminal papers with Brown and Collins themselves referred to as "first movers" by, e.g., Ørngreen (2015). According to Reimann (2011), Ann Brown introduced design research in an attempt to increase the relevance of theory to practice. Brown herself asserts her research to be "intervention research designed to inform practice" (Brown, 1992, p. 143) and she adopts the term proposed by Collins (1992): design experiments.

Labelling herself "a classic learning theorist" originally working with individual students in laboratory settings, Brown describes how she has come to see classroom life as a systemic whole, where, if you change one component it will influence other components. In addition, it is difficult to isolate and study the component parts independently from the whole system, as is typically done in laboratory experiments (Brown, 1992). Furthermore, it is irrelevant to do so in a study of actual learning situations. Brown (1992) further explains that her shift from laboratory experiments to design experiments in actual classrooms reflects changes in learning theory, especially "an awakening to the fact that real-life learning inevitably takes place in a social context, one such setting being the classroom" (p. 144). Brown (1992) goes on to claim that changes in theory and practice must be accompanied by progress in all aspects of research.

Allan Collins (1992) found that the design experiments undertaken at the time of writing were not conducted in a systematic way, varying considerably in both design and implementation, making it difficult to elucidate the design process. In addition, the design experiments were undertaken mostly by designers of technological innovation who were biased, looking only for favourable outcomes, and the experiments were not based on theory which made the results "largely uninterpretable with respect to constructing a design theory of technological innovation in education" (p. 4). Collins and colleagues therefore set out:

> (a) to construct a more systematic methodology for conducting design experiments, and (b) to develop a design theory that can guide implementation of future innovations. We anticipate a methodology that will involve working with teachers as co-investigators to compare multiple innovations (media and software) at one site and with no vested interest in the outcome. (Collins, 1992, p. 4)

Collins proposed as critical parameters the involvement of teachers as co-investigators, working under the constraints and addressing the questions identified by the teachers, and the teachers collaborating with researchers to develop and improve the designs to be tested. Collins (1992) was very preoccupied with the identification of "all the variables that affect the success or failure of any innovation, and [wanted to] specify critical values and combinations of values with respect to these variables" (p. 4) in effect bringing the essence of laboratory experiments into the classroom.

In contrast, Brown embraces and accepts the complexity and systemic nature of the classroom and advocates the use of theory to inform interventions and rigour in data collection, analysis and dissemination of results. On this point, the present thesis adopts Brown's (1992) perspective while also lending inspiration from Collins (1992) with respects to collaborating with practitioners. When launching into this research project, I adopted the term design experiment (Brown, 1992; Collins, 1992). However, peers explicitly associated this term with controlled experiments which caused me to adopt the term interventions instead to match expectations.

After this brief account of the origins of DBR, the *design* in DBR will be explored.

4.2 The design in DBR

According to the Design-based Research Collective (2003) "[d]esign is central in efforts to foster learning, create usable knowledge, and advance theories of learning and teaching in complex settings" (p. 5). In this thesis, design is defined as "*the human giving of concrete form to material*" (Dohn & Hansen, 2018, p. 26) and more specifically the giving of form to learning activities, materials, and tools to be used by students in learning situations. In explicating how this study makes use of design, Dohn and Hansen's (2018) presentation of design researcher Heskett's five senses of design (Heskett, 2002) is utilised:

1. Design as domain – *noun*
2. Design as a conscious and intentional action or process – *verb*
3. Design as concept/idea/proposal/plan/prototype– *the first manifestation– noun*

4. Design as the resulting product – *the concept made actual* - *noun*
5. Design as realisation of a conscious intention

These five senses of design intertwine with the four phases of the present DBR-study which are: 1. *Analysis*, 2. *Design*., 3. *Interventions*, and 4. *Reflection*.

Design for learning is the design domain adopted in this study (cf. chapter 3), i.e., design sense 1. In DBR-phase 1. *Analysis*, design was present as budding ideas for interventions, i.e., sense 3. Design as process, sense 2, intertwined fully with DBR-phase 2. Here design as process describes my and the teachers' collaborative efforts to give form to learning activities, materials and tools that could support the integration of CT with computational things in humanistic subjects in HE. Design sense 3, as idea, prototype, plan and revised versions, were outputs of DBR-phase 2. *Design*. Furthermore, design sense 3 was the pivot of DBR-phase 3. *Interventions*, where designs (sense 3), were tested, evaluated, improved/revised and tested anew. DBR-phase 3 thus also involved re-design as process, i.e., design sense 2.

Each iteration of an intervention was design in sense 4 with participants engaging with the planned learning activities, materials and tools. It is worth noting that participants typically do not simply enact a design as planned, rather they will "always act on and react to a design (sense 3) in its implementation" (Dohn & Hansen, 2018, p. 31) which means that the realised design (sense 4) can be quite different from the intended one (sense 3). A learning design cannot program practice (Dohn & Hansen, 2018). Rather learning activity is emergent with learners exercising agency as they co-create and co-configure the planned learning activity including ways of participating and use of available resources (Carvalho & Goodyear, 2014; Yeoman & Wilson, 2019).

The fifth sense of design points to the interrelationship between and ties together the second, third and fourth senses of design in that "[t]he intentional creation of new possibilities takes place through a process articulating the conscious intention into a plan which is then realised in a resulting product" (Dohn & Hansen, 2018, p. 26). Attentiveness to this fifth sense of design supports the researcher in creating alignment between the aims and research questions of a DBR-study and the design process, ideas, plans and resulting products. Indeed, this fifth sense of design seems to capture the very essence of design in DBR and will be notable in the development of design principles in DBR-phase 4. *Reflection*, the purpose of which is exactly to communicate (in this particular study) how to intentionally design for learning with CT and computational things in humanistic subjects in HE.

4.3 Collaboration with practitioners, bias and the role of the researcher

This study adopted a democratic and inclusive DBR approach with close collaboration between researcher and practitioners rather than the classical predictive research approach in which the researcher herself defines the initial hypothesis (Amiel & Reeves, 2008; Ørngreen, 2015). This collaboration extended to the classroom with me co-facilitating activities and interacting with students, thus taking on multiple roles.

Overall roles for the participating practitioners and for me, the researcher, were initially agreed upon. The practitioners provided the pedagogical challenge and relevant subject-related course material, and I provided the theoretical underpinning of the co-design process as well as CT knowledge and collected data during interventions. The planning of each intervention was also a joint effort, and presenter and facilitator roles were negotiated and distributed between the practitioners and me depending on how confident each practitioner felt with respects to facilitating the planned CT activity. Such initial distribution of roles and matching of expectations are essential to uncover and handle any tensions that might exist between the goals of researchers and practitioners (Ørngreen, 2015).

The close collaboration between practitioners who have practical insight and the researcher who has the time and the competences to undertake systematic research is a strength of DBR. The problems identified by researchers and research can differ from the problems identified by the practitioners. This is seen as an advantage of the method by Amiel and Reeves (2008) who state that "[t]eachers become active partners in identifying priorities for research and contributors throughout the research process itself" (p. 36). Thus, DBR can strengthen the connection between practice and research and increase the relevance of the latter.

However, the deep involvement of the researcher in practice is also a point of critique; it can pose challenges in relation to trustworthiness and bias since the researcher is both involved in the design of the intervention as well as the intervention itself, and, furthermore, is responsible for data collection and analysis (Barab & Squire, 2004). Conversely, according to Anderson and Shattuck (2012), "some qualitative proponents argue that the researchers themselves (with their biases, insights, and deep understanding of the context) are the best research tool", but also admit that "wisdom is needed to walk this narrow line between objectivity and bias" (2012, p. 18).

In DBR, confirmation, pleasing as well as collaborator bias can occur. The researcher can be eager to confirm any hypothesis formulated and therefore might give weight to data confirming the hypothesis while ignoring data that do not (see e.g. Spencer & Heneghan, 2018). The involvement of fellow researchers in the analysis and/or discussion of the data collected is an important step in avoiding this type of bias. Furthermore, Ørngreen (2015) proposes to develop and test alternative designs to overcome the eagerness to or pitfall of confirming one's hypotheses or assumptions. Good/bad participant bias can occur when participants try to provide responses that they think will please the researcher (good participant bias), and collaborator bias happens when collaborators do likewise in an attempt to preserve harmony and good relations. Bad participant bias can occur when participants want to disprove what they think is your hypothesis, e.g. In chapter 6 on data collection, I discuss how I have attempted to deal with bias issues.

Below, I turn to the design-related outputs of DBR.

4.4 Outputs of design-based research

Typical outputs of DBR are representations of design knowledge, such as design principles and patterns. It can be difficult, however, for practitioners and researchers to assess such representations of design knowledge and determine the potential for reuse. Many parameters are considered when looking for inspiration for the development of new learning designs (e.g, learner characteristics, subject and level etc.). This makes the context of discovery (Schickore, 2022) important; in which context and under which conditions was the design knowledge developed? Transparency in this regard helps practitioners and others assess whether the knowledge is applicable to their own context.

The following chapter presents a literature review that examines current methodological practices and issues in relation to the development of reusable design knowledge. The conclusion is that a wealth of different terms is used and that methodological awareness in relation to the development of design knowledge is lacking. In this thesis, I have aimed to be transparent about methods used in the development of design principles for the integration of CT in humanistic subjects in HE. Chapter 10 presents the initial and final design principles and also explains and discusses the development process.

In order to find a sufficient number of papers reporting on the creation of design knowledge, the scope of the review was fixed to interdisciplinary HE; a broad term that covers the integration of two or more subjects in a learning activity and thus also covers interventions that aim to integrate CT into humanistic subjects in HE.

5 Creating Reusable Design Knowledge in Interdisciplinary Education: Current Methodological Practices and Issues

Publication 3. Authors: Inger-Marie Falgren Christensen and Lina Markauskaite (2024)

Abstract

Educational practitioners and researchers often aim to produce design knowledge, such as principles, patterns, guidelines, etc. that can inform educational design decisions within and beyond local settings. However, approaches used for creating design knowledge in educational innovation are rarely examined which poses challenges in relation to transparency and reusability for those who create such knowledge and those who use it. In this chapter, we examine how design knowledge is created, initially building on commonly cited methodological literature to introduce the notion of design knowledge. Then, drawing on an integrative literature review, we examine current approaches for creating such knowledge in interdisciplinary tertiary education. Two main pathways are identified: 1) research first that draws on theories or empirical evidence, and 2) experience first that draws on current design practices, user needs or experiences. Based on the review, we claim that current practices for creating design knowledge often lack methodological rigour and transparency which raises critical questions about trustworthiness, justifiability, reusability and practical usefulness. We conclude that methodological awareness is needed to enhance methodological robustness, and practical usefulness.

5.1 Introduction

This chapter examines current practices for developing design knowledge with the overall purpose of creating awareness about and supporting reflection on methods used. Design principles, patterns, frameworks, models, constraints, prototypes, etc. are examples of terms that are used to describe design knowledge and ways in which this knowledge is represented in educational research and innovation. There is an abundance of such terms and representations in the education literature (Herrington & Reeves, 2011). Design knowledge can be defined in different ways, but broadly it is "principled-practical knowledge" (Bereiter, 2014) that can guide researchers, practitioners and other stakeholders in the design of educational interventions that support specific learning processes and outcomes. An important aspect of design knowledge is the relationship between theory and practice. Bereiter (2014) explains that principled-practical knowledge has characteristics of both practical know-how and scientific theory, indicating that there is a practical, experience-based as well as a theoretical, research-based component to the concept. Plomp (2013) describes design knowledge as heuristic statements derived from examples of success, which stresses their experience-based and contextualised nature. However, others argue that it is also important to document and learn from failures in educational design, to iteratively refine design knowledge products, and to illustrate the different ways in which they can be employed in practice (Kali et al., 2009).

If design knowledge is to be perceived as trustworthy and reusable, methodological transparency when reporting research is important (McKenney & Reeves, 2012), but often it remains opaque how design knowledge is actually created. This lack of attention to methodology detracts from the trustworthiness and interpretability. When a clear methodology is lacking, it is difficult to assess representations of design knowledge and judge how this knowledge can or should be reused, refined or improved in new contexts. Therefore, to put current practices for creating design knowledge on the agenda and focusing on one area of educational innovation: tertiary interdisciplinary education, this chapter aims to answer two questions:

- *How is design knowledge created in interdisciplinary education?*
- *What concepts are used to denominate representations of this design knowledge?*

Via an integrative literature review, this chapter identifies the approaches used for creating design knowledge and the concepts used to denominate the representations of this design knowledge. The aim is to provide a basis for discussing methods for and issues in relation to the creation of design knowledge. First, we elaborate on the concept of design knowledge followed by a section on the method employed in the integrative literature review. Subsequently, findings are presented and issues relating to current approaches are discussed. Finally, conclusions are drawn and suggestions for a way forward are made.

5.2 What is design knowledge?

Design knowledge in educational contexts is defined in different ways in the methodological literature. Broadly, it can be understood as recommendations for design for learning and should, ideally, be "well-researched ideas" that practitioners can use as "guidelines for their own efforts to enhance student engagement and learning outcomes" (Herrington & Reeves, 2011, p. 595). Reusability and usefulness are thus inherent in the concept. Design knowledge can provide practical guidance and inform educational design at different levels of granularity, from the design of a single learning activity to a full curriculum, building bridges between research, theory and/or prior experience and practice. Many different terms are used to denominate representations of design knowledge, including principles, patterns, models, frameworks, guidelines, constraints, prototypes, and conjectures (Bakker, 2019; Falconer et al., 2007; Goodyear & Retalis, 2010; Sandoval, 2004).

Many researchers discuss how design knowledge is "validated", see e.g., Plomp (2013), i.e. justified as true or of value. According to van den Akker (2013), design knowledge, such as design principles, is founded in empirical work as, e.g., generalisations of curriculum design research findings, and thus are validated through such research. Van den Akker (2013) points out that design knowledge that is validated through successful design of several interventions and in different contexts is more powerful.

Some researchers discuss challenges related to the representation of design knowledge (Falconer et al., 2007; Goodyear & Retalis, 2010; Kali et al., (2009). For example, Kali et al. (2009) point out that it can be difficult to communicate design principles because these are generalisations abstracted from context. Likewise, it is difficult to reuse design knowledge since this is an open-ended task that requires interpretation; a set of design principles, e.g., can lead to different design solutions. Supplementing design principles with other representations of design knowledge that illustrate different uses of principles in practice, such as the typical design pattern, may remedy some of these challenges, as can the interlinking between design principles (Kali et al., 2009).

Overall, the form of the representation matters. Kali et al. (2009) suggest that design principles, to support practitioners during the design process, should provide "a general rationale, theoretical underpinning, and important considerations, such as pitfalls, tradeoffs and limits of practical use" (p. 1069), while van den Akker (2013, p. 67) suggests capturing design principles in the format: if you want to design intervention X for purpose Y in context Z, you are recommended to give that intervention the characteristics C1, C2, etc. and to do that via procedures P1, P2, etc., because of theoretical arguments T1, T2, etc. and empirical arguments E1, E2, etc. Such formulations might be helpful when practitioners select design knowledge for particular design tasks, but they do not disclose methods that were used for creating this design knowledge. Overall, such methods are rarely discussed within the field of education even in methodological literature, such as design-based research. Although some literature reviews exist on methods for creating design knowledge in various domains of industrial design (e.g., Fu et al., 2016; Kulak et al., 2010), no such reviews were found in the field of education, even when including synonyms in the search as explained in Table 5.1 below. The field of educational design knowledge is growing, and there is a need for a thorough review to map existing methodological practices, make them explicit and inform future practice. Therefore, in this chapter, we aim to review different methods used to generate design knowledge in education.

5.3 Method

The integrative literature review "reviews, critiques, and synthesises representative literature on a topic in an integrated way such that new frameworks and perspectives on the topic are generated" (Torraco, 2016, p. 404). The aim of our review is to provide an integrated account of methodological practices for creating design knowledge. To make the scope manageable, yet aiming to preserve the complexity, we focussed on how design knowledge is created within the field of interdisciplinary tertiary education, one of the most complex areas of educational design and innovation (Lyall et al., 2015).

A range of keywords was selected (Table 5.1) to make the literature search as open as possible.

Table 5.1. Search matrix of keywords used for the literature search

Topic: Design +	Context 1	Context 2
principle*	education	interdisciplinary
knowledge	teaching	cross-disciplinary
guideline*	learning	multi-disciplinary
rule*	training	trans-disciplinary
constraint*		cross-curricular
heuristic*		integrative curriculum
pattern*		

The search was performed by first conducting a search for all topic keywords in column 1 using OR. This was repeated for all keywords in contexts 1 and 2 respectively. Finally, the three saved searches were combined using AND to retrieve literature that included keywords pertaining to the topic and contexts 1 and 2. The cleaning and screening process followed common steps and procedures for conducting systematic literature reviews: removal of duplicates, automatic filtering of abstracts using the search keywords to remove papers outside the scope, manual screening of the abstracts and reading of full papers (Figure 5-1). All 42 retrieved sources were examined; only literature on the creation of design knowledge in tertiary interdisciplinary education (including higher education and continuous professional development) and from peer-reviewed English-language sources was included. In the final step, 14 additional references known to us as falling within the scope but not retrieved via the systematic search were added. In cases when the same project was reported in several sources, only the most comprehensive source was included.

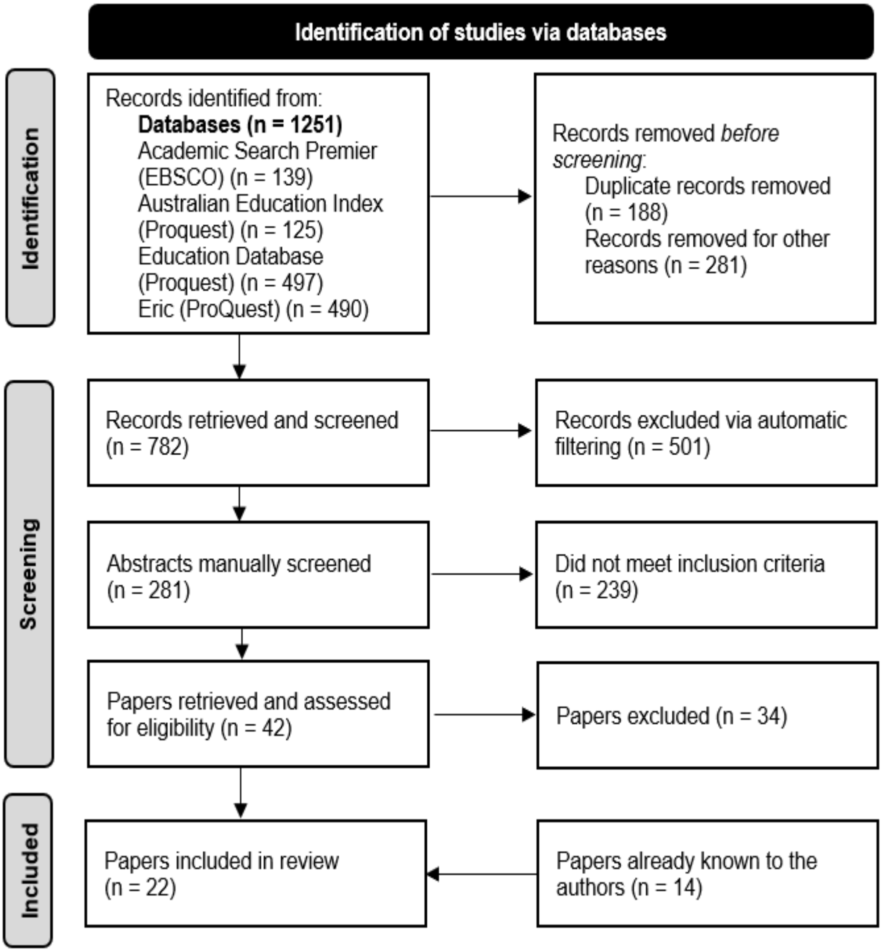

Figure 5-1. Screening of literature. Based on PRISMA 2020 (Page et al., 2021)

The final 22 papers were read in full and their methodological features were summarised in a spreadsheet. Features such as type of literature, educational level, geographical context, nature of interdisciplinarity, terminology used, unit of analysis/design, methodological approach and author's reflections on approach were noted. Following this examination, patterns in the data were identified. Our findings are presented below.

5.4 Findings

What concepts are used to denominate design knowledge?

Across the 22 papers, more than 30 different concepts were used to denominate the design knowledge created (Table 5.2). These concepts can broadly be organised into six groups. The most common concept is 'principles', mentioned in 14 papers, appearing on its own or in constellations such as 'didactic principles', 'design principles', 'core principles' or 'guiding principles'. 'Guidelines' are used in a couple of texts and 'heuristics' are mentioned by one paper. The second group of concepts employs terminology that conveys that the design knowledge in question is derived from learning theory or pedagogy, namely 'conjectures', 'pedagogical propositions', 'conceptual framework', 'pedagogical configuration' and 'theoretical assumptions'.

The third group consists of concepts that explicitly include 'design', namely 'design knowledge', 'key design insights', 'design features', 'critical design aspects', 'design vision' or that denominate typical design process artefacts such as 'prototypes'. The use of 'principles' is linked to both the second and third groups; some usage falls into the second group and connects to learning theory and pedagogy, as in 'didactic principles', whereas, in other cases, the usage of principles falls into the third group explicitly mentioning 'design', such as 'design principles'. A fourth group reveals a notion of design knowledge as recipe-like, namely 'key ingredients', 'formula for success', 'essential elements' and 'exemplar materials'. The latter is also interpreted as reusable design knowledge that provides "a practical example and demonstrates how the tools provided could be used in the development of new curricula" (Navarro et al., 2016, p. 372).

The fifth group includes terms that point to the notion of design *advice*, namely 'suggestions', 'recommendations', 'areas for consideration', 'key advice' and 'lessons learned' conveying the experiential and tentative nature of design knowledge and the need for user interpretation. The last group contains concepts that point to the step-by-step nature of the design process, such as 'model', 'strategy', 'strategies' and 'approach'. In most of the papers, concepts are used, but not defined or explained and sometimes used unsystematically; e.g. McDonald et al. (2019) mention 'principles' in the abstract and conclusion, but never use the term in the body of the article where instead 'design vision' is used.

How is design knowledge created?

Two main pathways for creating design knowledge were identified: research first and experience first. Each pathway includes several approaches reflecting practices and methodological decisions made when creating design knowledge (Table 5.2).

The *Research first* pathway includes three approaches that focus on theories or empirical evidence:

1. *Theory-based* approaches: one or more learning theories are translated into guidelines to support the educational design process.
2. *Evidence-based* approaches: empirical research (e.g. ethnography, experiment) is undertaken to establish possible mechanisms or causal relations between the design of an intervention and its effects on learning. This includes design principles constructed drawing on original, first-hand empirical research (Newstetter et al., 2010) as well as on second-hand literature reviews (Nandan & London, 2013).
3. *Design-based research* approaches: combine theory and empirical examination via iterations of theory building, design, implementation, data collection, analysis and revision.

The *Experience first* pathway consists of approaches in which current practices, user experiences or needs are the point of departure for the creation of design knowledge:

1. *Practice-based* approaches: current design, teaching and learning practices in authentic settings serve as a springboard for proposing design solutions.
2. *User/stakeholder focused approaches*: input from users/stakeholders (students, future employers etc.) forms the basis for creation of design knowledge. This includes a range of approaches from the conventional analysis of user/stakeholder needs as part of design to participatory co-design in which design knowledge is co-created by or with students, teachers, researchers, designers and other stakeholders.

The majority of papers (15) fall into the research first pathway and 7 into the experience first pathway (Table 5.2). Some of the reviewed literature mixes approaches within and across pathways and describe, e.g., how evidence for theoretically inspired design principles was sought in texts reporting positive outcomes of empirical testing (e.g., Friesen & Jacobsen, 2021) or how a “broad philosophy” was created via a practice-based approach which was synthesised with the academic literature (e.g., Navarro et al., 2016). In cases where multiple methods were used to create design knowledge, we used the point of departure in our mapping.

Table 5.2. Design concepts and approaches

Approaches/-sources	Design concept(s) used	Country(ies)
Research first: Theory-based (6)		
Ashby and Exter (2019)	Strategies, platform, constructive alignment design principles, design process models and considerations	USA
de Greef et al. (2017)	Principles of constructive alignment, model, design concept, key advice, design principles	The Netherlands
Friesen and Jacobsen (2021)	Model, principles, design knowledge, key design insights	Canada
Kähkönen and Hölttä-Otto (2022)	Guidelines, genetic mechanisms	Finland, Singapore
Meyer and Lees (2013)	Guiding principles, conceptual framework	UK (England, Wales)
Soboleva and Karavaev (2020)	System of principles, didactic principles	Russia
Research first: Evidence-based (3)		
Nandan and London (2013)	Pedagogical configuration, guidelines for designing	USA
Newstetter et al. (2010)	Design principles, agentive principles	USA
Rives-East and Lima (2013)	Strategies	USA
Research first: Design-based research (6)		
Cremers et al. (2016)	Design principles, heuristics, conjectures	The Netherlands
Gosselin et al. (2020)	Activity centred analysis and design (ACAD) framework, conjecture mapping, theoretical assumptions, key design elements, basic tenet	USA
Kidron and Kali (2015)	Pragmatic design principles, core principles, conjectures, design features	Israel
Perkins (2015)	Core principles and priorities, learning design principles, recommended design principles, prototyping	Australia, UK
Spelt et al. (2015)	Key design aspects, prototypes, constructive alignment: design framework with hypothesised relationships between potential key aspects	The Netherlands
Verster and van den Berg (2021)	Pedagogical propositions, design principles	South Africa
Experience first: Practice-based (4)		
Lyall and Meagher (2012)	Suggestions, approach, recommendations, guidance notes, mechanisms	UK
MacLeod and van der Veen (2020)	Ideas, design aspects, elements of the design that contribute to success, model, principles, lessons, strategy	The Netherlands
Navarro et al. (2016)	Guiding principles, essential elements, exemplar materials	USA
Seethaler et al. (2013)	Key ingredients, formula for success	USA

Experience first: User/stakeholder focused approaches (3)		
McDonald et al. (2019)	Design vision and principles, prototyping	USA
Ripley et al. (2024)	Critical design aspects, design principles	Australia
Woolmer et al. (2016)	Insights, areas for consideration, suggestions, lessons	UK (Scotland)

The concepts used to denominate design knowledge identified above were associated with the two pathways. For example, the concepts from the second group that focus on the connection to learning theory or pedagogy were associated with the research first pathway. The use of 'conjectures' and 'pedagogical propositions' were tied to design-based research. The third group of concepts that link to the field of design can be found in both pathways as can the design advice terms and the group of concepts focusing on the step-by-step nature of the design process. The recipe-like concepts, however, are only found in papers belonging to the experience first pathway.

The papers came from 11 countries and dealt with different units of analysis and design from the development of one activity, over courses and modules to full programs. However, there was no clear association between the unit of analysis and design and design approaches or concepts, for example the term 'principles' is used to describe the design of a problem in a single course (MacLeod & van der Veen, 2020) and an entire program (Friesen & Jacobsen, 2021).

Below, each pathway is elaborated by discussing one example.

Research first practices

Practices for creating design knowledge described in Friesen and Jacobsen (2021) are grounded in 8 years of experience, but exemplify *theory-based approaches*. Design efforts focussed on restructuring professional graduate programs in a Canadian university aiming to "move away from information delivery approaches to scholarship, and towards participatory and collaborative learning" (p. 73) and provide students with interdisciplinary learning experiences. The design method described in this paper involves formulating an overall philosophy based on "research that indicates the optimal learning for adults" (p. 65), creating a practitioner-scholar model and cohort model "drawing on conceptual and research literature on exemplary professional graduate programs in education" (p. 66), agreeing on "signature pedagogies" to be incorporated in the design, and finally developing specific principles for design and delivery derived from the learning sciences.

For each principle, relevant theoretical concepts are examined and general affordances are outlined. Then empirical evidence from relevant studies and practical implications are presented together with the authors' experiences.

The paper presents the research grounding, the alignment between philosophy, model, principles and designs and details of implementation. However, the key design insights communicated, concern "local design knowledge" (Friesen & Jacobsen, 2021, p. 71), such as the achieved outcomes in terms of students' learning experiences, successful completion, faculty development, etc. Reflections on practices mainly focus on faculty's collaboration during the redesign process, rather than design knowledge or methodological practices that can be reused beyond the local setting. Further, the described redesign consists of several phases, but the nature, number and order of phases are not always clear making it difficult to identify what approach was used and when. Thus, methodological rigour is found in the theoretical and empirical grounding of design knowledge but does not extend to the overall design process.

Newstetter et al. (2010) exemplify *evidence-based* approaches. They examine the optimal way of designing, structuring and implementing new and more authentic learning experiences in the undergraduate biomedical engineering (BME) laboratory at an American university. The authors explicitly pose the question "Where should we take our inspirations and derive principles for the design of these ''synthetic'' laboratories?" (p. 3257) and propose to gain inspiration from the reasoning practices of experts within BME and "the learning processes of graduate and undergraduate researchers in sites of authentic research activity"(p. 3258).

The authors employ ethnographic methods interviewing members of two BME research labs, observing work in the labs, attending lab meetings, PhD proposals and defences, mentoring meetings, and lab tours for visitors. The aim is to gain an understanding of the "complex in-the-world learning environments (*in vivo* sites) and then appropriately translating findings into design principles for classrooms (*in vitro* sites)" (Newstetter et al., 2010, p. 3257). Four principles were distilled from the data, such as "learning is driven by the need to solve complex problems, and "learning is relational". The paper describes each design principle in detail and provides theoretical justification, but the path from empirical evidence to principles is described using just one word "distil" which renders methodological procedures for creating design principles less than transparent.

The *design-based research* approaches are exemplified by Cremers et al. (2016) who develop design principles for hybrid learning at the interface between school and workplace in the Netherlands. The paper details the methods used to create design principles and explains how theoretical perspectives and the 'craft wisdom' of the designers gradually manifested in a set of initial design principles during the first iteration. These were then refined and consolidated based on a revisiting of the theoretical underpinnings and analysis of data collected during two subsequent iterations, reducing a set of nine principles to seven. The paper features methodological rigour and transparency: it traces each principle from its origin to implementation. Further, the paper addresses the issue of the usefulness and reusability of the developed principles and, to this effect, connects each principle with features and their impact on learners exemplifying how the principles can be used in different contexts.

Experience first practices

Navarro et al. (2016) detail a *practice-based approach*. The authors explain how a steering document with guiding principles and essential elements together with exemplar materials for the design, implementation and evaluation of integrative curricula in engineering education at an American university were developed. First, an interdisciplinary consultant team of faculty with expertise in humanities and social sciences was established. In the span of a year, the researchers held meetings with this team who were asked "to define the level of functional knowledge in their disciplines that engineering students needed to make connections between social sciences, the humanities, and engineering" (p. 374), i.e., existing practice formed the point of departure.

The team's discussions led to the development of 'a general philosophy' and a recommended 'topic structure' to guide faculty in the development of interdisciplinary course materials and curricula. The broad philosophy was synthesised with academic literature and resulted in the steering document with guiding principles. The perceived usefulness of the guiding principles, essential elements and exemplar materials were then evaluated with faculty and students. The authors conclude that 1) the guiding principles and essential elements can be used in other disciplines and thus advocate their usefulness and reusability and 2) the exemplars that aim "to facilitate faculty's job" (Navarro et al., 2016, p. 382) need further work in terms of length, diversity and familiarity of topic, to be useful.

Woolmer et al. (2016) exemplify a *user/stakeholder focused approach* to the development of a 'problem-solving skills in science course" for Physics and Astronomy, Geographical and Earth Sciences, and Chemistry students at a Scottish university. Academics and undergraduate students from these disciplines co-developed the course, with the students researching best practices for teaching problem-solving skills and producing course materials, and the academics taking on the role of project managers and consultants. The paper describes the design knowledge offered as insights, areas for consideration and suggestions regarding how students can be engaged as partners in the co-creation of interdisciplinary learning experiences. The design knowledge is derived from academics and students' joint reflections on the design process and informed by literature. The creation process is transparent, and the focus is on communicating the lessons learned to the benefit of others. However, the vocabulary used does not include common design concepts which means that the design knowledge produced might not easily be retrieved and reused.

5.5 Discussion and concluding remarks

This chapter examined current practices for creating design knowledge. Via an integrative literature review, we found a plethora of terms for and ways in which design knowledge is created which shows that it is a domain characterised by terminological and methodological pluralism. This raises some critical questions that we discuss below.

In the analysed papers, design terms and methods for creating design knowledge were rarely discussed or reflected in depth. Often, reasons were not given for selecting a certain term or approach or combining several approaches. In addition, the description of methods for creating design knowledge often stayed on a very general level, lacking the detail necessary for interpretation of outcomes or reuse of methods. Where more than one approach was used, it was often difficult to identify the sequence and to understand how the results of different approaches informed each other. Some papers articulated specific design methods that were employed, such as conjecture mapping, ACAD, constructive alignment, design thinking and prototyping, but others did not have such methodological details. Few texts contained reflections on methods used and few texts revisited the design knowledge produced after the learning experience had been designed and empirically tested. The main concern was students' experiences and collaboration across departments and disciplines to create interdisciplinary education, rather than the robustness or reusability of the design knowledge created or the methods employed beyond the specific setting.

While there were exemptions, methodological rigour and transparency were often lacking in current practices for creating and reporting design knowledge. This limits the potential for reusability and cumulative advancement of design knowledge which means less building on the work of others and less testing of design knowledge in new settings with a view to refining it and adding to its trustworthiness. Instead, it becomes a case of one-off use which is not sufficient for the research community or for practitioners who are looking for robust principled-practical knowledge. There is a need for more methodological guidance and critical reflection on how design knowledge is created and how to ensure its trustworthiness, reusability, and practical usefulness.

The pathways and approaches presented in this chapter contribute to the methodological awareness in the field of educational design by consolidating current practices and providing a foundation for further progress. The papers we examined had different units of analysis and design and came from different educational and geographical contexts. While we did not identify patterns across these entities, further research should explore deeper possible associations between methodological and contextual aspects. Our focus was how design knowledge is created in the field of interdisciplinary tertiary education; such inquiries should be expanded to other educational domains.

6 Data collection

This chapter first describes the contexts in which data were collected and the challenges of doing research in naturalistic settings during a pandemic. Then follows an account of the data collection methods employed, the purpose of selecting these approaches and reflections on implementation. After this, the chapter explains how data were prepared for analysis.

As the data collection methods below will indicate, the study is, first and foremost, of a qualitative nature and characterised by a flexible design, the use of relatively unstructured data, an emphasis on the researcher as research instrument, the in-depth inquiry into a small number of naturalistic cases, and the preference for verbal rather than statistical analysis methods (Hammersley, 2012).

6.1 Empirical data

Multiple cases were selected for the empirical work, and each case constitutes a naturalistic setting for development and testing of interventions. It brings context to the centre of attention and enables in-depth studies while attempting to understand complex social phenomena such as classroom activities (Xu et al., 2018).

At the conception of the study, practitioners were recruited from three domains at the Faculty of Humanities at SDU, namely Philosophy, Media Studies and American Studies. These domains were chosen to gain access to different humanistic contexts, e.g., subjects of a more theoretical nature versus some of a more empirical nature, thus achieving a balanced representation and the opportunity to gain nuanced insights concerning the integration of CT with computational things in the humanities. However, at the start of the study, the practitioner from American Studies declined to participate due to research funding that took him overseas when interventions were to have been developed and tested. Therefore, the study commenced with two cases. See chapter 3 for an account of these.

A year into the study (autumn 2021), the teacher of the course: Design Research 1 on the first semester of the MA in IT Product Design (ITPD) proposed a collaboration around the adaptation and use of the activity and tool that had been designed for Philosophy and Media Studies. I accepted the proposal, and Research Design 1 was added as a third case to investigate whether implementation in a new context at the Faculty of Humanities at SDU would yield the same or different results. In addition, case 3 would add further respondents to the pool of learners who had tested the activity and tool. Case 3 is described in more detail below.

Case 3

Design Research 1 [1] is a 5 ECTS course on the first semester of ITPD. The course revolves around the critical analysis of design research activities and strives to support students in obtaining design research skills, more specifically:

- Knowledge on central design research methods and traditions and the ability to reflect on different methodological approaches to design.
- The skills to apply design research methods and communicate in academic writing.
- The competences to plan, carry out and critically analyse a design research activity.

Students have different educational backgrounds with some coming from profession-specific education, such as engineering or art, and others from more theoretical subjects. A practical implication of this is diversity in students' academic reading and writing skills. Design Research 1 is delivered as a series of design research methodology and writing workshops with presentations from the teacher, time set aside for students' writing and for teacher and peer feedback.

For their exam submission, students must write two papers. Each paper should account for and provide a retrospective analysis of a design project already completed by the student in the preceding months. According to the teacher, this retrospective perspective confuses students who have difficulties generating ideas and problem formulations for their papers and figuring out what to include in them.

A fourth case was added in spring 2022, when a colleague invited project suggestions for students at ITPD who were to do a Professional Apprenticeship (PA) project in their second semester. These were the students who had engaged with the activity and tool in the subject Design Research 1 described above. I pitched a project to students in which they were to evaluate the tool they had experienced and develop alternative designs (see the brief for

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[1] The course description for Design Research 1 can be accessed via https://odin.sdu.dk/sitecore/index.php?a=searchfagbesk&bbcourseid=H830007201-1-E21&lang=en

students in appendix 14.2). This is in line with Ørngreen's (2015) suggestion that the development and testing of alternative designs can help overcome confirmation bias. Furthermore, students would be involved as co-designers and could, from this perspective, contribute a critical examination of design aspects and provide further insight into students' experiences. Seven students opted to do the project which was titled *Tangible Interaction for Creativity*. Case 4 is described in more detail below.

Case 4

Professional Apprenticeship[2] is a 10 ECTS module at the second semester of the ITPD that aims to make students aware of their professional identity by giving them the opportunity to work closely together with researchers and explore a research area of interest. Via the apprenticeship, students are to:

- gain knowledge within the research area,
- practice skills in relation to the selection and application of research methods and in relation to communicating research findings,
- build competences to engage in critical reflective practice and develop their future professional identity.

Design process as well as products are essential components of the inquiry undertaken in the Professional apprenticeship.

See Figure 6-1 below for an expanded version of the 4-phase model adopted for this DBR-study. The figure includes cases 3 and 4 that were added after the commencement of the study and shows their location in and contribution to the study.

[2] The course description for the Professional Apprenticeship can be accesses via: https://odin.sdu.dk/sitecore/index.php?a=searchfagbesk&bbcourseid=H830013201-1-F22&lang=en

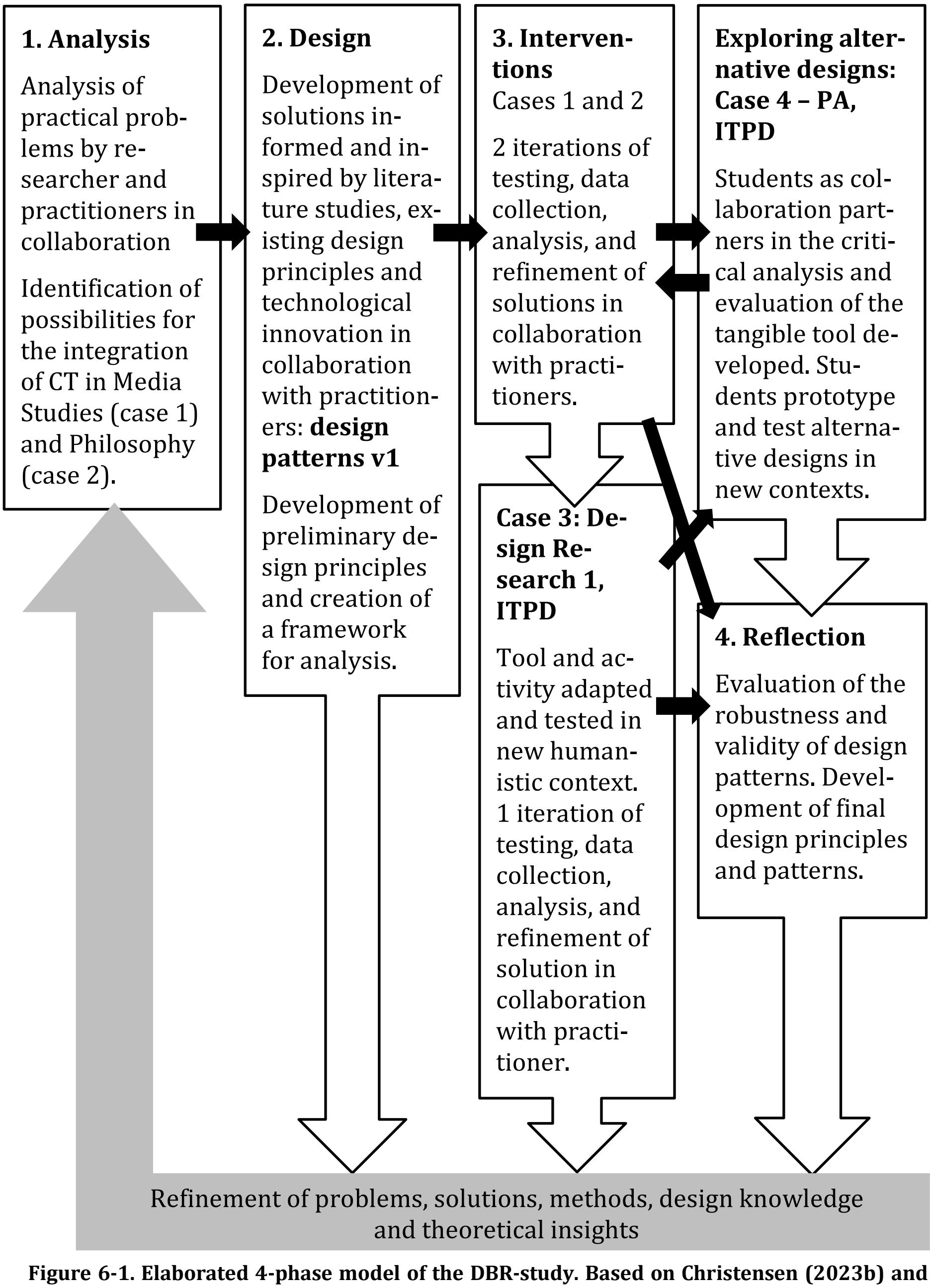


Figure 6-1. Elaborated 4-phase model of the DBR-study. Based on Christensen (2023b) and inspired by Reeves (2006)

6.2 Unit of analysis and case contributions

Cases 1 - 3 consisted of interventions in a particular course, and these interventions formed the *unit of analysis*. This included both the design process, i.e., the development of activity and tool, and the actual unfolding of the activity in the classroom. When focusing on interventions as the unit of analysis, it becomes possible to investigate activity systems (cf. section 7.2.2), i.e., examine how learners interact with peers, with the teacher and external resources in the learning situation, more specifically what role, computational things come to play. Cases 1-3 contributed empirically tested design patterns for CT activities with computational things for the humanities in HE.

In contrast, case 4 did not involve my development and testing of interventions. Instead, students were collaboration partners in the critical assessment of the tangible designs arrived at in cases 1-3, and they developed alternative designs for similar pedagogical challenges. This provided further input for phase 4. Reflection of the DBR-study.

In the following, the challenges of doing research in naturalistic settings during a pandemic are discussed.

6.3 Research in naturalistic settings during a pandemic

In this section, the overall challenges in relation to the present study are discussed, and specific issues relating to the data collection methods employed are covered in section 6.4 below where relevant.

Fieldwork where the researcher visits the naturalistic setting being studied to immerse herself in the context and collect data in-person is a hallmark of qualitative studies (Howlett, 2022; Neuman, 2014; Savenye & Robinson, 2005). It is also essential in a DBR-study that seeks to bridge research and practice (McKenney & Reeves, 2012). Since I collaborated with practitioners in all four phases of the study, access to the field was imperative. The plan was to investigate students' embodied cognition and learning with tangible, computational things, therefore face-to-face (F2F) interventions on campus were necessary.

However, when I started my PhD in September 2020, Danish society had just closed down again with COVID-19 restrictions that prohibited F2F appearance at university buildings. The social distancing enforced meant that the first interventions had to take place online, since both the teacher from Philosophy and from Media Studies were eager to get started and the courses concerned were spring courses. Of course, there was the challenge of having to use digital models rather than tangible, physical models of the materials and tools developed. This meant that students' interactions with materials and tools were phygital (Due & Toft, 2021), rather than physical, i.e., a combination of finger and hand movements on keyboard, mouse and/or screen and the resulting manipulation of digital objects on screen.

My supervisor and I believed, however, that it was still worth conducting the interventions to obtain first experiences with the activities and tools developed that could inform the subsequent iterations. Furthermore, we had no idea when Corona restrictions would be lifted. It was an important factor that the HE activities I was studying were not discontinued during the lockdown. Instead, the field as such moved online to exist as asynchronous and synchronous activities on various online platforms during lockdown periods; teachers, students and I created the field through online co-presence (Howlett, 2022).

My fieldwork began in November 2020, about eight months into the pandemic, which also had a bearing on the field I was accessing since, by then, both teachers and students had gained experience and skills with regards to using online platforms which is essential for online fieldwork (Gray et al., 2020; Howlett, 2022; Lobe et al., 2020). In addition, It-services at SDU had upgraded capacity to provide more reliable, stable, and easy to use environments for online sessions.

The move to online fieldwork and data collection methods brought with it data protection issues, more specifically, the challenge of complying with GDPR and ensure the safe recording and storage of data. For this, only SDU sanctioned platforms could be used. Compliance with the regulations influenced choice of videoconferencing platform, cf. section 6.4.3.

Corona restrictions gradually lifted during spring 2021, which meant that, of the interventions reported in this thesis, only iteration 1 at Philosophy had to be conducted online. The rest were conducted F2F. This brought the additional issues of preparing data collected partly online and partly F2F for analysis, and of finding an analysis method that would secure a fair and unbiased representation of findings from the different interventions. E.g., I initially engaged in multimodal conversation analysis (Mondada, 2016) of the video recordings from the online interventions which provided a profound insight into students' actions and interactions with computational things. However, the video material collected from the F2F interventions were not of a sufficient quality to make this possible which meant that an alternative method had to be found (see section 8.1).

Below, the data collection methods employed in this study are presented, illustrated and discussed, including issues in relation to COVID-19 where relevant.

6.4 Data collection methods

In cases 1 and 2, two iterations were conducted whereas case 3 involved one iteration. Each iteration involved data collection as described below. As mentioned, case 4 did not involve interventions, but I kept a journal and made audio recordings of sessions to document students' assessment of the tangible tool and their development of alternatives. During each iteration, data were collected to document the design-process, to study how the interventions unfolded, and to evaluate the learning designs with a view to improving these for the next iteration. The evaluation was partly an open exploration of the role of the tool as seen from the perspective of students, teachers and me as researcher, and partly an evaluation of the instructions provided to students and the design of the tool with a view to uncovering what could be improved to facilitate student engagement with activity and tool to complete the posed tasks.

An important point in relation to data collection, as well as data analysis, in DBR is awareness of potential selection bias (Ryu, 2020). Selection bias occurs when researchers focus too narrowly on confirming or disproving theoretical assumptions which can cause blind spots that leads the researcher to ignore data that are unfavourable in relation to assumptions or evaluation of developed designs. Using a methodological bricolage approach (Bueddefeld et al., 2021) can help overcome the challenge of selection bias since the use of multiple methods for data collection will yield different types of data that can provide more nuanced and in-depth understandings of the phenomena at play (Ryu, 2020). The term methodological bricolage well describes the data collection approach chosen for this study.

Not only interventions but also data collection methods and instruments are evaluated and improved in a DBR-study (Reeves, 2006). Therefore, the presentation of data collection methods below also includes reflections on implementation and any changes made from one iteration to the next.

6.4.1 Research journal

I kept a journal for each case with the purpose of documenting the design process. I recorded minutes from planning meetings with the practitioners, my preparation for these meetings and the design process including design ideas as they were created, discarded and/or pursued. As I started collecting data, my journal writing became more reflective. I explored, among other things, challenges related to data collection in naturalistic settings, my own experiences and reactions before, during and after interventions, questions that arose and that I wanted to further investigate, tentative interpretations and possible improvements to the designed interventions. I thus engaged in reflective writing (Borg, 2001).

When a research journal becomes a space for reflection, “ideas [can be] generated and explored and discoveries made in and through writing” (Borg, 2001, p. 160). The following entry was made after the first meeting with the teacher from Philosophy and shows how the idea for the computational tool that was later developed emerged:

> Proceed with:
>
> Algorithms for the processing of project ideas […] Students’ idea generation is sometimes very general – could be nice with an auxiliary tool to concretise ideas.
>
> Give the option of decomposition in relation to formulating problems. Turning discs [drejeskiver] for, e.g., question words (how, why, what…]. Make students aware of the impact on their project when choosing a given question word.
>
> CT – decomposition of problem formulation: how do I investigate it? What is encompassed? The analysis step. NB: debugging. Students assess own and each other’s decomposed problem formulations.
>
> Tool(s) to be introduced in seminar series, students test it. Can help students later in their projects when they can use it on their own. Scaffolding students’ systematic exploration.
>
> Unplugged, analogue, manual. E.g., turning disks with component parts to investigate […] By manipulating the turning disks one can explore in which direction the different question words will take one.
>
> (Entry in Philosophy journal for iteration 1 made on 15 December 2020)

A research journal can also support the researcher in holding on to illusive thoughts to further develop these and gain new insights (Borg, 2001, p. 170). This entry is from Philosophy and was made after looking through the video recordings from the first intervention:

> Is it an expression of CT when students engage with the activity with the idea generation tool and write concepts (component parts) on the circles to then combine these crisscross and talk themselves through the “whole” of a specific combination?

> Does it express a lack of CT skills (decomposition, algorithmic thinking, combinatorics) when students don't really get started using the tool and when they indicate that they prefer free talk/brainstorming? CT not meaningful for students?
>
> Can step by step instructions (algorithms for using the idea generation tool) be made clearer/more meaningful?
>
> (Entry in Philosophy journal for iteration 1 made on 8 April 2021)

I recorded the following in my journal for Design Research 1 as I was in the process of collecting data via interviews after the intervention. The entry shows how I grapple to understand the role(s) of the computational tool developed as realised in the learning situation:

> So far this week, I have had interviews with two students from Design Research 1 who have told me about their use of the idea generation tool and their experiences. Both students mentioned that the tool was a way of communicating ideas and knowledge to other students. One student communicated her idea to her fellow students by showing them her selection. The other student told fellow students how to go about generating ideas and demonstrated this on the tool. This indicates that the tool is an important external representation (of ideas, knowledge), a social artefact (where does that concept come from?) that enables a student to show his/her idea to other students.
>
> (Entry in Design Research 1 journal made on 11 January 2022)

6.4.2 Participant observation

With inspiration from ethnography, I undertook observation of interventions and produced fieldnotes adopting an overt approach and a participating-to-write style (Emerson et al., 2011). In Spradley's (1980) terms, I took on the role of participant observer with the dual purpose of 1) engaging in some of the activities as facilitator (as described in section 4.3) and 2) observing people, actions and interactions in the virtual or physical environment.

The purpose of observation and production of fieldnotes was to record how the designed interventions unfolded in practice, i.e., to document the realised design so that this could be compared and evaluated against the intentions of the planned design. In addition, the fieldnotes supported the writing of thick descriptions (Cowie, 2009) to make transparent the context and conditions of the study (Barab & Squire, 2004).

Notes were written down in a notebook together with *asides* (Emerson et al., 2011, p. 101), such as my reflections on or questions in relation to what I observed (see example below). Following each intervention, notes and asides were typed into a word-document for easy retrieval.

> **Time**: 14.15
>
> **Note**: I observe less use of the tool after the break. There is much talking in the groups while the tool rests on the tables in front of students here and there in the room.
>
> **Reflection**: What does this signify? Students used the tool a lot during the individual idea generation. They had the tool in hand. Must ask about this in the upcoming interviews with students.
>
> (Field note from iteration 1 at Media Studies)

One advantage of using ethnography-inspired observation is that the researcher gains first-hand experience of the phenomenon being studied by being present in the classroom herself (Cowie, 2009). It is not always possible, however, to interpret what is going on. Therefore, I have found it valuable to be able to bring back observations to students to seek explanations and inquire into motives. Indeed, observation is most optimally used with other data collection methods, such as e.g., interviews or the collection of student products, to gain a deeper understanding of phenomena discovered.

The focus of observation was a given intervention as it unfolded (cf. the unit of analysis), particular attention was given to the different phases of the intervention and how students engaged (or did not engage) with the tasks, each other, the tool, the teacher and me (when I acted as facilitator) during each of these phases.

Participant observation as a data collection method have certain weaknesses: it is time-consuming, it is difficult to secure broad coverage if you are not a team of observers, hence you must select what to observe and what not to observe, and bias might occur caused by the participant observer's participation in the unfolding activities (Yin, 2018). This bias is twofold; as a participant observer, I had both designed and facilitated some of the activities, thus both staging and manipulating events. In addition, I was an overt observer, and I briefly introduced my study to students, just stating however, that I was investigating alternative teaching methods and tools. Nonetheless, this can have an effect on students and cause the "observer's paradox [that] assumes that the act of observation will change the observed person's behavior" (Cowie, 2009, p. 177).

I experienced this in practice as some students' preoccupation with me getting useful data, or their explicit remarks about my presence. In addition, some students seemed to make an extra effort to complete activities even though they indicated these activities did not make sense to them. This indicates a form of good participant bias, i.e., the students trying to please and help me. However, students only focused on me and the data collection for short periods of times and quickly returned to engaging fully in the activities. Therefore, I conclude that this did not compromise the data, but rather lead to the collection of nuanced data that helped me more fully understand students' engagement or non-engagement with the computational tool.

6.4.3 Video observation

Video observation was added as a data collection method to overcome the problems of coverage and selectivity in connection with conducting participant observation mentioned above. The video recordings captured events as they unfolded (Heath et al., 2010), allowed me to return to specific moments and phases of an intervention after its conclusion, and observe and take detailed notes. Thus, my observational powers were enhanced via the video recordings (Derry et al., 2010).

MS Teams was used for the online intervention at Philosophy because this enabled the recording of several group meetings at the same time and the safe storing of recordings. Conducting interventions in MS Teams proved a challenge, since teaching sessions normally took place in Zoom during the corona lockdown. A written step-by-step guide was prepared, and help was solicited from an e-learning consultant from the SDU Centre for Teaching and Learning who helped students gain access to MS Teams. Students were asked to download a digital model of the idea generation tool and take turns sharing screen as they worked with the tool. This made it possible to observe how the activity unfolded with a particular focus on students' actions and interactions.

For F2F interventions, I used a fixed camera that was angled so that it could capture students from above (Heath et al., 2010) giving me access to study students' hands, their manipulation of objects and their interaction with fellow students. This resulted in the set up illustrated in Figure 6-2 below that shows how the activity of a single group was recorded, and Figure 6-3 that provides an overview of the set up for recording several groups in a classroom. In this way, I used video as a *lens* to "focus attention on selected aspects of classroom activity, affording strategic close-ups of prioritised events or objects" (Clarke & Chan, 2018, p. 11).

Figure 6-2. Video set up for the intervention at Media Studies, first iteration, spring 2021

Figure 6-3. Video set up in entire classroom. Media Studies, first iteration, spring 2021

I aimed to capture several groups to study any variations in tool usage, action and interaction and used one camera per group which resulted in a single viewpoint, i.e., observation of the unfolding events from one perspective. In this way, I adopted the role of observer rather than acting as a cameraman that holds the camera and follows the action (Heath et al., 2010).

Just as the presence and overt notetaking of the researcher can affect participants' behaviour as mentioned above, so too can the presence of a video camera (Heath et al., 2010). Signs of this can be participants' orienting themselves to the recording equipment and speaking directly to the camera and the researcher they know will be watching the recording later. I did find such instances in my data, but students' reactions to being recorded and to the equipment were only fleeting. Therefore, I conclude that the data collected were not corrupted. Rather, I found that the instances contained students' metacommunication on the task with which they engaged, and this gave me valuable insight from their perspective.

Several challenges with respects to doing video observation of students' group work F2F were identified. The most severe challenge was probably that of recording in classrooms which were large with high ceilings. After viewing recordings from the first F2F iteration, it became apparent that there was a problem of securing good audio of students' group sessions. When only one camera was operating in a space, the audio was remarkably good considering the quality of the equipment. But it was simply not possible to have several cameras operating in one classroom and secure good audio of each group conversation. Each camera would pick up too much sound from the other groups and students were too far away from the camera microphone. In later interventions, external microphones were added, but these did not remedy the problem. The best solution I found was supplementing each video camera with a dictaphone. The dictaphones in most cases provided sufficient audio quality to transcribe the dialogue taking place.

6.4.4 Evaluation questionnaires

During the first interventions at Media Studies (the activities not reported in this thesis) and Philosophy, electronic questionnaires were created in SurveyExact and made available via SDU's e-learning platform. The purpose was to obtain students' evaluations of the activity and tool to gain information on what had worked well and what could be improved for the second iteration. At the same time, we hoped that the questionnaires would help students reflect on their learning.

As can be seen from Table 14.1 on pp. 263-264, the response rate was very low. Therefore, it was decided to discontinue this data collection method and instead rely on the collection of students' responses to reflection questions, cf. below. An account of methods used to create questionnaire items can be found in appendix 14.3 together with the questionnaire employed at Philosophy.

6.4.5 Collection of student products and reflections

Students were asked to take images of the combinations they generated using the idea generation tool and to respond to a number of reflection questions. Students uploaded images and reflections to SDU's e-learning platform. The purpose of reflection questions was to prompt students to think about, articulate and share their learning process and their outcome of engaging with the activity and tool, thus also enhancing their learning (Rogers, 2001). Such collection of student products and reflections for analysis are common techniques in qualitative research because they provide access to participants' own articulations of perceptions and experiences (Neuman, 2014; Savenye & Robinson, 2005).

I phrased the reflection questions so as to gain insight into students' experiences working with the computational tool and any learning (subject-related or otherwise) they felt they achieved in the process. The set of reflection questions contained a few, general questions on tool use that were posed in all cases, and questions that were tailored to each, individual subject (see appendix 14.4).

The semi-structured interviews conducted in iteration 1 revealed that some students found it quite intimidating to have to generate problem formulations or research questions. This seemed a point worth pursuing, therefore the following question was added as an initial reflection before students engaged with the idea generation tool:

- How do you usually feel about generating ideas for exam papers?

The reflection questions were added as a substitute for the evaluation questionnaires and yielded more, quite insightful, responses. Therefore, and also in order to support students' personal reflections on the activity and tool, the collection of responses to reflection questions were continued.

6.4.6 Semi-structured interviews

Semi-structured interviews were completed with 2-5 students in each iteration and with all teachers. Interviews with students took around 30 minutes, and around 60 minutes with teachers. The semi-structured interviews were an opportunity to investigate puzzlements that emerged during interventions, as mentioned above, or upon reading students' reflections. One such example is my observation that students participating in iteration 1 at Media Studies used the tool less or not at all after the break. I brought this back at interviews and received very interesting answers that resulted in a more nuanced understanding of the tool. It is exactly the strengths of qualitative interviewing that it supports the exploration and broadens the understanding of a certain topic or phenomenon and informs the researcher's interpretation (Galletta, 2013; Nathan et al., 2018).

I conducted semi-structured interviews with the participating teachers to document their motivation for collaborating with me and to evaluate the interventions and our collaboration. When interviewing the teacher at ITPD (Design Research 1), I included questions regarding the adaptation of the tool to her specific context to probe into and document the re-design process.

When preparing the interview guides, I focused on formulating open-ended questions that would provide space for students to freely narrate their experiences (Galletta, 2013), and I tried to avoid posing leading questions (see appendix 14.5). E.g., question 3 asked: "What became possible using the idea generation tool?" If students asked for clarification, I would elaborate "- in relation to idea generation, exploration of idea, angling, delimitation?" And of course, question 4 asked "What was not possible?" to also uncover any challenges of using tangible, computational things. Furthermore, I sought to pose questions that would prompt students to relate what they did when using the tool rather than what they thought about the experience. E.g., question 2 asks students to "Describe how you used the idea generation tool", followed by prompts to explain usage in the different phases of the intervention, thus aligning the interview guide with the unit of analysis: the intervention and its different phases, students' actions and interactions.

Students were invited via e-mail and all interviews took place via Zoom since this was the most flexible approach considering time and place. I recorded the interviews using Zoom's recording option, but only kept the audio files for later transcription. The F2F interviews with teachers were recorded using a dictaphone.

At the start of each interview, I explained that I was conducting an open investigation, not looking for specific answers, but any information that could help me improve the intervention. I hoped this would make students comfortable sharing any criticism of tools and activity. During interviews, in line with the guidance provided in Galletta (2013), I followed the interview guide, rephrasing questions or providing more specific prompts when required for students' understanding, and then followed students' narratives. I ended each interview by asking whether the respondent had anything further to add to allow him/her to offer final perspectives.

The semi-structured interviews were found to be a valuable data collection instrument since students' responses helped me make sense of the data collected via other means. I consequently included interviews in iteration 2 and revised the questions to further probe the phenomena uncovered in iteration 1. One change concerned word usage. In iteration 1, the teachers and I had developed a *tool for generating ideas* and labelled it as such, but the analysis of data from iteration 1 revealed that the tool clearly had many more roles and functions from the student perspective. Therefore, I chose the more objective term cardboard model for the interview guide, iteration 2 at Media Studies. This move was made to discover what words, roles and functions the students themselves would use about the tool. In this way, using Galletta's (2013) words, "as thematic patterns emerge[d] and [were] explored and labelled as codes, [I became] more attentive to further evidence of these patterns in future interviews" (pp. 76-77).

For the interviews, I attempted to select students from different groups and consulted the uploaded reflections to select students with different attitudes and perceptions. In this way, I hoped to be able to collect nuanced data and ensure a broad (Galletta, 2013) as well as a fair (Nathan et al., 2018) representation of experiences and perspectives. I aimed for 5 students after each intervention, but in some cases only managed to get a yes from 2 students. Also, I had to recruit interviewees more broadly, since many students declined to participate, indicating they were busy studying for an upcoming exam, e.g.

Table 14.1 in appendix 14.6 provides an overview of data collection methods and data collected.

6.5 Preparing data for analysis

Raw data were examined and processed in the following manner in preparation for analysis. All interviews were transcribed verbatim either manually or automatically, in the latter case using Amberscript software. Automatically generated transcripts were checked and adjusted manually to more accurately reflect participants' own wording of responses as recommended by Savenye and Robinson's (2005) and with the purpose of enriching analyses with quotes. In the transcription process, the interviewees were anonymised and provided with a number: MS2 student 1, MS2 student 2 etc. Where the initials MS signified the empirical context in which the data were collected, in this case Media Studies. And the number following MS signified the iteration, in this case iteration 2. All transcripts were stored in SDU's OneDrive as recommended by the university, and later uploaded to NVivo for coding. Student products and reflections were downloaded from SDU's e-learning platform and also uploaded to NVivo for coding.

As explained in chapter 3, video recordings of students' group work during the online intervention went through a process of observation and memoing before analysis, as did the video recordings with sufficient audio quality from the F2F interventions. Students were anonymised in the process using only a single initial, letter or number to distinguish students from each other and blurring screenshots of videos. These memos constituted extensive field notes that informed interviews with students and teachers, were used for the thematic analysis and to inform improvements for iteration 2.

A snippet from one of the memos created is shown in Table 14.2 in appendix 14.7 to illustrate format and contents. This appendix also provides an overview of the number of video memos created, see Table 14.3.

7 Theoretical framework

This chapter presents and discusses a theoretical framework for design and analysis of learning activities with CT and tangible, computational things for students in the humanities in HE. Theory is important in several stages of a DBR-study (diSessa & Cobb, 2004), and in the present study, theory informs the formulation of design principles, explains and motivates the design of interventions, provides a framework for analysing empirical data, and is also a product of reflections on and generalisation of the findings from the empirical testing.

The framework is the result of an iterative process in which theories have been studied to inform the design process. Following tests and evaluations of designed interventions, new phenomena have been uncovered, and further theoretical studies have been undertaken to shed light on these. Furthermore, the theoretical framework is informed by a retrospective analysis of the computational thing developed. The iterative process of developing design principles, designing interventions, and undertaking further theoretical studies is elaborated in chapter 10. Chapter 10 also presents a visual model of the framework that brings together the different theoretical components and illustrates the connections.

Below, the different components of the theoretical framework are presented and discussed: 1) situated learning and cognition, 2) materiality, and 3) cognition and learning with tangible, computational things. First, I share insights derived from studying an early model of learning another subject with CT and tangible, computational things.

7.1 The legacy of Papert: designs for learning with computational things

A great source of inspiration for my research on students' learning of abstract concepts *with* CT and tangible, computational things is Seymour Papert who coined the term computational thinking in1980. Papert's mission was to develop a model for the use of computers to *innovate* education for children (math education is used as example below), rather than using computers to support *existing* educational perspectives and approaches which was the predominant inclination at the time.

Papert proposes to shift the focus from formal curricula prioritising dissociated, mathematical constructs (that are difficult for many children to grasp because they cannot relate these to prior experiences) to informal communities. These should provide learners with different objects-to-think-with, i.e. materials, in the form of tangible or intangible, external, computational representations, thus changing access patterns to, in this case, mathematical knowledge (Papert, 1980).

The focus in education should not be abstract, mathematical constructs, i.e., content, but computational procedures and procedural thinking with the purpose of supporting learners in articulating, reflecting on and continuously developing their thinking as well as their learning strategies. Papert's work is thus a prime and early example that illustrates the use of CT and computational things to learn another subject. Indeed, Papert's vision is that such objects-to-think- with can "help people form new relationships with knowledge that cut across the traditional lines separating humanities from sciences and knowledge of the self from both of these" (Papert, 1980, p. 4) thus welcoming "humanists" into the process of developing computational cultures.

Papert builds on Piaget's theory of stagewise cognitive development (Piaget, 2003) as the individual's exploration of the world and construction of schemas, i.e. mental models of the world. Children's cognition gradually develops from concrete thinking in early years and only later to formal thinking which is required for many math tasks and other systematic procedures. Papert further develops this conceptualisation of cognition and learning and proposes that the material available to learners at a given stage is essential for their development, likening the learner to a builder who must be provided with proper materials to develop, construct new knowledge, and learn. Thus, he opposes the view that children's cognitive development takes place in stages in a fixed and universal order. Rather he argues, it is a question of the sorts of materials that the society in which the child lives makes available at a given point in time.

Combinatorial thinking, the concept of interest in this thesis, is associated with Piaget's notion of formal thinking, and involves systematic procedures such as permutation generation. Papert asserts that current society does not sufficiently model such systematic procedures, leaving children with no personal experiences as point of departure. He believes that with computers and computational things, children will have both the "incentive [and] the materials to build powerful, concrete ways to think about problems involving systematicity" (Papert, 1980, p. 22).

Papert and colleagues developed the LOGO programming language and a computational object-to-think-with, the Turtle, that connects with both formal knowledge within a subject and with the learner's body knowledge, i.e. sensorimotor schemata. Thus, creating a relationship that is both abstract and sensory (Papert, 1980) and tapping into the child's many experiences with bodily exploration of the world.

Important concepts in Papert's (1980) work connect to current conceptualisations of CT. An important notion is debugging. Children program the Turtle to execute a certain geometrical figure. If at first the Turtle does not produce the desired figure, children can examine the code they developed, run the code by moving their own bodies (first left, then forward etc.) and thus figure out and correct any errors. With the ideas embedded in the Turtle, Papert wanted to get rid of teachers' correct/incorrect assessment of students' work and replace it with students' own development, testing, evaluation and fixing of procedures (Papert, 1980).

In addition to algorithm design, testing and debugging, which Papert refers to as procedural thinking, i.e. solving problems in a step-by-step, systematic, mechanical fashion as described above, "playing Turtle" (Papert, 1980) also supports students in engaging with other computational practices. For example, decomposition (Papert labels it modularisation) is needed to separate a drawing into geometrical figures that can be programmed using the LOGO language and drawn by the Turtle. And pattern recognition comes into play when learners draw on their existing knowledge to solve a problem - here Papert is inspired by Polya's advice on problem-solving (cf. chapter 3).

This thesis adopts the same mission as Papert to connect learners with formal knowledge in the form of abstract subject concepts via external, computational representations, but focuses on analogue, tangible, computational things. Where Papert's vision was to propose a new framing of and setting for learning, I have attempted to situate CT with computational things in existing formal HE within humanistic subjects. However, we both recognise the situativity of learning, i.e., the impact of context, people, objects and environment on the learning that takes place, and the role embodiment can play in enhancing student engagement and learning.

Students working with the idea generation tool designed in this study make use of their hands as they manipulate the individual circles of the tool. In the process, they get a tactile experience as they engage with the analogue paper-based material and use sensorimotor skills to turn the circles. In this way, the abstract, intangible, and often opaque process of generating an idea becomes mechanical, procedural, and concrete as students physically select and align abstract concepts from the different circles. Consequently, the idea generation process becomes a procedure - an entity that can be articulated, discussed, manipulated, debugged and changed (Papert, 1980).

The next section motivates the inclusion of situated learning and cognition in the theoretical framework and presents and discusses the theoretical constructs of relevance for the design and analysis of CT activities.

7.2 Situated learning and cognition

There is general agreement on the importance of integrating CT in core curricula as a 21st century competency that is necessary for both living and working in today's world and for solving problems in all domains (Grover & Pea, 2018; Voogt et al., 2015). However, this is often done via programming exercises (Kite et al., 2021), and students in, e.g., the humanities are left to transfer the learning from such exercises to their own subjects. In contrast, this thesis provides and examines a model for contextualising, i.e., situating CT within specific subjects in the attempt to create interdisciplinary activities that support students in creating links between the subjects involved (Kidron & Kali, 2015). In this way, learning is sought embedded in the context in which it is to be applied (Kirk & Kinchin, 2003).

In a situated learning perspective, the context in which learning takes place has impact; it forms and adds content to what is being learnt, making learning an integrated and inseparable aspect of social practice (Brown et al., 1989; Lave & Wenger, 1991). Likewise, knowledge is situated, being, to a certain extent, a product of the activity, context and culture in which it is created and applied. In this lens, learning is viewed as participation, i.e. situated activity that spans "mind, body, activity and culturally organized setting (which include other actors)" (Lave, 1988, p. 1). Thus, situated learning challenges the understanding of learning as "instruction and transfer of 'decontextualised', abstract knowledge" (Hansen, 2020, p. 5).

Learning as acquisition and learning as participation are two common metaphors used for describing conceptions of learning (Sfard, 1998). The acquisition metaphor dominates older writings. It conceives learning as concept development, and concepts as entities of knowledge that can be acquired, just as one would purchase goods. Hence, the notion of transfer of knowledge is part of the metaphor, as is the view that knowledge exists as permanent units. Around 1990, the participation metaphor for learning gained traction. This metaphor conceptualises learning as doing and shifts the focus from knowledge to activity and practice. In addition, learning is seen as a continuous, context-embedded and social process, i.e., as situated. Thus, learning revolves around participation rather than acquisition.

Within situated learning, we find the seminal works of Lave and Wenger (1991) who, i.a., present the constructs of communities of practice and trajectories of participation from legitimate peripheral to full participation. However, since the empirical part of this thesis deals with interventions that are limited in timespan and focus on learning situations that consist of single units within a course, it is not possible to adopt a trajectories perspective or to make an in-depth study of any community of practice. Instead, the present work rests on the notions of valued activity, practices and participation and on activity systems as the unit of analysis (Greeno, 2006; Greeno, 1998; Greeno, 2011). These constructs are described and discussed below.

7.2.1 Activity, practices and participation

Activity is a focal point in learning designs underpinned by situated learning theory keeping in mind that "significant aspects of activity evolve in processes of co-construction and negotiation between participants and other systems in situations" (Greeno, 1998, p. 14). The implications of this for design is that a learning activity must provide space and time for learners, teachers and other participants to not only complete tasks but to also interact in sense-making and negotiation of meaning around the tasks posed and how to engage with these. Emphasis should be placed on the practices involved in different types of learning activities, since the learning that happens in a given situation does not only relate to a given subject content; the tasks and steps the learner must complete also teaches something. E.g., learners taking a multiple-choice test are more likely to learn the skill of taking such a test than the actual content being tested. This gives primacy in the design process based on a situative perspective to the development of valued types of activity that support equally valued modes of participation (Greeno, 1998).

7.2.2 Activity systems as focus of analysis

Greeno emphasises that the focus of analysis in the situative perspective is activity systems consisting of "behaving cognitive agents interacting with each other and with other subsystems in the environment" (Greeno, 1998, p. 5). As such this corresponds to *interventions* as the unit of analysis (cf. section 6.2). Activity systems are "complex social organizations containing learners, teachers, curriculum materials, software tools, and the physical environment" (Greeno, 2006, p. 79). From a situative perspective, it is thus of interest to study the construction of meaning and understanding, interactions between learners, learners and teachers, and learners' interaction with the material resources that are available in the environment.

According to Greeno (2006) and from a situative perspective, it is particularly interesting to examine the principles of coordination of such activity systems. Coordination or alignment, both of understanding and action, is important for the successful interaction between the components in an activity system; activity is negotiated and actively constructed by participants. Eventually, participants' continued efforts to coordinate and secure alignment will lead to shared social practices within the subject in question. These social practices include conventions that solve the coordination problem (Rescorla, 2007) and include appropriate ways of communicating, of working on tasks and constructing material representations, and of interacting with technologies and tools etc. (Greeno, 2006).

For example, a class of HE Philosophy students or HE Media Studies students will build shared social practices as they, guided by their teachers, communicate about and engage with tasks, technologies and tools during their studies. This will result in social conventions – a tacit agreement (Rescorla, 2007) regarding what constitutes appropriate ways and means of doing Philosophy or Media Studies. Effective participation in class involves being attuned to these conventions and practices (Greeno, 2006).

As conventions come to exist in a community, preferences for and expectations that members of this group conform to the conventions arise, and there is a tendency for these to become norms (Rescorla, 2007, referring to Lewis, 1969). Such norms might result in bias, in a lack of recognition of and an unwillingness to adopt novel practices in the classroom. This, of course, poses challenges for the introduction of CT with computational things.

7.2.3 Implications for design

In the design of tasks for students' situated learning with CT using computational things, it is important to first identify what constitutes valued activity and useful practices in the context in question and then attempt to design for students' engagement in these, creating authentic tasks. The valued activity and useful practices in the subjects participating in this study can be deduced from the pedagogical challenges related by the teachers, cf. chapter 3, namely:

- Showing understanding of and applying the key concepts of the subject in dialogue and discussions with peers and teacher.
- Independently generating viable ideas, i.e., ideas of theoretical and/or empirical interest within the scope of the subject.
- Sharing and discussing ideas, giving, receiving and incorporating constructive feedback from peers.

Furthermore, designs must support students in negotiating and constructing meaning and understanding, in interacting with fellow students and with teachers and in interacting with material resources that enable effective engagement in activity and practices. On the matter of attunement to the conventions of the subject in question, there might be tensions since interventions by nature will involve the introduction of new methods (Papert, 1980). As a way to resolve this tension, it should be explored how the new methods can be introduced in a way that is seen to enable the accomplishment of significant tasks in the subject, and how present conventions can be extended to accommodate the new methods and tools.

7.3 Foregrounding materiality

Situated learning perspectives acknowledge that both social and material factors influence learning; but things and materiality are often neglected in accounts (Fenwick, 2015; Sørensen, 2009). However, since this study investigates how tangible, computational things can be integrated in humanistic subjects in HE, it is important to investigate the roles that things and materiality can come to play in educational practices. Therefore, a discussion of materiality will follow below with inspiration derived from Dourish (2017).

Researchers of materiality have a common interest in examining the impact of the material on society and vice versa. However, there are many research foci and approaches to such studies. In our current networked society, according to Dourish (2017, p. 4), the study of materiality can be approached from an anthropological position, e.g., examining the *material culture of digital goods*, i.e., the significance and meanings that people attach to and the roles that digital artefacts, such as smart phones, social media and podcasts, play in their lives. Another anthropological stance examines the *transformative materiality of digital networks* to uncover how ICT (that offers, i.a., synchronous and asynchronous communication spaces) transforms our (work) lives and perception of space and time.

Materiality can also be approached from a socio-economic and political stance examining the *material conditions of information technology production* from an interest in discovering how such production impacts economy, labour and environment. From a linguistic position, the *consequential materiality of information metaphors* can be investigated to gain insight into the impact of ICT metaphors on public discourse and our perception of cultural conditions, such as, e.g., the population being divided in an A and a B team in the digital transition.

Dourish (2017) represents a fifth position that he labels the *materialities of information representation*. Referring to the design of hardware and software and drawing parallels to the creative production of potters and carvers working with clay and stone, Dourish (2017) defines materiality "as the nature of the substrates and the properties that constrain and condition the designerly encounter" (p. 5). This definition emphasises the material and the way it enables or objects to the shaping and giving form that is the purpose of a design process. Design is here viewed as "a reflective conversation with materials" (Dourish, 2017, p. 5. Referring to Schön (1990)).

Without distinguishing between the digital and non-digital, Dourish (2017) more specifically defines the materialities of information as "those properties of representations and formats that constrain, enable, limit, and shape the ways in which those representations can be created, transmitted, stored, manipulated, and put to use – properties like their heft, size, fragility, and transparency" (p. 6). The concern here is that of the specific material forms in which data are represented. Whether these forms are analogue, digital or hybrids between the two, and how these forms of data representation impact interpretation and our perception of possibilities for action.

This thesis adopts Dourish's (2017) understanding of materiality as forms of data representation and the action and interaction possibilities afforded by different representation formats. This theoretical lens aligns with the present study's focus on the impact of tangible, computational things in learning situations.

By foregrounding the things and materials involved in learning, this thesis takes a material turn (Dourish, 2017) putting the focus on objects and object properties and how objects participate in and frame learning situations as enablers or constrainers (Hodder, 2012). There are different views concerning how to understand the notion of properties (see e.g. Ingold, 2007); however, rather than engaging in this discussion, this thesis adopts a pragmatic view and the term properties is used to refer to what matters, i.e., what makes a difference in practice, leaving open the question of whether properties are inherent.

Returning to computational things, we find that these can constitute physical and tangible, technological objects in the case of CT unplugged using analogue artefacts. Or they can combine the physical and the digital, the tangible and the intangible, in CT activities employing robots, virtual reality glasses or similar digital artefacts. There will thus be an abundance of materials and properties to consider when making design choices in the planning of CT activities.

In the case of physical materials, "tactile, tangible, and embodied skills [are] activated in the encounter with these objects, but they also evoke different ideas, memories, and forms of reflection and engagement" (Dourish, 2017, p. 35). This means that students' prior experiences with things are brought into the learning situation and impacts practices, activity and participation in perhaps very unpredictable ways.

Below, the notion of things seen from an embodied cognition and learning perspective will be explored to elucidate the nature and role of things in learning situations.

7.4 Cognition and learning with tangible, computational things

Being analogue and physical learning materials, the paper-based, computational things developed in this study can be characterised as *manipulatives* (Manches & O'Malley, 2012). Manipulatives have a set of characteristics that make them useful for embodied cognition and learning: 1) they are external representations of abstract concepts, 2) they constitute tangible resources in the environment that students can interact with and thus the computational things allow for bodily active, i.e., physical learning and 3) they make possible interactive, embedded, and embodied problem-solving.

Below, each of these three characteristics will be explored theoretically and following that implications for design will be elucidated. First, the notion of external representations of abstract concepts will be explored.

7.4.1 External representations of abstract concepts

External representations play a crucial role in situated learning in relation to, i.a., coordination and alignment. They should not be seen as ends in themselves, but as tools that can be used to construct and share understanding (Greeno & Hall, 1997). In Philosophy studies, e.g., arguments are a vital form of representation that students must master and come to appreciate, as are graphical and visual representations, such as 3D models, in engineering, and algorithms in computer science.

In Philosophy, the creation and assessment of arguments constitute valued activity and practices since arguments provide the means for expressing, sharing, debating and assessing philosophical ideas and concepts. These are given an external form, either as speech or text, which allows peers to question, critique and/or further develop the presented ideas. Forms of representation are thus essential for engaging in valued social practices and activity and for competent participation.

In this thesis, external representations are defined as "'symbolic elements', external to the brain and body, that stand in for the actual entities and phenomena of study" (Pande, 2021, p. 464). External representations contain knowledge within a specific domain; knowledge that is embedded in a certain physical configuration, e.g., sentential, or diagrammatic (Larkin & Simon, 1987) that imposes structure as well as external rules, constraints or relations onto the knowledge represented (Zhang, 1997). However, a physical notation does not in itself constitute a representation but is merely a potential representation until it is interpreted and given meaning by a person (Greeno & Hall, 1997).

In the above examples, verbal or written arguments represent philosophical ideas in a sentential form, 3D models (computer-based or physical prototypes) represent buildings and other physical structures in a diagrammatic form, and algorithms represent procedures for executing tasks. The latter can be represented in both sentential and diagrammatic (flow chart) form.

Representations and materiality

External representations allow us to "install some aspects of our thinking in stable, reproducible, manipulable, and transportable physical form. These external forms become in a very real sense part of our thinking, remembering, and communicating" (diSessa, 2001, p. 6). The notion of external representations thus involves giving material form to abstract concepts and using such material representations to support cognition and learning.

According to diSessa (2001), external representations constitute the material pillar of literacy and can be materialised in different ways through different technologies, analogue as well as digital. The materiality or forms of representation are important since they determine "what can be expressed [in terms of content, objects and relations] and how much room for interpretation is left" (van Bruggen et al., 2002, p. 121). Furthermore, the materiality of representations makes possible certain actions and constrain others (cf. section 7.3 above), thus impacting the mode of learner interaction and task execution.

The functions of external representations

Greeno and Hall (1997) make the very important point, that representations are not only *of* something in a domain, i.e., inscription devices for encoding information, they are also *for* something. External representations, e.g., can constitute "thinking and learning devices" (Pande & Chandrasekharan, 2017, p. 31) that potentially fulfil a number of different functions. The following is a synthesis of relevant functions discussed in Greeno and Hall (1997), Zhang (1997), van Bruggen et al. (2002), Kirsh (2010), and Pande (2021).

There is general agreement that external representations can augment cognitive activity and that the role of external representations as *memory aids* for cognitive offloading is only a minor benefit. Among more important benefits is the offloading, or rather distribution (cf. discussion below), of *processing* in which a representation provides the learner with a novel type of operator or tool for the processing of information. The representation makes information explicit, e.g., as text, numbers, visual illustrations etc., and thus materially available for reordering, rearrangement, processing or computation, i.e. for interactive cognition in Kirsh's (2010) terms.

External representations can also provide anchors that structure cognitive activity via visual hints and/or rules embedded in the physical configuration, i.e., the materialities of the representation. Such rules enable certain actions and processes while constraining others. This means that the material form of a representation and the action possibilities offered by it and perceived by the learner impact and change the cognitive task at hand since the processing can now be distributed across the learner and the representation (van Bruggen et al., 2002; Zhang, 1997). From this perspective "tasks with and without external representations are completely different tasks from a task performer' point of view, even if the abstract structures of the tasks are the same" (Zhang, 1997, p. 183).

According to Greeno and Hall (1997), external representations that match the problem-solving process at hand can provide a model for students' thinking as they work through the problem. Furthermore, external representations are especially useful where complex problems or structures are concerned because they provide material support.

The material aspect should be highlighted, since through their physical configuration, external representations can make present and tangible, abstract ideas, objects, and activities giving these a material form as "persistent referents" and "shareable objects of thought" (Kirsh, 2010). This further allows learners, as they work with and perhaps annotate the representation, to keep track of ideas, organise their continued work, and discover new perspectives that, e.g., visual forms of representations can help uncover. In addition, such persistent referents create the basis for not only sharing thoughts but also discussing and further developing these.

Kirsh (2010) concludes that the many functions of external representations "allow people to think more powerfully with external representations than without. They allow us to think the previously unthinkable" (2010, p. 441). Because they provide access to new, external operators, they make possible the encoding of complex structures: "external mechanisms allow us to bootstrap to new ideas and new ways of manipulating ideas", or they make it possible to "run a process with greater precision, faster, and longer outside than inside—you can harness the world to simulate processes that you cannot simulate internally or cannot simulate as well" (p. 442).

Exploring abstract concepts and generating ideas with external representations

The idea generation tools developed in this study constitute external representations of abstract concepts. Each tool physically represents, in the mode of concentric paper circles, the different categories of components needed to generate a viable idea, a research question or a problem formulation, within the subject in question, see example in Figure 7-1 below. Each circle further materialises the valid and important instances of concepts within the category in question. The tool thus represents a decomposed version of the abstract concept of a good idea within its domain. This situates each idea generation tool in the humanistic subject in question, as a representation *of* that domain, and makes it relevant for students and teachers in connection with the generation of ideas for exam papers and projects.

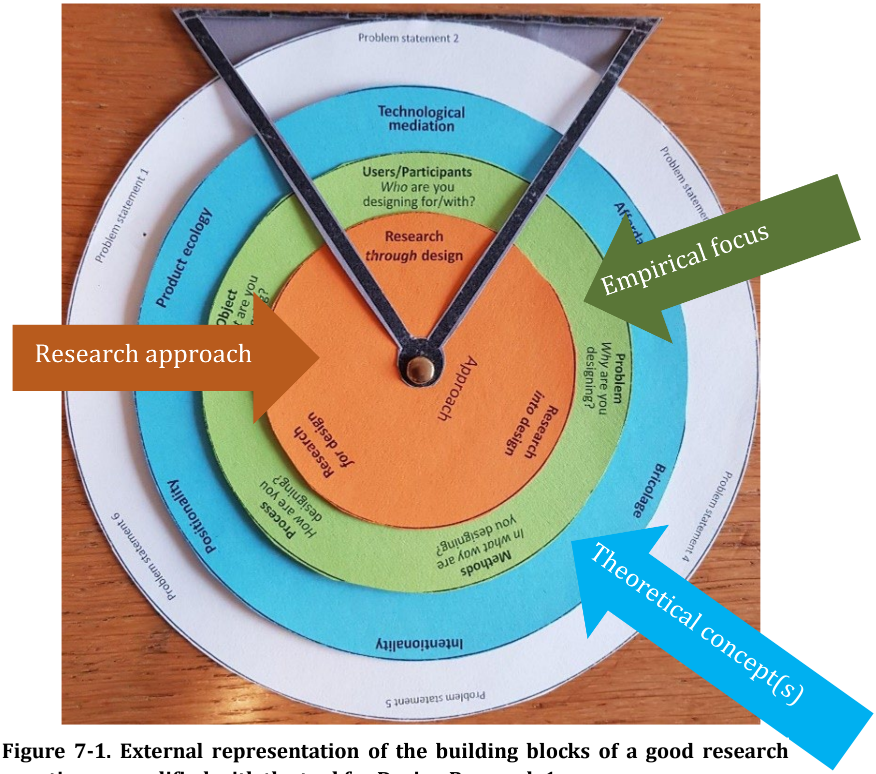


Figure 7-1. External representation of the building blocks of a good research question exemplified with the tool for Design Research 1

Greeno and Hall (1997) divide external representations into standard and nonstandard types. The form of representation used for the idea generation tool is hybrid in that a more conventional and standard representation, a 2D diagram in the Media Studies case and sentential representations in the other two cases, has been transformed into a nonstandard, 3D cardboard model.

This model allows the learner to manipulate each circle independently of the others to align a concept from each circle within the marker triangle, as in Figure 7-1 above, then investigate the combination derived at to assess its possibilities. Furthermore, the learner can annotate each circle and insert text into a circle that is dedicated to user input in the form of cases or problems of interest. These can then be combined with abstract concepts, theoretical perspectives, from the other circles to elucidate and uncover interesting ideas that might form the basis for research questions.

As the title suggests, the idea generation tool was to provide students with an external resource that 1) could function as a persistent referent to the building blocks of the good idea and 2) would allow students to engage in the tangible manipulation of these building blocks to 3) systematically, mechanically and independently generate, investigate and assess possible ideas. The external representation is *for* idea generation. The intention was to support interactive cognition distributed across learner and external resource and the enhancement of computing power.

At the time of design and testing, the notion of the idea generation tools as shareable objects of thought and persistent referents that facilitate questioning, dialogue and discussion was not in focus. Rather, it was the tangible and computational aspects that were at the forefront. However, the data analysis reveals that external representations in the form of subject-specific idea generation tools are powerful conversation starters (cf. chapter 3).

Above, the intentions embedded in the computational things developed in this study were outlined. However, for these to be realised in a learning situation, the learner must perceive the value and the usefulness of the external representations, both content and form – the *of* and the *for* - and must be attuned to these as appropriate for the task at hand and the subject in question.

The materialities of information representation was highlighted above as an essential aspect that impacts, i.a., transparency, interpretation, function, perceived action possibilities and use. Below, the physical aspect of manipulatives will be explored.

7.4.2 Physical manipulation and tangible investigation

A defining feature of a manipulative is that it allows "some degree of bodily interaction of the learner with the environment, if not, it ceases to be a manipulative" (Pouw et al., 2014, p. 67). Thinking and learning with manipulatives therefore always involves sensorimotor activity in the form of manual movements performed by the learner in interaction with the external resource. A well-known manipulative is the centicube for mathematics learning (Cheeseman et al., 2014). Centicubes are used to enhance children's numeracy in that they make possible children's physical manipulation of numbers and their tangible investigation of different arithmetic operations.

Manipulatives can be understood as a class of external representations that are physically manipulable and rearrangeable. They thus differ from, e.g., 2D models in textbooks or a table, since this type of representation, albeit being external, cannot be physically manipulated and rearranged. Note that the above account describes the traditional understanding of manipulatives. A new generation of manipulatives, digital manipulatives in the form of computer programs that allow learners to simulate and investigate dynamic and complex systems (Resnick et al., 1998) have been gaining ground for the past couple of decades.

Today, manipulatives are common in kindergarten and elementary education (Resnick et al., 1998) which are also the settings for which they were originally developed. The idea behind manipulatives is to provide physical materials for hands-on-learning that support children's cognitive development. The physical materials contribute concrete and bodily experiences that children can relate to and construct new knowledge from, postponing the meeting with dissociated abstractions (cf. section 7.1 on the legacy of Papert above), i.e., concrete operations first and then formal operations later (Piaget, 2003). The vision of the originators of the concept of manipulatives (i.a., Friedrich Froebel and Maria Montessori) was to support children's playful inquiry and personal exploration through the senses. For an elaboration of the origins of manipulatives, see Resnick et al. (1998) and Manches and O'Malley (2012).

Thus, manipulatives are perceived as standard types of representation in kindergarten and elementary education. This might pose a challenge to the introduction of manipulatives in the humanities in HE where they will more likely be perceived as nonstandard forms. HE is focused on building abstractions (Ashby & Exter, 2019), and the use of manipulatives could be seen as a return to the concrete operations associated with young children. This makes it even more important to firmly situate an analogue, tangible, computational thing in the humanistic subject in question and connect it to valued activity and practices. At the same time, when designing such a manipulative, it should be ensured that it adds new possibilities for action that supports cognition and learning (Pouw et al., 2014).

The idea generation tool developed in this study allows students to use their hands to rotate the circles and align the concepts represented on these. The tool affords (cf. discussion below) manipulation of physical representations of abstract concepts and the tangible and mechanical investigation of possible combinations of these; something that would be difficult to do systematically without the tool. The hope was that the physical configuration of the idea generation tool would provide a useful and unconventional way for students to engage their sensorimotor skills to gain familiarity with the abstract concepts of their subject.

Above, the notion of external representations as well as the idea of physical manipulation and tangible investigation of abstract concepts were theorised and discussed to arrive at a characteristic of the computational things developed in this study. Below, we zoom out and explore theoretical perspectives that can shed light on the embodied phenomena made possible through the use of tangible, computational things.

7.4.3 Interactive, embedded and embodied cognition

In the introductory chapter of the Oxford Handbook of 4E COGNITION, Newen, Gallagher, et al. (2018) present a framework that encompasses the concepts of embodied, embedded, extended, and enacted cognition, together also labelled *embodied approaches*. This framework promotes the idea that cognition is not confined to the head, but also involves body and environment. A brief introduction to the four Es is provided by Abrahmson and Mechsner (2022) who interpret the framework in the following way: The mind is

> Embodied: The body is vital for cognition. Embedded: The "thinking body" is inextricably situated in an environment. Extended: Processes and tool-enabled manipulations outside the body (such as writing or knitting) are part of cognition. Enactive: The living and thinking person produces itself (i.e., its biological and psychological identity) in an adaptive way, of which cognition is an aspect. (Abrahamson & Mechsner, 2022, p. 1815)

According to Abrahamson and Mechsner (2022), the learning of abstract concepts should be embodied and take as the point of departure physical activity to "instantiate—and thus seed—the concepts to be learned" (p. 1836). Physical activity is thus seen as an integrated part of working with and learning abstract concepts which supports the ideas presented in this thesis. The focus here is students' use of a tangible, external resource as they work with abstract concepts. This brings into play the embodied, embedded and extended approaches described above, which will subsequently be explored in more detail. However, to connect back to the situated view of cognition and learning, the term interactive, instead of extended, cognition will be used (cf. discussion below).

Extended or interactive cognition

Clark and Chalmers (1998) argue that human beings have always used both their body and resources in the external environment to not only aid but extend cognition. In this sense, cognition is more than an internal process; it is distributed across the human being and the external resource employed. According to Chalmers (2008), the smartphone is an example of an external resource that has coupled with our brain and body and become part of our cognitive system thus extending our cognition. E.g., a smartphone can take over central functions of the brain, such as storing phone numbers and addresses.

Clark and Chalmers (1998) represent the point of view that cognition is extended. Seen from this perspective, the role that computational things can play in HE students' cognitive work, would be that of, e.g., memory or storage devices for concepts of relevance. This view, however, emphasises affordances such as offloading memory and cognition and seems to give weight to the individual and the physical environment and disregard the social context or setting.

In the notion of extended cognition, there seems to be an inherent view of cognition as the storage, retrieval and processing of information, i.e., a cognitivist view of learning, albeit extended from internal processes to also include external resources in the environment. Consequently, the extended approach does not translate well to situated CT activities with computational things. Kopcha et al. (2020), in contrast, point to the learner's continued perception of and interaction with the environment as central to embodied cognition which they see as an

> ongoing, emergent 'back-and-forth' dynamic between person and environment as one interacts with different objects and people in the world. This notion sets embodied cognition apart from information processing in that cognition is based on our ongoing, bodily perception of the world (i.e., brain and body) rather than the way we store, process, and retrieve information. (Kopcha et al., 2020, p. 3)

This is in line with Kirsh (2010) who argues that thinking and sense making is interactive and explains this interaction as a "back and forth process: a person alters the outside world, the changed world alters the person, and the dynamic continues". Likewise, Pande (2021) emphasises the importance of interaction and states that cognition depends on "one's body, material (and sociocultural) elements in one's surroundings, and body-based sensorimotor interactions one has with those elements" (p. 464).

In this thesis, Kirsh's (2010) notion of *interactive cognition* is adopted to shift the focus of design and analysis from cognitive offloading, which albeit might constitute a starting point, to sensorimotor interaction with external resources in the environment. In addition, the notion of *embedded* cognition (Pouw et al., 2014) is adopted to emphasise that the perceptual and interactive richness of manipulatives can potentially solicit sensorimotor actions on the part of learners that engage and embed their cognitive activity in the external environment.

The terms *interactive* and *embedded* are used in this thesis to pinpoint the embodied approaches at play, namely the learner's continued physical and sensorimotor interaction with external resources in the environment and thus the embeddedness of the learner, as well as her cognitive activity in this environment. Through their physical, sensorimotor interaction with and embeddedness in the environment, students think about, make sense of and attempt to solve the task at hand.

There is further the potential that students' bodily and sensorimotor experiences from using manipulatives in their cognitive work can support subsequent *embodied* cognition. Embodied cognition is realised when/if students internalise, or embody, their physical and sensorimotor experiences from first using the tool, and then in subsequent stages of the task rely on this embodied experience in their cognitive work, rather than actually manipulating the tangible tool again (Pouw et al., 2014). Thus, the embodied approach suggested for design and analysis, is that of *interactive, embedded and embodied problem-solving*.

An important question that remains unanswered is: what drives the realisation of tangible, computational things as tools for cognitive work? This is, i.a., a question of perceived affordances, a concept that will be elaborated below.

Tangible, computational things and affordances

Newen, Gallagher, et al. (2018) sees cognition as affordance-based in a relational and ecological way as in Gibson's (2014) account of the concept; the cognising human agent exploiting the possibilities offered to it by its physical environment, understood as physical artefacts, other people, social or cultural structure and even abstract concepts, the affordances of which are viewed in relation to the current cognitive task or problem faced by the human agent.

Thus, In Gibson's (2014) understanding, an affordance is a possibility for action that is offered by the environment and realised by person or animal to solve an experienced cognitive task or problem. This suggests that the affordance is there in a latent form waiting to be activated by somebody realising the potential. But it also suggests that affordances can only be exploited when perceived. From this follows that a student will not be able to make use of a tangible, computational thing if she does not perceive it as a tool that affords support for the cognitive task at hand. In Naur's (1965) words "TOOLS only exist as such in so far as some people think of them as the proper things with which to solve some problems" (p. 196).

Implications for design follow below.

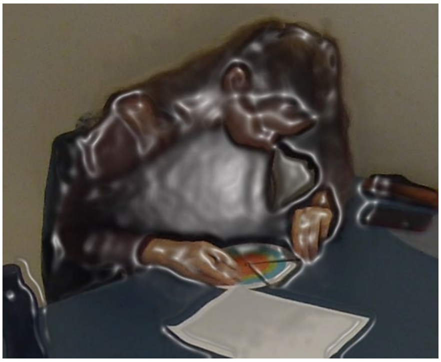
7.4.4 Implications for design

When developing CT activities for students' interactive, embedded and embodied cognition and learning, the design challenge is how to "select, create, and facilitate physical interactions that give rise to conceptual reasoning and thinking that is aligned with desired educational learning outcomes" (Abrahamson & Lindgren, 2014, p. 362). Alignment between the physical configuration of an artefact, the types of interaction it affords and solicits, and intended learning outcomes is thus central in design.

Design considerations concerning physical configuration must be brought together with the abstract concepts to be investigated by students. In this way, integrated forms of embodiment can be created, where the embodiment is part of the task and constitute steps necessary for completing the activity and working towards the intended learning outcomes. This involves adopting a task-oriented view in Skulmowski and Rey's (2018) terms.

Finally, physical designs that tap into valued activity and practices are important to guide students as to helpful ways of interacting with fellow students, the teacher, and things in the learning situation. This will help realise the potentials of situated, interactive, embedded and embodied cognition and learning.

Chapter 10 discusses the iterative process involved in creating the theoretical framework presented above, visualises the framework, and shares the initial and refined design principles derived from it. Chapter 8 below shares the details of the empirical work undertaken in this study, including details on the analysis method employed.


8 Empirical work and data analysis

This chapter elaborates on the analysis method briefly described in chapter 3 where the findings from iteration 1 were also presented. In addition, findings from iteration 2 are reported.

8.1 Thematic analysis using a hybrid approach

A detailed account of the approach chosen for the thematic analysis is provided below to make transparent the process from codes to themes and illustrate how the themes arrived at are grounded in the data. A six-phase approach (Braun & Clarke, 2006, 2012) was used to perform the thematic analysis:

1. Familiarising myself with the data
2. Generating initial codes
3. Searching for themes
4. Reviewing potential themes
5. Defining and naming themes
6. Producing the report

Since several of the data collection methods involved my interaction with the empirical context being studied, such as participant observations and semi-structured interviews, I got an early start with regards to familiarising myself with the data (Nowell et al., 2017; Xu & Zammit, 2020). This process continued as I prepared the data for analysis. Having familiarised myself with the data, I generated initial codes using first a deductive, theoretically driven approach and then an open, inductive one. Both approaches were framed by the aim of the thesis, the overall research questions, and the additional research questions for the empirical work. Thus, I approached the data with the intention of unpacking:

- Students' creative problem-solving using CT with computational things
- CT and students' professional development
    - The relevance and usefulness of CT with computational things to students and teachers in the humanities, including situated and embodied perspectives on cognition and learning
- Computational thinking in relation to students' investigation of abstract concepts from their humanistic subject
- Computational things in relation to students' independent idea generation
- Algorithmic processing – engaging with algorithms
- Automation/mechanisation of idea generation

With my research focus and the unit of analysis (cf. section 6.2) as point of departure, I created higher order codes (Nowell et al., 2017), such as, e.g., problem-solving, role of tool in the different phases of an intervention, and algorithmic processing. In the light of the additional research questions, problem-solving was interpreted as understanding abstract concepts and generating ideas.

Furthermore, where relevant to capture nuances and to ground the thematic analysis in the data, I created lower order codes (Nowell et al., 2017), or sub codes, using in vivo coding, i.e., codes created on the basis of the language used by participants (Xu & Zammit, 2020). See appendix 14.8 that also illustrates how some of the higher order codes were renamed as my understanding of the data grew. E.g., students mentioned how the tool helped them consider alternative angles or combinations, thus supporting divergent thinking. In addition, students explained how sparring with peers helped delimit ideas, thus supporting convergent thinking. This led me to rename the code "idea generation" into "converging and diverging".

Open coding was used to uncover unanticipated phenomena of relevance for my research and give voice to students' experiences and views. During my participant and video observations, e.g., I had noted cases of, what I then called, non-use of the computational tool and had also noted that something seemed to spark a very lively conversation between students during interventions. In the open coding, I therefore approached the data with the intention of investigating and gaining an understanding of these phenomena. In the open coding, I first undertook in vivo coding to establish a nuanced understanding, and then later, where relevant, collapsed the codes into higher order codes to get an overview of the type of phenomena concerned.

The result of phases 3 – 5 of the thematic analysis (searching for themes, reviewing potential themes and defining and naming themes) is shown in Table 14.6 in appendix 14.8. A theme is here understood as "an abstract entity that brings meaning and identity to a recurrent experience and its variant manifestations. As such, a theme captures and unifies the nature or basis of the experience into a meaningful whole" (DeSantis & Ugarriza, 2000, p. 362).

The codes created in the deductive coding process were clustered in 4 themes (themes 1 to 4 in Table 14.6) that each unpacks an aspect of the theoretical lenses applied in this study. In addition, two themes were created on the basis of the inductive coding process, namely *A conversation tool* and *Rejection of tangible tools in HE* (themes 5 and 6 in Table 14.6). Except for theme 6. Rejection of tangible tools in HE, the themes are thick themes, i.e., there is enough data to support them (Braun & Clarke, 2012). Theme 6 is represented in all cases, cases 1-3, however it is based on only a few students' experiences and thus is not as richly supported as the other five themes. Hence it is a thin theme (Braun &

Clarke, 2012). None the less, it is included as a theme because it refutes the idea that tangible, computational tools support students' situated and embodied learning and poses a challenge to the successful introduction of such tools in humanistic subjects in HE. Themes 1 to 6 are reviewed in section 8.2.1.

A code book was created on the basis of the codes arrived at in iteration 1, see Table 14.7 in appendix 14.9. This codebook was used for the thematic analysis of data collected in case 3 and in the second iteration in cases 1 and 2. The codes derived from the open coding in iteration 1 were included in the code book to discover whether these phenomena were general or case/context specific. In addition, open coding was performed to uncover any unanticipated experiences and perceptions as in iteration 1.

8.1.1 Reflections on thematic coding

A weakness identified connects to the practice of using in vivo codes to, i.a., demonstrate how the analysis and themes arrived at are anchored in the actual data collected. When I used the codes created in the analysis of data from iteration 1 in the analysis of data collected in iteration 2, a clash occurred with regard to the actual word usage of participants. This challenge can in part be overcome by using higher order codes and creating new subcodes below these that reflect the word usage of participants from the iteration in question. Codes in a codebook for subsequent iterations must be sufficiently abstracted from in vivo codes to be useful.

Another challenge is the translation of responses from Danish into English. E.g., several Danish students explain how the tool "styrer" their ide generation. "Styre" can be translated into English as "direct" or "control", each word bringing with it certain associations. In this particular case, I chose "direct" since I found this to be most in accord with the overall gist of the responses.

8.2 Testing refined interventions: Results of iteration 2

In autumn 2021, the tool was adapted for and tested with students in Design research 1 at ITPD (case 3). Details of this re-design process can be found in appendix 14.10. Based on data collection and analysis, the Media Studies and Philosophy interventions were adapted and refined before iteration 2 that took place in spring 2022. Furthermore, the idea generation tool for Philosophy was now prototyped and made available as a tangible, physical model. Changed framework conditions meant that the timing and duration of interventions had to be adjusted both at Media Studies and Philosophy, see appendices 14.12.2 and 14.13.2 for details.

Below follows a presentation and discussion of the findings from the analysis of the collected data.

8.2.1 Iteration 2: themes revisited

The data collected in case 3 and in iteration 2 at Philosophy and Media Studies were analysed as describe above. Subsequently, the original six themes presented in chapter 3 and in Table 14.6 on p. 269 were revisited to capture the more nuanced understandings that the further testing and evaluation of the tool and activity had brought about. The results are presented case by case, including quotes from participants, in appendices 14.11.2, 14.12.3 and 14.13.3. Below follows a cross case analysis that provides an overview regarding how themes unfolded. All the six original themes were found to be present in each intervention but to varying degrees with theme presence fluctuating from case to case. The presentation of findings below focuses on new phenomena discovered that shed light on the six themes.

Theme 1. Problem-solving: what is the problem?

Theme 1 captures students' accounts of the problem in focus and the solution the tool is perceived to provide if any. The analysis of data from iteration 1 found that students experienced other problems in addition to that of generating ideas, and this aspect was also present in case 3 and in iteration 2 at Media Studies and Philosophy. Most notably, the tool itself became the problem in focus in case 3 with some students struggling to figure out what the concepts on it meant and how to use the tool. In these cases, the tool obstructed rather than enabled students' cognitive work. This was also reflected in iteration 2 at Philosophy where the wheel became a joint problem to solve:

> Overall, I think that it was very educational to discuss with my fellow students, and the wheel seemed ok in relation to giving us a joint problem to solve. (Reflections Philsophy2 student 3)

In addition, some students at Philosophy seemed to perceive the completion of the circles as a goal in itself and highlighted the importance of having a finished tool. Here the algorithmic process of data generation is in focus as an imperative step in the process of generating ideas. Thus, there is an overlap with theme 2 below:

> So, my wheel is not.. It is almost. Like, lack two topics, I think, and then it will be completely filled out. But actually, it made me feel that I was sitting with a fairly completed tool. Really, I could imagine that there were others who have been sitting, and then there have been fairly many holes, or perhaps it has looked half-

> finished, and that in itself is not sufficient. But, it also makes the further work with it harder. Towards the end, in any case. So yes, I also think, it was good or lucky that I were together with two others with whom I had established a reasonable rapport where that was concerned, like. So, we got something written down and talked about it. And we got something more written down, so it looked fairly finished in the end […] It becomes very clear that the less or more you put into the tool, the more or less ehm you get out. Or will it be possible for you to generate, I think. (Interview with Philosophy2 student 1)

Theme 2. Algorithmic processing: computing with concepts

Theme 2 outlines students' engagement with algorithmic processes. Students intuitively and systematically investigated different possible combinations in a stepwise process where each circle constitutes a step that asks students to assess data and make a decision. In case 3, one student explicitly mentions the modularised, physical configuration of the tool:

> So, it makes sense the way this, eh, circle is designed. Ehm, it's easy. So, the fact that it's modular, it makes it very easy to, eh, to play around, right? So, while you keep the same starting point, you can still change the next ones, right? So, you might decide on one thing, but then you can always […] change the other ones, right? So, it's like in the process you could solidify something, but then the other things are still modular. Ehm. So, that was very nice.
>
> (Interview with DR1 student 3)

When analysing the data, it is obvious that the learning design incorporates algorithmic processes in an implicit manner. Students use vague formulations that non-the-less point to the task of computing with concepts:

> Eh. So, for me, it was really helpful to first break down: what is a concept, what is an empirical focus, what is an approach, and then how do they interrelate with each other? And there I think for me personally, that it was very, very helpful. […] it was really helpful also not to be overwhelmed by the amount of concepts, but I could take the ones that are most interesting to me. The ones I already know … were applied during a project and I could put them […] on there and be like, okay, and now I'm focusing on that and I'm just ignoring the other ten, I know.
>
> (Interview with DR1 student 1)

The quotes above suggest that the tool and activity bring into play the algorithmic processes of abstraction, decomposition and combinatorics. In iteration 2 at Media Studies, decomposition was much in focus with some students indicating that they prefer the stepwise process enabled by the tool while others found it confusing to work from the parts towards the whole like they did in part 1 of the iteration 2 intervention. In part one, students cut out each layer of the media systems model while the teacher did a mini lecture on the layer. Only after a review of all three layers of the model, did students assemble the tool and could see the complete model (see details in appendix 14.12.2).

Theme 3. Interacting with a tangible, computational thing

Theme 3 focuses on students' experiences in relation to materiality and embodiment. The physical configuration of the tool made idea generation more tangible and concrete, which again made it possible to visualise and keep track of ideas. In the sharing of ideas and discussion phase, some students had internalised the tool. Case 3 provided further evidence of such embodiment:

> She [the teacher] made us write the problem statement. So, I did that. And then I went with that to her and explained, basically went through the steps of the tool while explaining what I'm planning on doing. So, kind of not the tool physically itself, but me explaining my idea went through the same steps as the tool. (Interview with DR1 student 1)
>
> But then in the paper I needed also to make a problem statement. So, in order to create that problem statement, I thought about the steps, eh, that we had in this tool. (Interview with DR1 student 3)

Theme 4. What is automated (made mechanical)?

Theme 4 captures students' perceptions of the distribution of tasks between themselves and the tool. The tool provided perspectives, puzzle pieces or building blocks for idea generation, and systematised the idea generation process. Students experienced that they had to formulate the ide/problem statement themselves.

The data from iteration 2 at Philosophy seem to suggest that what was mechanised or put into system via the activity and tool was data generation, idea generation, peer learning and work with the problem formulation for one's bachelor project. A student reports how the tool and activity helped him "skip a few steps" so he was "forced to perhaps not overthink things too much" but instead within a short timeframe "to get quickly going" (Interview with Philosophy2 student 1).

Another student explains that it was nice to have a guide:

> Like how can we approach this? Because it can be very abstract and broad. And how do we get it concretised? That's the impression I got from some of my fellow students that it was nice to have something to be guided by. (Interview with Philosopohy2 student 2)

This student also explains how the tool "directed his idea generation because [...] These things that we could delve into were like lined up".

Theme 5. A conversation tool: a tool for visualising, sharing and discussing ideas

Theme 5 outlines students' experiences of the tool as a foundation for thoughts and a facilitator of conversation and peer feedback. In all cases and most iterations (see exception below), this was a richly represented theme which consolidates the potential of the tool for situated and social, i.e., peer-to-peer learning. In addition, new potential uses of the tool related to peer-to-peer learning are mentioned by students. E.g., one student related how the tool could work as a teaching tool and help make what could be labelled tacit knowledge explicit (cf. the discussion in chapter 11) and present for first year students:

> I have a feeling that it would be... It would work well with younger students, maybe [...] with students who are less experienced, eh, students, academically. [...] No, but looking at that tool, I think that would have been something fantastic for early, first year students to have and bachelor's, because I remember when I was there and so many people would be struggling for even like in second year, people were struggling for like how to write this paper or what should I call it? Like I don't get how to kind of approach it [...] and... It would be hard to it, like, cause it would be some of my friends and it would be hard to explain to them at the time. Like, I couldn't quite put it into words myself, but that tool would do everything you'd need it to do for them. So, I think that would be a great teaching tool. (Interview with DR1 student 5)

The quote below provides further indications that the tool makes tacit knowledge concrete and present:

> I think it [the tool] is good, eh, but it is also because it relates so much to design research that we have had with teacher J. Ehm. And also really nice to have kind of a division into.. that.. because sometimes, you can, because design research is so theoretical that it is, sometimes you can feel that it gets kind of ehm (exhales), well a bit fluffy, or how can we say. Sometimes, it can be difficult to

> draw out: What is it, we have learned like, or what is it that we can do with it? You know, like seize on to it. Ehm. And I think the orange [circle] does that very well, really. Like, oh yes, that is actually, if you, like, were to roughly split it up, then that is actually sort of what it teaches us. Ehm. So, I think, it was actually very nice (laughs), like to get it down on paper, like, oh yes, it is in fact [down on paper] (laughs). (Interview with DR1 student 2. My translation)

In effect, the tool became an analysis tool in case 3, since students were to create problem statements that would help them investigate already completed design projects:

> The tool made it easy for me to differentiate between approach and empirical focus, which is something I struggled before this. I felt like it gave me a good tool to look back at the projects I did on a more meta-level and see what I did. (Reflections, DR1 student 1)

In iteration 2 at Media Studies, theme 5 appeared as a thin theme. Most students did acknowledge the importance of dialogue and the benefits of social and peer learning, but the tool was not broadly articulated as the foundation for this. The reason is likely that for some students, the tool worked more as a theoretical tripwire or obstacle, than an enabler. It forced them to consider and integrate theoretical perspectives. However, some students failed to acknowledge the words on the different circles as useful concepts, lacking a definition and/or explanation of the terms to be able to use them in their idea generation. In the video observations, I saw how some students came to a halt in their idea generation and abandoned the tool because they were unsure about the meaning of the concepts on it. In these cases, the tool did not function as a conversation tool and students did not enter into discussions on the abstract concepts themselves. Another reason appears to be students' preoccupation with media content.

In the data, a tension between students' preoccupation with media content and concrete cases on the one hand and theoretical perspectives on media systems on the other is visible. This confirms the teacher's statement that students have difficulties understanding the media systems perspective (see chapter 3) and in this case, also of working at that particular level. Some students, do however, remember to integrate theoretical perspectives, the tool acting as a reminder and becoming more of a mapping tool than an idea generation tool:

> D asks: But where on the disk is it (D points to his tool on the table).

> A: Where on the disk we are? […] I'm actually a bit in doubt about the orange (he has picked up the tool and turns the orange circle) […]
>
> D seems to be turning the relevant concepts on the blue and green circle inside the marker triangle: Culture and citizens actually, right?
>
> E: Yes. Culture, citizens and then the entire media system.
>
> D: And the entire media system. (Video memo MS2 part 2 group 2)
>
> So, in that way, I have used it [the tool] to visualise and then perhaps also, like, explain to myself, what direction I want to go. Sort of being able to map, okay, well, I would like to stick to this here level, delimit myself to this, right? (Interview with MS2 student 1)

In contrast, theme 5 was firmly consolidated in iteration 2 at Philosophy. Students remarked on the importance of dialogue, explained how the tool formed a joint point of departure for discussion, and also indicated how much they were inspired by fellow students and how their input brought their learning forward. The teacher and students talked about community, and "community feeling" was added as a subcode, see Table 14.11 in appendix.

> Well, I don't know if I.. I still think I have felt it more like a collective introduction to it. Like, that we have helped each other think of topics and angles […] But.. but well, I, like think it was rewarding to sit together (i fællesskab) and have the feeling that together, we found.., yes generated eh. Like because, anyway, I was personally very open towards the others' ideas. Also, because, we had sat down and said, well, now, now we try to cultivate each other's ideas and each other's themes and such. And there were also some things that were further away from my own thoughts about what to work with. But, I feel for sure it had value. So, I think I had more of a sense of community than of me having to sit and work on my own project. (Interview with Philsophy2 student 1)

Theme 6. Rejection of tangible tools for HE

Theme 6 explains how, in some cases, students did not use the tool and captures the different reasons provided: wrong timing, mismatch with subject, perceptions of or preferences in relation to learning in HE. This theme was more richly represented in case 3, i.a., because I persuaded a student who rejected the tool to let me interview him. The interview brought forth a more nuanced understanding regarding what might cause rejection of tangible tools, especially the following quote is enlightening and points to the idea that tangibles are for young children and do not belong in HE:

> Ehm. (Pause). They were, I've never done anything like that before, so it was different and I was a bit surprised, I think. When I'm going into a lecture and I'm sitting there cutting things out, it almost took me back to being in primary school, which was a bit strange. So, I think that's, maybe that was a possible reason for me, just rejecting it before I'd even tried it ehm. (Interview with DR1 student 5)

Student 5 explains that the tool felt very alien to him and calls the activity and tool a "strange method of working". He further explains how he prefers his own system and method which is not a linear process, and how he prefers to work individually to generate ideas and write papers. The tool, he says, makes something that comes natural to him, very complex.

In iteration 2 at Philosophy, a physical model of the idea generation tool was tested. This provided deeper insight into students' perceptions and experiences in relation to materiality (theme 3) with the teacher and some students referring to "handwork" and "handicraft". In addition, theme 6 was consolidated since some Philosophy students found the handwork distracting and time-consuming. These sentiments were reflected in iteration 2 at Media Studies.

It was the new part 1 that was added to the intervention in iteration 2 at Media Studies that brought into focus tangible materials and handicraft. As mentioned above, in part one, students were to cut out each layer of the media systems model as the teacher provided a mini lecture on this layer. Students were divided between two different positions in relation to the cutting out of circles. Some students found it time-consuming, distracting and unnecessary, whereas others found it fun and related how it enhanced their learning to have something that visualised the components of the model; it provided overview and focused attention. The negative comments resulted in the new code "No value at university" (see Table 14.9). The following quote illustrates the teacher's position:

> And it is not something, I normally ascribe value to: That you are to sit and cut in cardboard at a university. Quite the contrary […] Also that they [the students] thought it was fun. Like, they were laughing, and they were having fun, and you are allowed to. It is not something that we usually assign importance to. Like, it is a bit of a creative arts class [formningstime] to carry in, right (laughs).
>
> (Interview with teacher MS2. My translation)

Prerequisites for students' tool use

I observed several instances of non-use of the tool in case 3 with students not engaging with the planned subtasks, but instead discussing more general concerns related to their studies both with peers and the teacher. This was reinforced by the teacher's more fluid facilitation and adoption of topics brought forth by the students, mainly relating to the exam. Consequently, not all activities were carried out as planned. This leads me to conclude that facilitation and timing of subtasks are important for the successful use of the tool.

The changed framework conditions at Philosophy (se details in appendix 14.13.2) impacted the intervention in different ways. Both students and the teacher indicated that two hours were not enough to satisfactorily complete the activity. Also, I observed that only few students reached the subtask where they were to generate ideas. Students spent much time cutting out the circles and then helping each other fill these out with concepts. The task instructions specified to first fill out the circles and then assemble the tool. This was done to make it easier for students to write text on each circle. However, this delay in assembling the tool might have impacted students' perception of interaction possibilities:

> Student A mentions that she is thinking about what the teacher said about applying a new angle. One or other interpretation of Platon: That could be interesting.
>
> B agrees: Yes, it could. If you could find something topical today. Not necessarily topical, but a new angle.
>
> A: Yes.
>
> B: But I have difficulties believing that we can.
>
> A: Yes, and..
>
> B: Not that it is not possible. But you need to be creative to do it.
>
> My reflections:
>
> The students have not yet assembled the tool. Would they have seen the possibility to be creative and find new angles if they had assembled the tool?
>
> (Video memo Philosophy2 group 1)

Figure 8-1 below illustrates how themes come together in factors that support tool use and factors that lead to rejection of tool.

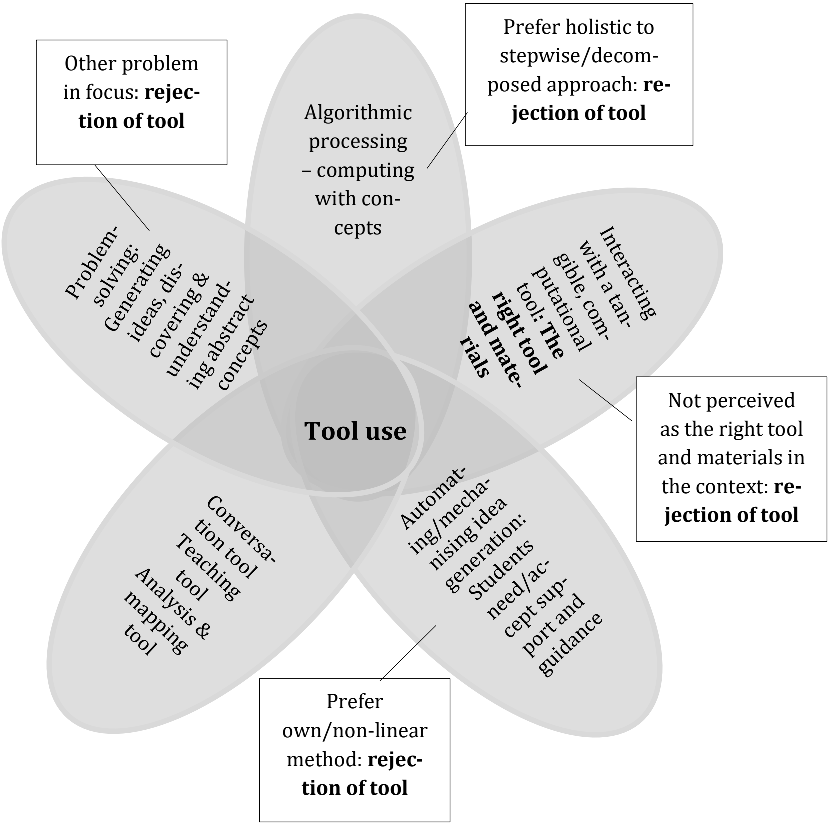


Figure 8-1. How themes come together in factors that support tool use (petals) and factors that lead to rejection of tool (boxes)

Suggested improvements

Across the cases, there were suggestions for improvements such as laminating the tool to make it more durable or adding more space for writing. Students in case 3 asked for criteria to be inserted in the tool that could help them determine: is this a concept? The teacher in case 3 and I, furthermore, discussed the idea of introducing the tool from the start (cf. section 8.3 below), perhaps even in connection with students' design projects that are the object of retrospective analysis in exam papers.

In iteration 2 at Media Studies there was the specific suggestion to make the "environment" level green because this makes sense and to then give the actors a different colour. A student also called for the possibility to document selected combinations, e.g., using pins to indicate which idea fits what concepts.

At Media studies, there were suggestions for improvements to both parts 1 and 2. There were suggestions to spend more time on each layer (both for review and for buzz meetings to find own examples and cases) in part 1 and to add a concluding sub-task in which the connections between the concepts on the circles could be reviewed and the use of the wheel for analysis could be illustrated. One student recommended to go through the circles and how they work as a whole before cutting them out.

Both the teacher and students in iteration 2 at Philosophy suggested new categories of concepts for circles (philosophers, great thinkers, periods in the history of philosophy, concepts within a selected theory) which leads me to the idea of also providing blank circles where students themselves can decide on the category of concepts. One might also consider letting the students themselves create external representations and physical configurations that suit their preferences and areas of interest.

8.3 Exploring alternative designs with students as collaboration partners

This section reports on case 4 in which ITPD students doing the Professional Apprenticeship project, Tangible Interaction for Creativity, were invited to conceive, build, and evaluate digital-physical prototypes for systematically generating and testing ideas (see project brief in appendix 14.2). Case 4 brought *designerly thinking* into the picture; here understood as the practice of professional designers and viewed as a concept embedded in the academic field of design (Johansson-Sköldberg et al., 2013).

The point of interest in case 4 was students' approach to design. How would these designers-to-be perceive and interpret the design task and what designs would they come up with? Students' evaluations of the original design and suggestions for alternatives are presented below.

In the first session, students provided detailed feedback on the design of the computational tool they had themselves tested in Design Research 1. They were guided by a set of questions provided by the lead teacher (see appendix 14.14). Students' evaluations, i.a., concerned the tangible interaction, i.e., how to turn the wheels, and what to turn: wheels, triangle, all wheels at the same time? There were also comments that one could investigate the elements and concepts on each circle while cutting it out. One student explained how the tool systematised the process of finding out what to put in a paper, and another explained how a new mix of concepts was found. In contrast, a student said the tool was hard to apply to his/her own situation, and another said that it was different to his/her way of thinking; he/she felt out of control. A third student indicated that he/she already had an idea and therefore did not use the tool.

The issue most frequently mentioned in students' evaluations was wrong timing. Students had difficulties understanding why the tool was introduced towards the end of the course; it did not become an integral part. There were suggestions to introduce it at the start of the course instead.

A final evaluation activity asked students to name one thing they would change in the tool and to consider potential new users of such a tool. The changes suggested (see full list in appendix 14.14.1) included making the tool bigger to accommodate more notes, connecting the colour of each circle to the contents of it in order to show importance/hierarchy, choosing more durable materials, adding a digital component that goes into detail with the concepts on circles, and adding a mechanism that locks a selection made and hides the rest to avoid distraction. One student suggested a universal, blank canvas to be used for any education and another suggested to make building blocks available to users so they could construct their own shapes. As such, the evaluation of the tool in case 4 reflects the findings and suggestions for improvements in cases 1 – 3.

In session 2, students shared sketches of alternative designs they had created on the basis of design constraints proposed by the lead teacher (see details in appendix 14.14.2 that also include sample sketches). Design constraints were, i.a., to design a tool that uses a micro:bit output or input, a large scale tool and a wearable tool.

The subsequent sessions were used to explore the underpinnings of and intentions behind the computational tool developed in the context of cases 1-3 and to discuss ideas for alternative designs. Students generated, presented, tested and refined ideas and prototypes and received feedback from their teacher and me as co-teacher. In addition, there was a *design crit* (peer feedback session) mid-semester where all students doing a professional apprenticeship project presented, tested, and received feedback on their work.

Students divided into two groups for the ideating and prototyping. One group took as point of departure their experiences of having to give and receive feedback during the design crits mentioned above and being tasked with the exercise of completing the sentence starters: I was troubled by.. and I was drawn to…" They had felt intimidated by this and wanted to investigate how to provide tangible support for the giving, receiving and use of peer feedback. This group designed a tangible feedback tool called Feedback on a plate (Marchetti et al., 2023), see Figure 8-2 below. The tool is modelled on a restaurant dining metaphor, and the algorithm of a restaurant visit is used to scaffold the feedback process.

Figure 8-2. Feedback on a plate

The other group chose the design problem of developing a tangible design to support people in understanding concepts related to AI. This problem was based on the group members' experience that people are often confused regarding what AI is and is not. The group developed the Input/Modelling/Output (IMO) framework which is a model for facilitating conversations on AI. The tangible support consists of 7 cardboard triangles, see Figure 8-3 below. The two orange represent input, the two green represent output, and the three blue represent modelling. In the centre of each triangle is a title, a leading question and a set of keywords as conversation prompts. The starting point for using the IMO framework is the choice of a particular AI technology, e.g., drones. The facilitator then supports participants' investigation through the questions on the cardboard triangles.

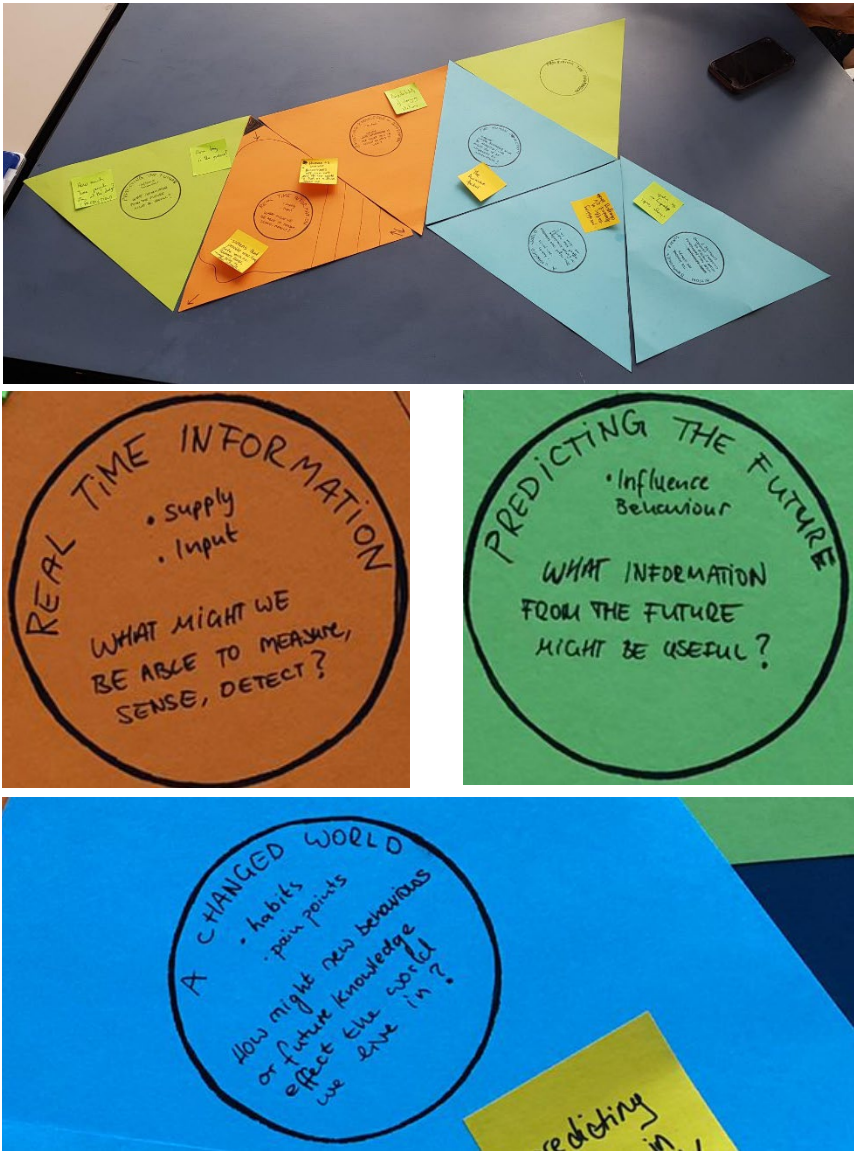


Figure 8-3. The IMO framework with tangible support for conversations on AI

The account above illustrates that students' design processes veered away from the original brief to conceive, build, and evaluate digital-physical prototypes for systematically generating and testing ideas. However, CT is embedded in students' designs, and just like the CT method, Computing with concepts using tangible, computational things, students' designs are examples of analogue CT that provides computational or algorithmic support for users' understanding of and cognitive work with abstract concepts. In addition, CT is both content and scaffold in group two's solution, and thus a case of explicit CT, whereas the CT in

Feedback on a plate is embedded implicitly as a computational or algorithm scaffold.

It has been a great source of inspiration to watch students' design process in the Professional Apprenticeship project. It has been especially valuable to experience concrete methods to sketch and prototype alternative designs before taking crucial design decisions. Such designerly thinking can help educational practitioners and researchers stay in the design process and truly explore possibilities before deciding in which direction to go. At the end of the day, practitioners are pragmatic and the time that can be set aside for a design process is limited. However, the Professional Apprenticeship project has illustrated how quickly and systematically, alternative designs can be sketched and explored when adopting designerly thinking.

9 An unplugged CT method for students in the humanities in HE

Computing with concepts using tangible, computational tools: a 21st century competency for teachers and students in the humanities

Publication 4. Author: Inger-Marie Falgren Christensen (2023a)

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.

9.1 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.

9.2 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 (2023b). 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, 2023b). 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.

9.3 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 Llull'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 Llull'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). Llull'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).

Llull 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 9-1 below. The figure is known as Llull's fourth figure and allows ternary combinations (Bonner, 2011), i.e., the selection and combination of a letter from each of 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 9-2 below.

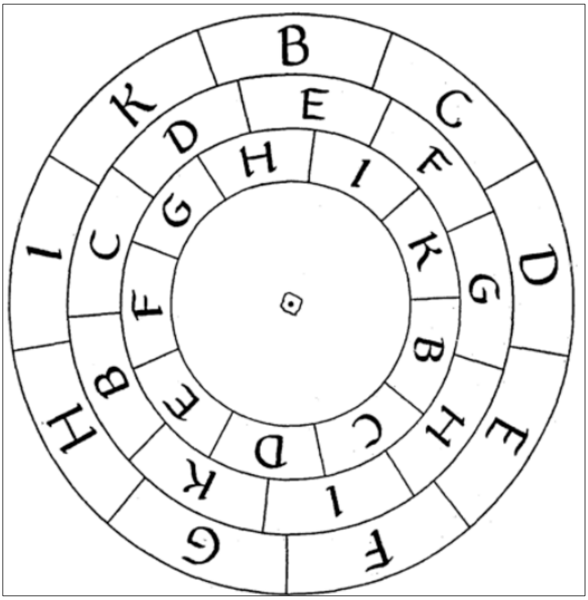


Figure 9-1. One of Llull's logical wheels (Bonet, 2011, p. 101). Reprinted with permission from the author

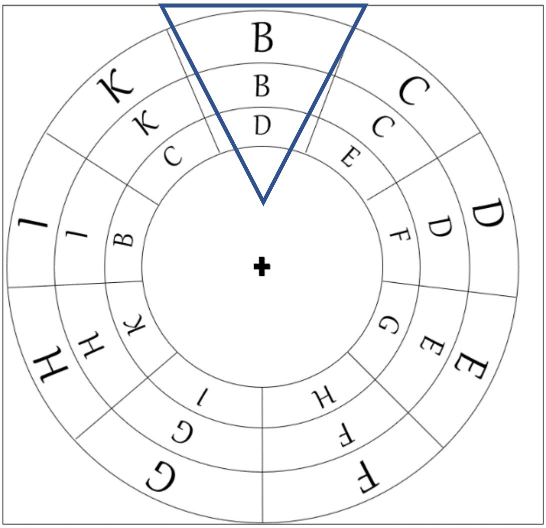


Figure 9-2. Computing with concepts by selecting a letter from each circle and aligning these. Selection marked with blue triangle above

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 Llull 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, Llull'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. Llull'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. Section 9.9 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 9-3 below that also illustrates the core model of the subject.

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.

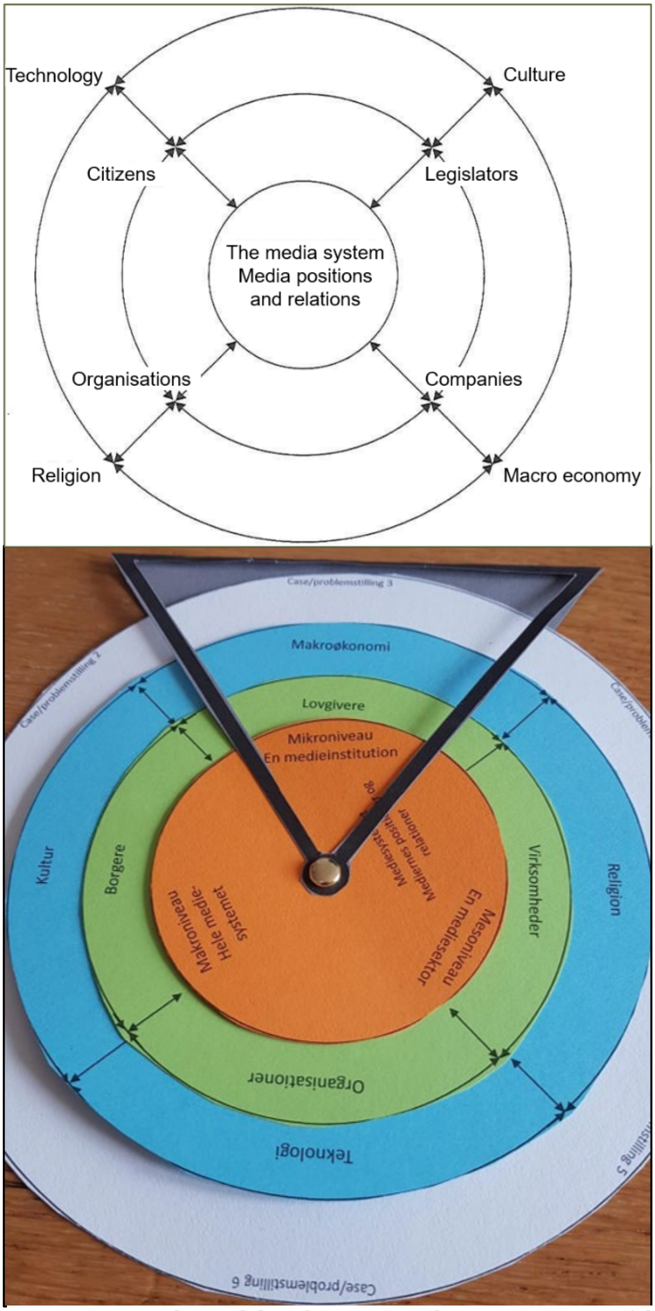


Figure 9-3. Top: the model *Media, actors and macro structures of the media system* (Vestergaard, 2007, p. 70. My translation.). Bottom: the idea generation tool for Media Studies. Both images are from Christensen (2023)

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, 2023b, p. 26)

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 9-4 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.

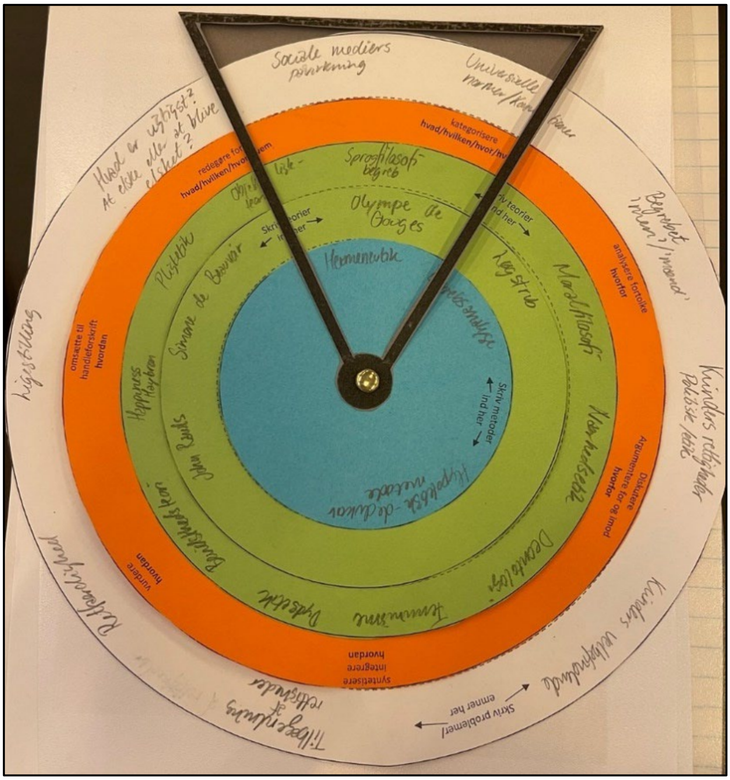


Figure 9-4. The idea generation tool for Philosophy – a student's completed version

The design pattern developed for Philosophy, see section 9.9, 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.

9.4 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 9.1 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 9.1. 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

9.5 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 9.2 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 9.2. 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.

9.6 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.

9.7 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.

9.8 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.

9.9 Appendices: Design patterns

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

<table>
<tr><th>Target group</th><th>HE Teachers and students in the field of Media Studies</th></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 9-5 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 9-5. 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 (2023b)

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

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.

Table 9.4. Design pattern for integrating computing with concepts using computational tools in Philosophy

<table>
<tr><td>Target group</td><td colspan="2">HE Teachers and students in the field of Philosophy</td></tr>
<tr><td>Context</td><td colspan="2">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 colspan="2">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="3">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.</td></tr>
<tr><td colspan="3">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.</td></tr>
<tr><td colspan="3">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)</td></tr>
<tr><td colspan="3">Step by step description of activity</td></tr>
<tr><td colspan="2">Time</td><td>Activity</td></tr>
<tr><td colspan="2">Introduction (15 minutes)</td><td>By the teacher:
Introduction to the good problem formulation
Review of exemplars explaining the individual components</td></tr>
<tr><td colspan="2">Group work (30 minutes)</td><td>Each student is given a set of materials and instructions.</td></tr>
</table>

	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

10 Design Principles for Integrating Computational Tools in Humanistic Subjects

Publication 5. Author: Inger-Marie Falgren Christensen (2024)

Abstract

This chapter presents design principles and a theoretical framework developed in a design-based research study to support the integration of computational thinking with tangible, computational tools in humanistic subjects in higher education (HE). The chapter explains the process of creating and refining design principles while simultaneously undertaking theoretical studies to underpin both design and analysis of interventions. Preliminary design principles were created based on notions of situated and embodied cognition and learning and practitioners' identification of a pedagogical challenge, namely students' difficulties understanding core concepts and generating ideas for projects and papers. A tangible, computational tool was developed and tested as a possible solution. Findings indicate that the tool has potential both for idea generation and as conversation tool, but also reveal that some students reject the idea of tangible tools in HE. This suggests that design principles can be too narrow causing blind spots in the design process and illustrates the need to refine design principles to incorporate lessons learned. The chapter concludes with a critical examination of the design process and discusses how design knowledge representations can be elaborated to communicate unanticipated potentials as well as challenges that may arise as students engage with a design.

10.1 Introduction

There is a general call for the integration of computational thinking (CT) as a 21st century competency at all educational levels (Tekdal, 2021). A common definition of CT is "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Wing, 2010, p. 1). CT is often narrowly understood as thinking like a computer scientist (Wing, 2010) and implemented as programming activities which are seen as ideal means of teaching and learning CT (Tikva & Tambouris, 2021; Voogt et al., 2015). This view often leads to CT being introduced as generic coding exercises with little or no apparent link to the content and goals of the courses or study programmes in which they are implemented, and with no connection to students' interests or experiences (Resnick, 2017).

Many efforts to spread CT are linked to the promotion of computer science and recruitment of students, but there is a growing focus on integrating CT in core curricula across subjects and educational levels because it supports students in acquiring generally applicable problem-solving skills (Kite et al., 2021) and provides computational methods that add creativity to problem-solving (Voogt et al., 2015). Liao et al. (2022) investigated how to introduce non-STEM college students to CT with the aim of improving "their critical thinking skills while encouraging a more innovative and forward-thinking mindset to discover computational solutions" (p. 3) to the problems of their particular subject. Likewise, Yadav et al. (2016) propose an integrated approach, supporting the view that CT is cross-disciplinary and "exposes students to computing ideas and principles in the context of the subject areas they are already learning" (p. 565).

However, there is a gap in the research regarding how CT can be implemented in non-STEM fields, especially in higher education (HE), and a lack of diversity in the types of technology applied (Tekdal, 2021). Research that investigates "different programming tools, technologies, and environments that contribute to the development of CT skills and bring a new breath to the field" is called for (p. 6523). There is thus a need to develop design knowledge that can guide practitioners and researchers in the development of both CT activities and technologies for non-STEM contexts. In response, this chapter describes, discusses, and reflects on the approach used in a design-based research (DBR) study to develop design principles for the integration of CT and computational tools in humanistic subjects in HE.

Students' engagement with algorithmic processes are seen as a defining feature of CT learning activities (Dohn et al., 2022), therefore the following definition of CT is employed in this chapter: "*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).

The chapter examines the following research questions:

- *How do you develop design principles for HE humanities students' situated and embodied learning and cognition with computational tools?*
- *What are the strengths and weaknesses of using a theoretical and challenge-driven approach in this context?*

Initially, the DBR-study is described in brief. Then follows an account of the process of creating and refining design principles, as well as identifying theoretical lenses to inform design and analysis of interventions. The resulting design principles and theoretical framework are presented, and the creation process is discussed. This is followed by reflections on the usefulness and reusability of the design principles and the strengths and weaknesses of the approach used. Thus, the aim of the chapter is not to report on the findings of the study, but to describe, discuss and reflect on the process of creating design principles while simultaneously constructing a theoretical framework. A detailed description of the study can be found in Christensen (2023a, 2023b).

10.2 Context and background

In 2020, a DBR-study was initiated to investigate how to implement CT with computational tools in humanistic subjects in HE and produce design knowledge in the form of empirically tested design principles and patterns to guide future efforts in the field. Inspired by Reeves (2006), the study was organised in four-phases: 1. Analysis, 2. Design, 3. Two iterations of empirical testing at a Danish university, data collection, evaluation and improvement. Phase 4. Reflection, in which the robustness, usefulness and reusability of the design knowledge created were assessed, and final design principles and patterns were developed.

The study was underpinned by situated and embodied perspectives on cognition and learning which lead to the following constraints in relation to the design of CT activities:

1) In order to make CT relevant and useful to students and teachers in the humanities, designs were to be situated within specific humanistic subjects, i.e., contextualised in the sense that CT activities were intertwined with the subject-related learning objectives. This approach was chosen, rather than introducing CT as stand-alone activities, since "there is a risk that if we teach concepts as stand-alone and out of context, they do not transfer into real situations and authentic problem solving" Caeli and Yadav (2020, p. 6). The adoption of a situated learning perspective meant that learning was conceptualised as participation, situated activity and practice (Lave & Wenger, 1991) in the design process.

2) With the aim of investigating the potential of embodied cognition and learning, the decision was made to integrate CT with computational things. The latter is understood as tangible entities that can be used for computing, i.e., processing an input via a sequence of steps (an algorithm) to arrive at a certain output. Computational things can be digital, e.g., robots (CT plugged), or analogue, e.g., paper computing machines (CT unplugged) (Valente & Marchetti, 2020). Computational things provide students with tactile, bodily experiences, as they handle a robot directly, e.g., whereas

students who use a computer, interact with keyboard and mouse when manipulating items on screen.

Thus, the tangible, computational things were to support students in interacting actively with and in the learning context using sensorimotor movements. Such embodiment can situate and provide tangible support for students' learning of abstract concepts (Abrahamson & Bakker, 2016). The more generic term, computational 'thing' rather than 'tool' was used at the outset of the study, since we did not know how these things would materialise in the design process.

To meet design constraint 1, it was necessary to involve and collaborate with practitioners who could help situate CT activities and computational things in specific humanistic subjects. Practitioners from two different subjects were recruited and invited to identify pedagogical challenges and relevant course topics that could form the basis for design of interventions. Thus, practitioners were invited into the study as problem owners (McKenney & Reeves, 2012), and the time they could allocate to interventions (this proved to be one to two units of 2-3 hours) constituted an additional design constraint. In addition, the framing of a potential solution to the pedagogical challenges identified by the practitioners was a set rather than an open problem in that CT was selected for investigation at the conception of the study. This left us to determine the specific CT definition and concepts to be used.

The study commenced with the two cases describe below that each constitutes a humanistic context for and in which, CT activities with computational things were developed, tested and evaluated.

Case one involved the subject *Media institutions, industries and systems* at the second semester of the Master's degree programme in Media Studies. The course aims to provide students with a comprehensive introduction to the subject, and assessment is an oral examination based on a synopsis. Many students fail to adopt the media institution perspective and do not fully comprehend the abstract concepts of the subject until the exam. In addition, they have difficulties generating ideas for their synopses and often approach the teacher to ask her for ideas. For the teacher, the goal of the intervention was to facilitate students' early understanding of the core concepts and support them in independently generating synopsis ideas.

Case two concerned a *workshop series* for undergraduate, fourth semester Philosophy students that aimed to facilitate students' *early start on their bachelor projects* and support their idea generation and formulation of problem statements. Students are often superficial in their idea generation, discussion and peer feedback and tend to give more weight to teacher feedback, receiving this uncritically. 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 more substantial discussions and peer feedback.

A third case was added a year into the study and provided a new, humanistic context for and in which, the CT activity and computational thing could be adapted and tested. The subject was *Design Research 1* at the Master's degree programme in IT Product Design. For the exam, students must submit two research papers that each is to contribute a retrospective analysis of design projects that students have previously completed as part of their study programme. Students must formulate a research question for each paper, and according to the teacher, they find this difficult and are insecure regarding what to include in their papers. Thus, the teacher reported similar challenges as the practitioners in cases one and two and sought new ways of supporting students in generating ideas for their papers. This made Design Research 1 a relevant context for the further testing of CT activity and computational thing.

10.2.1 CT method developed

Looking at the pedagogical challenge common to the above cases through a CT lens, it can be categorised as a combinatorial problem, i.e., in how many different ways can a set of symbols (abstract concepts) be combined to generate ideas? Applying CT to solve this problem involved the identification of possible algorithm solutions, in this case permutation generation (Skiena, 2020), the identification of relevant categories and instances of abstract concepts within the participating subjects (decomposition) and the development of a computational thing to help more efficiently solve the problem. We labelled the CT method developed *"computing with concepts using tangible, computational tools"* (Christensen, 2023a, 2023b). Rather than learning CT, students learn *with* CT and computational things. The latter were dubbed idea generation tools to signify the function and provide a more specific name than 'thing'. The CT method is described in Table 10.1 below:

Table 10.1. Computing with concepts using tangible, computational tools

The CT method step by step	
1.	Students receive sets of materials and scissors, and teacher or researcher explains and demos how to compute with concepts using the idea generation tool.
2.	Students cut out and assemble the tool – see Figure 10-1 below.
3.	Students input data (Philosophy and IT Product Design): Whereas the circles of the tool for the Media Studies students already contains the theoretical perspectives of their subject, students at Philosophy and IT Product Design are faced with the extra task of first discussing and deciding on concepts to be added to one or more of the circles of the tool developed for their subject. Students work in groups of three to identify and add concepts to the relevant circles.
4.	Students now generate ideas individually by turning the circles, selecting a concept from each circle and combining these. Selected concepts are aligned within the black marker

triangle (see Figure 10-1). The combination within the marker triangle constitutes an intermediate result that serves as input for students' formulation of ideas/research questions. Students can now generate and test different combinations of concepts by turning the circles and replacing the concepts within the marker triangle.

5. In groups of three, students share, discuss, receive, and give feedback on the developed ideas/research questions and refine these.
6. In the last step, students reflect on their learning and experiences by responding to a set of reflection questions.

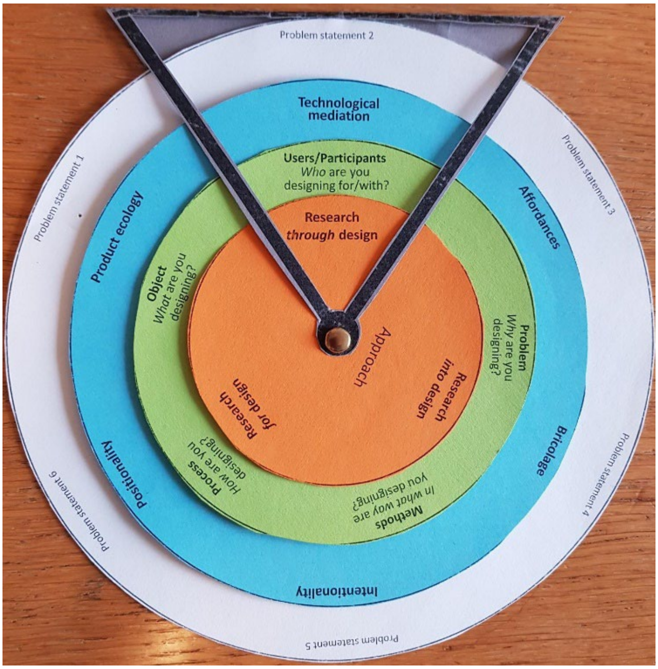


Figure 10-1. The idea generation tool developed. For a more detailed description see Christensen (2023a)

The findings from the empirical testing suggest that the use of tangible, computational tools supports students in systematically investigating possible combinations of, e.g., topics, theoretical perspectives and methods (Christensen, 2023b). The tool becomes a means for students to model and visualise ideas for bachelor projects, exam papers or the like, and enables the sharing and discussion of these ideas with fellow students who can employ the tool to suggest alternatives for consideration; thus, the tool enables students' subject-related conversations. It also enables students' individual as well as collaborative analysis and exploration of subject-related abstract concepts and supports divergent thinking by prompting students to consider multiple ideas before making decisions on the direction to take. However, some students hesitate when presented with tangible tools and explain that they prefer and/or expect more abstract ways of learning in HE and in connection with their subject.

The next section accounts for the stages involved in creating design principles and presents the design principles developed.

10.3 Creating design knowledge

Manzini (2009) defines design knowledge as a product of design research that can be used by designers and non-designers in design and co-design processes. He further explains that content-wise, design knowledge constitutes various cognitive artefacts from visions through proposals to tools. Form-wise, design knowledge cannot be “implicit and integrated in the design but […] must be explicit, discussable, transferable, and accumulable” (Manzini, 2009, p. 6); points also discussed in chapter 5 of this thesis. Furthermore, chapter 5 explains that many papers reporting representations of design knowledge focus on discussing the learning design developed and neglect to revisit and reflect on the design knowledge created and methods used. To enhance usefulness and reusability, this chapter attempts to make explicit and discussable the design knowledge representations, in this case design principles, created, and the methodological approach used.

10.3.1 Initial design principles

During the two months leading up to the first iteration, researcher and practitioners held meetings to first generate design ideas, then prototype CT activities and computational things and to prepare learning designs (design patterns version 1). During the first iteration of design and implementation, the design constraints and theoretical studies gradually manifested in a set of initial, general- substantive and general-procedural (Dohn et al., 2020) design principles (Table 10.2), while the creative inspiration and experience-based wisdom (McKenney et al., 2015) of the teachers and researcher informed the learning design, i.e. the development of tasks for students.

Table 10.2. Initial design principles. Based on Christensen (2023b, pp. 16-17)

General- Substantive design principles: general practical goals of the learning design	
1.	Students can employ CT competences to gain an in-depth understanding of core questions or concepts related to the specific subject they are studying.
2.	Students can make use of computational things to gain an in-depth understanding of core questions or concepts related to the specific subject they are studying.
3.	Students can employ CT competences to identify, formulate, and solve subject-related problems.
4.	Students can make use of computational things to identify, formulate, and solve subject-related problems.
5.	Students can participate in situated learning, making use of mind, body, fellow participants, activity, and cultural setting in their learning process.

6.	Students can reflect on their learning from engaging with alternative learning activities and tools.
General- procedural design principles: procedural guidelines for design of interventions	
1.	Design tasks that address core questions or concepts in the specific subject.
2.	Facilitate students' use of select CT competences as method to explore these subject-related questions or concepts.
3.	Facilitate students' use of computational things to explore the subject-related questions or concepts. Investigate how to create tangible and manipulable representations of these abstractions.
4.	Iterate between items 1–3 above, until tasks that allow students to work in a situated and embodied manner with subject-related questions or concepts using CT and computational things as tools have been arrived at.

Following iteration one, the focus of the design process was to improve the learning designs based on findings from empirical testing and arrive at design patterns version 2, to be used in the second iteration. E.g., instructions were simplified and embedded in the tool where possible, and the computational tool for Philosophy students was further anchored in the subject by having the teacher develop exemplars that illustrated where the different categories of abstract concepts fit into a good problem statement.

10.3.2 Revisiting design principles

After the second iteration, the initial design principles were revisited and found to be disconnected and theoretical, especially the general-substantive principles that are more akin to core ideas (McKenney & Reeves, 2012) and might thus be difficult to put into practice in specific learning designs. The question was, therefore, how to refine the design principles to contribute design knowledge of a more useful and reusable nature. Such revisiting, elaboration and refinement "remains an ongoing process throughout the design research trajectory" (McKenney & Reeves, 2012, p. 120). Further theoretical studies were undertaken on situated learning (Greeno, 2006), embodied cognition (Newen et al., 2018), things and materiality (Dourish, 2017; Hodder, 2012) and external representations (diSessa, 2001; Kirsh, 2010; Pande & Chandrasekharan, 2017) to refine the design knowledge representations.

In addition, a retrospective analysis of the CT method developed was undertaken to gain further insight. The analysis was informed by reflections on the findings from empirical testing. It revealed how the theoretical underpinnings of the different design principles connected in the design and formed potentials for the enhancement of student learning with computational things. This new insight led to the creation of a visual representation of the theoretical underpinnings of the study, see Figure 10-2 below. This figure presents a theoretical framework that 1) displays core concepts and key questions for creating CT activities with computational things for students in non-STEM domains and 2) identifies tangible, computational things as entities that have the potential to bridge situated, embodied and computational thinking perspectives. This is elaborated below.

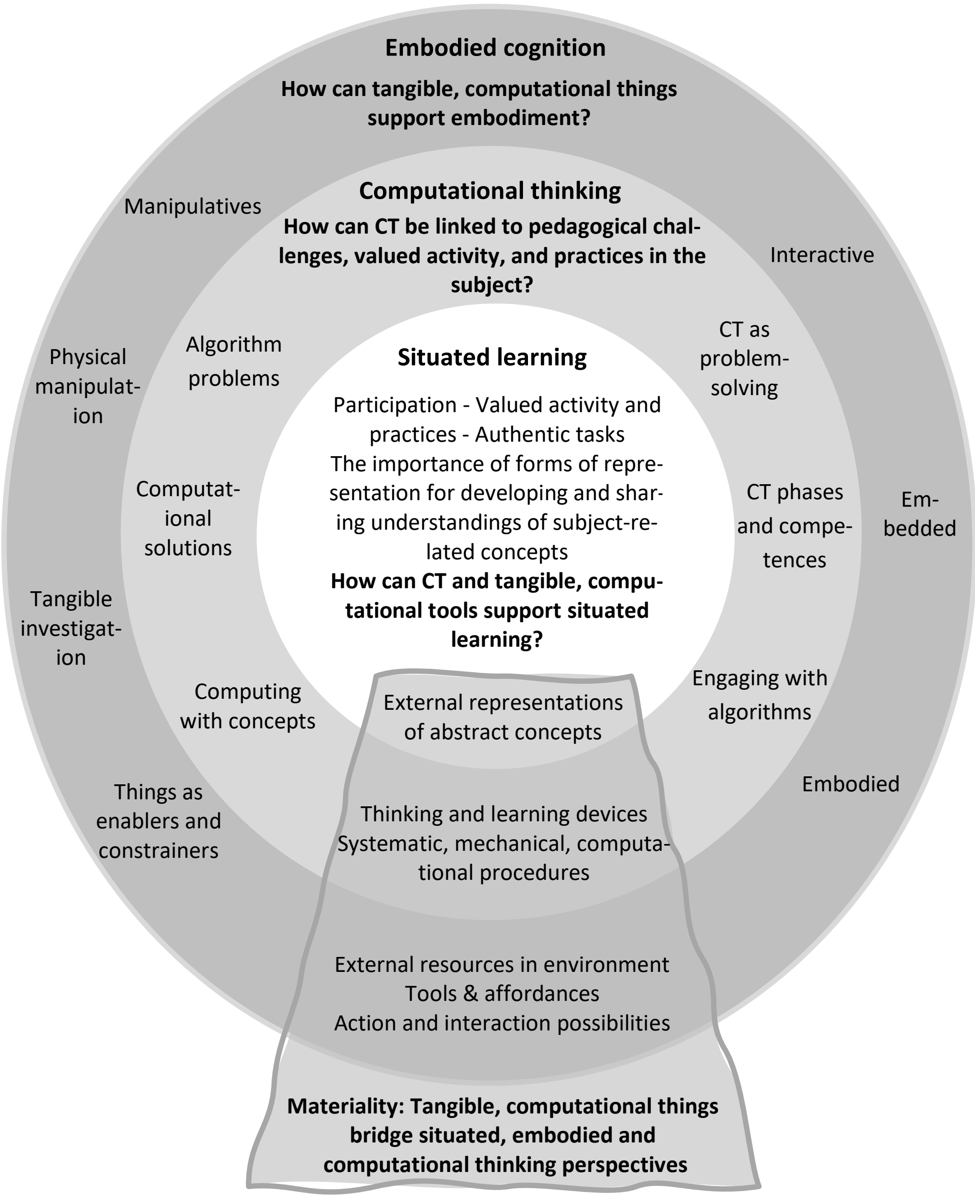


Figure 10-2. Theoretical framework for designing for students' situated and embodied cognition and learning with tangible, computational things

The further theoretical studies undertaken identified new, relevant aspects related to the situated view of learning; aspects that the collaboration with practitioners and findings of the empirical testing had pointed to as significant. This concerned supporting students in participating in *valued* activity and practices by designing *authentic tasks* and students' *access to and mastery of external forms of representation* to be able to develop and share understandings of abstract subject-related concepts. The practitioners had identified students' independent idea generation as a valued activity and practice, and the findings of the empirical testing showed that the idea generation tool in most cases supported this practice and, in addition, constituted an external form of representation that made it possible for students to share, discuss and further develop ideas.

These were intriguing findings that prompted further investigation to identify theoretical lenses with which to understand the phenomena uncovered. It was the tangible and physical nature and configuration of the tool that was the object of examination, i.e., materiality and the embodied phenomena made possible. Inspiration was derived from Dourish's (2017) approach, the *materialities of information representation*, which are understood as "those properties of representations and formats that constrain, enable, limit, and shape the ways in which those representations can be created, transmitted, stored, manipulated, and put to use" (p. 6). Materiality in this sense concerns the possibilities created by a certain form of representation, but also the limitations that follow. This draws attention to the materials selected and the physical design, or configuration, of a tangible, external representation. These aspects can be further understood by drawing on the notion of manipulatives.

Manipulatives are external representations of abstract concepts and tangible resources that students can interact with physically. The aim is to support embodied cognition and learning (Manches & O'Malley, 2012). Manipulatives do this via their physical configuration that offers learners opportunities to interact with tangible representations of the abstract concepts being learnt and to investigate and manipulate these physically as learners attempt to solve the problem with which they have been assigned. The tangible, computational tool developed in this study can be regarded as such a manipulative. The physical configuration of the idea generation tool enables computational practices, in the form of permutation generation, that support what teachers see as valued activity, namely students' independent idea generation.

The embodied phenomenon made possible, when students use the idea generation tool, is interactive and embedded problem-solving. Students' cognitive work is supported via interaction with the idea generation tool and becomes embedded in the external resource that the tool constitutes. In addition, there is the possibility that students internalise the steps offered by the computational tool, so that these are embodied and accessible to the learner even when not using the physical tool.

10.3.3 Materiality as bridging construct

The challenge in this study was how to integrate CT with computational things in humanistic subjects in HE. The idea was to support students' situated and embodied cognition and learning. At the outset of the study, more general notions of situated and embodied cognition and learning were used to frame and direct the design of interventions. The empirical testing led to a more nuanced insight into the situated, embodied as well as computational phenomena at play and also uncovered unanticipated phenomena. Through a retrospective analysis of the computational thing developed that included further theoretical studies, as described above, a more nuanced understanding was arrived at, and it became possible to find links between the components of the theoretical framework.

It is the notion of materiality understood as forms of representation, and more specifically tangible, external, computational representations that constitutes a potential bridge. Figure 10-2 above shows how materiality in the shape of tangible, computational things can constitute external representations of abstract concepts that situate students' cognitive work within a particular subject. Furthermore, CT, more specifically computational procedures for permutation generation, can be integrated into the design of such a tangible, external representation and thus allow for the systematic and mechanical computation of concepts. In the case of the idea generation tool developed in this study, the tool incorporates CT that connects to valued activity and practices in the participating humanistic subject-domains, namely the investigation and application of key concepts in discussions and idea generation for exam papers and projects.

The external representation becomes a thinking and learning device. This is only realised, however, when the physical configuration of the external representation solicits relevant interaction and action on the part of the learner and thus embeds the learner's cognitive work in the environment with the possibility of the learner's physical and sensorimotor experience becoming internalised for subsequent embodied cognition and learning.

Perception and interpretation are important factors for engaging with computational things. For a thing to be perceived and interpreted as relevant and useful for a certain purpose, the user must possess the knowledge to recognise both the thing and its use (Hodder, 2012). When perceived as useful, a thing takes on the role of enabler, but if not perceived as useful for the cognitive task at hand, a thing can take on the role of constrainer. In this way, things can either enable or obstruct action and interaction in learning situations.

The visual representation of the theoretical framework presented and discussed above was essential in refining and connecting the design principles, and their theoretical underpinnings, with the aim of making the design principles more useful and reusable (cf. chapter 5). The refined design principles are presented below (Table 10.3).

10.3.4 Refined design principles

By way of simplifying the design principles, CT and computational things were merged, so that only computational things are mentioned, since the application of a computational thing requires engagement with algorithmic processes and thus CT. To enhance the usefulness and reusability of the design principles, insights from reflections on the design process, the design and the further theoretical studies were explicated in the refined versions below. In addition, the initial *general* design principles were made *specific* since the empirical testing generated knowledge regarding the integration of CT and computational things as "specific practical ends" and "specific procedural guidelines in a specific context" (Dohn et al., 2020, p. 163), i.e., humanistic subjects in HE.

Table 10.3. Refined and specific design principles (DP) for students' situated and embodied cognition and learning with computational things

Specific - substantive design principles: core ideas	
1.	Students can make use of computational things to gain an in-depth understanding of core questions or concepts related to the specific subject they are studying (initial DPs 1 + 2).
2.	Students can make use of computational things to identify, formulate, and solve subject-related problems (initial DPs 3 + 4).
3.	Students can engage in valued activity and practices, i.e., participate in situated learning, making use of mind, body, fellow participants, tangible, external representations and cultural setting in their learning process (initial DP 5 elaborated).
4.	Students can reflect on their learning from engaging with alternative learning activities and tangible, computational tools in the shape of external representations of abstract concepts (initial DP 6 elaborated).
Specific - procedural design principles: design guidelines	
1.	Situate the design in the humanistic context a. Identify a relevant pedagogical challenge and associated valued activity and practices in the subject-domain in question (new). b. Design authentic tasks that 1) address the challenge, core questions or concepts in the specific subject and 2) create opportunities for students to engage in one or more of the associated valued activity and practices identified (initial DP 2 elaborated).
2.	Apply a CT lens to the pedagogical challenge identified in 1 (new) a. Investigate how/whether this can be reformulated as an algorithm problem and if yes, identify the specific algorithm problem.
3.	Apply CT to develop potential solutions (new)

	a. Using CT, investigate and develop possible solutions to the algorithm problem identified, i.e., decomposition, algorithm design etc.
4.	Embed physical and tangible interaction in a computational tool that allows students to explore subject-related questions or concepts and engage in valued activity and practices (initial DP 3 elaborated) a. Identify or develop a tangible, computational tool that can support students' problem-solving, i.e., automation or mechanisation of the algorithmic processing. b. Connect the situated, embodied and computational perspectives by investigating how the computational tool can be merged with external representations of the subject-related abstract concepts and make these tangible and manipulable. c. Explore and test various tools and formats of tangible, external representations.
5.	Iterate between the items above, until tasks that allow students to work in a situated and embodied manner with subject-related questions or concepts and engage in valued activity and practices using computational things have been arrived at (initial DP 4 refined).

10.4 Discussion and reflections

This chapter examined how to develop design knowledge for HE humanities students' situated and embodied cognition and learning with computational things, aiming to uncover the strengths and weaknesses of using a theoretical and challenge-driven approach in a DBR-study. The above account and analysis indicate that the combination of a practitioner-led, challenge-driven approach and a researcher-led, theoretical approach is a useful method. This combination overcomes the problem outlined in the introduction of CT activities often being disconnected from the content and goals of the course in which they are implemented. The practitioner-led identification of pedagogical challenges and course topics helps firmly situate the solution and design knowledge in the subject-domain, and the researcher-led, theoretical investigation provides inspiration, uncovers relevant concepts, contributes theoretical frameworks, and thus anchors the solution and design knowledge in existing research while adding to theories and practice in the field.

In addition, the chapter has illustrated the importance of revisiting and refining design knowledge representations created, which often initially take the form of design ideas. To enhance the usefulness and reusability of this design knowledge, it should be further informed via, e.g., analysis of the solution created, reflections on findings from empirical testing, and through further theoretical studies that can shed new light on phenomena uncovered in data analysis. This will ensure that unanticipated potentials or pitfalls of a solution are made explicit and reflected in design knowledge representations to inform future efforts. When reflecting on the findings from data analysis, it might also be possible to discover how design principles connect and to reflect this back into the underpinning theoretical framework, thus contributing new theoretical insights. A DBR-study is ideal for such iterations of design, empirical testing, evaluation, refinement, and theory building.

Failures can inform future design processes (Kali et al., 2009) in valuable ways, and further design knowledge can be derived by reflecting on the weaknesses and challenges of a design and design process. The empirical testing in this study revealed that a few students reject the idea of tangible tools in HE. Clearly, this means that the design developed does not fully achieve the goal and indicates that the design principles were too narrow in scope causing blind spots in the design process. How can this challenge be overcome, and is it possible, keeping in mind that some elements of learning activity are designable, and some are emergent (Goodyear et al., 2016)? Further research should explore this affective dimension and create design knowledge regarding how to better match expectations with students. In the light of this, a weakness of the CT method developed might be that CT is embedded in the tool and thus only implicit in the design. Can a more overt approach to CT, as well as to tangible, external representations as course content and object of reflection remedy this?

A possible way of better matching expectations with students might be to invite them in as co-designers, as discussed in Ripley et al. (2024). This would, however, be a more time-consuming approach. The design knowledge and solution of the study reported in this chapter also reflect the conditions of educational research in HE and the challenge of gaining access to classrooms, negotiating the length of interventions with practitioners etc. Design knowledge based on short term interventions is still valuable. It is a means of gaining experience within new areas of educational research and can uncover potentials and pitfalls that can inform future, more comprehensive studies. Thus, short term interventions might serve as a means to convince practitioners, researchers, and other stakeholders to contribute time and funding.

11 Discussion

11.1 Testing the usefulness of the theoretical framework

Below follows a discussion of themes from the thematic analysis and their associated codes using the lenses provided by the theoretical framework established in chapter 7. The purpose of this is to test the practical usefulness of the framework in relation to the analysis of students' experiences and perceptions when engaging in CT activities with tangible, computational things.

The situatedness of the CT activity

An important point of the design process was to situate the CT activity in the humanistic subjects in question to make it useful and relevant to students and teachers. This subject-related situatedness was sought achieved by identifying valued activity as perceived by the participating teachers. The developed CT activity made available new, computational practices and tools that were to help students more competently participate in the valued activity. The thematic analysis showed that we partly succeeded.

The inductive code *framing and framework* from iteration 1 indicates the context-embeddedness (Kirk & Kinchin, 2003) of the CT activity and tool designed. Most students perceive the tool as a framework of their subject and/or of the good problem formulation and its component parts. Furthermore, some students express that they find the valued activity of independently generating ideas identified by the teachers, intimidating and stressful which indicates the importance of supporting students in handling such activity and helping them participate more competently cf. the view on learning as participation adopted by situated learning theory. The code *potentials* captures a few students' experiences that the tool and activity provide them with a novel way of finding an idea and new knowledge regarding how to approach the idea generation process.

In the second iteration at Media Studies, however, some students do not acknowledge the tool as a representation of the media system and its surroundings. They cannot make sense of the concepts, and consequently they do not interpret the tool as intended. This shows the significance of interpretation for successful or realised tool use. And it also shows that the tool is not always successful in helping students understand and work with abstract concepts.

Most students found the computational practices introduced with the tool and activity intuitive and helpful for their exploration and generation of ideas evidenced by the theme *Algorithmic processing: computing with concepts* containing the codes *using the tool/algorithmic processing* and *converging & diverging*. Thus, the CT activity and tool provides a situated means of supporting students in achieving more competent participation in the valued activity. However, there are also indications of students perceiving the computational tool and practices introduced to be too deviant from the practices they value and prefer in connection with their HE humanities studies. This creates a clash between the tangible, computational practices introduced and the activity of doing Philosophy or Design Research, e.g. This is evidenced by the theme *Rejection of tangible tools in HE* and indicates that computational practices with tangible tools and learning in the humanities seen from a situated learning perspective may not be compatible.

An external representation for conversation

The code *framing and framework* indicates that the tangible, computational tool is a successful representation *of* the humanistic subject in question and the components of the good problem formulation respectively. But, as mentioned above, the tool is not interpreted or realised as an idea generation tool in all cases, i.e., the tool is not always perceived as an external representation *for* generating ideas. However, the theme *A conversation tool: a tool for visualising, sharing and discussing ideas*, and its associated codes, points to the unanticipated, but frequent realisation of the tool as an external representation *for* dialogue and constructive peer feedback. It is the successful way in which the tool provides a persistent, external representation (cf. section 7.4.1) of abstract concepts from the humanistic subject in question that creates a foundation for conversation as evidenced by the code *foundation for thoughts, idea generation and dialogue* from iteration 1. Thus, the tool becomes an enabler for social learning.

The thematic analysis reveals how the tangible, computational tool developed constitutes an external representation that matches the problem-solving process perceived by students and provides a model for students' thinking as they work on the problem (Greeno & Hall, 1997). The problem-solving process perceived by the students in iteration 1 is that of identifying the bounds of the subject and that of overcoming the stressful task of generating ideas as evidenced by the theme *Problem-solving: what is the problem*?

However, not all students adopt the tangible, computational model of problem-solving offered by the tool, but prefer to engage in the abstract thinking more well-known to them. This further proves the point mentioned in section 7.4.1 that, from a learner perspective, tasks with and without external representations are significantly different even though the abstracted task is the same. In addition, it points to the significance of materialities of information representation. Materiality matters and makes a difference to HE students, and the tangible, computational tools developed participate in learning situations either as enablers or constrainers.

In the role of enabler, the tool invites students to engage in divergent thinking. It is the physical configuration of the tool, the tool as a manipulative, that solicits students' systematic, mechanical generation and exploration of ideas as evidenced in themes 2., 3. and 4 (see Table 14.6 in appendix 14.8). Here, the potential affordances of external representations (cf. section 7.4.1) are perceived and realised by students who turn the circles, combining concepts and testing alternatives. Abstract concepts are made tangible, manipulable and computable. In addition, the tool enables the sharing and discussion of ideas which supports students' negotiation of meaning and understanding in relation to the abstract concepts depicted on the tool and the combinations generated, further informing students' idea generation and facilitating convergent thinking.

As such, the theoretical framework has proven helpful for the design of situated and embodied CT with computational tools for humanistic students in HE and also for providing theoretical lenses with which to obtain an in-depth understanding regarding how such activities support students' situated, embedded, interactive and embodied cognition and learning.

However, the theme *Rejection of tangible tools for HE* advises us to proceed with caution regarding the general applicability and usefulness of the established framework. Abstract concepts made tangible, manipulable, and computable is not a material form of information representation that is perceived as helpful by all. On the contrary, such materialities of information representation are perceived by some students as constrainers that object and stand in the way of their cognitive work, of the practices they usually engage in when doing Philosophy etc.

In these cases, the tangible, computational tool was not perceived as the proper thing with which to solve the problem at hand (Naur, 1965). This points to a blind spot in the theoretical framework relating to material attunement, or the lack thereof, in humanistic subjects in HE. Materiality, in the form of tangible, computational tools, does not always bridge situated, computational and embodied perspectives on cognition and learning, but instead sometimes severs the connection.

As mentioned above, *Rejection of tangible tools* in HE is a thin theme that only represents a few students' voices, but since it poses a barrier to the introduction of CT with tangible, computational things in humanistic subjects, it should be explored further to obtain a more nuanced understanding of students' perceptions of tangible tools and computational practices. A possible direction for such exploration is the in-depth study of CT as a kind of literacy (cf. chapter 2) that “has the potential to transform while simultaneously being transformed itself by pedagogic discourse” in the contexts in which it is integrated (Tannert et al., 2022, p. 86). What do computational practices add to humanistic subjects and how do they mutually transform each other? What is gained and what is lost? What is the impact of materiality, of tangible, computational things, in this connection?

The thematic analysis of data collected in iteration 2 uncovered how the weight of themes shifts from iteration to iteration, from context to context. These shifts reflect students’ perceptions and experiences in relation to what they are preoccupied with, what they find easy and difficult, and what they perceive to be problems in the learning situation and more broadly in their study programme. It is in the light of this that students interpret the tangible, computational tool and it is realised as enabler, constrainer or perhaps even obstacle. Adapting Naur’s (1965) words, the analogue, cardboard devices are only realised as tools when students “think of them as the proper things with which to solve [their perceived] problems” (p. 196).

11.2 Forms of knowledge embedded in the tool

Chapter 3 explains how the circles of the tool represent abstract categories of subject-related concepts and in some cases also include the actual concepts within each category. This form of knowledge can be labelled propositional knowledge or “know that” (Dohn & Klausen, 2020). This study has shown that it poses a problem for some students to articulate such subject knowledge both at the category and the instance levels. The tool, most often, is seen as a welcome external representation of this subject knowledge; a representation that makes the categories and concepts explicitly and physically present. This again prompts discussion and negotiation both at the category level, what is a theory, and the instance level, what is meant by affordance?

Quotes from the interviews with students indicate that with the tool, “fluffy” or abstract processes are made physical and tangible, embodied as steps in the physical configuration of the tool. It may even be possible with the tool to understand idea generation as the knowledge form: “procedurally realised routines”, i.e., “clearly definable action sequences which lead to specifiable, predictable results” but which might be difficult to articulate (Dohn & Klausen, 2020, p. 26). Thus, with the tool, tacit knowledge is made explicit and given presence.

There is not a clear line between procedurally realised routines and the knowledge form practical knowledge or “know how”. In some cases, the former will be a prerequisite for the latter (Dohn & Klausen, 2020). What is striking is that several students mention how the tool provides the steps, the method or process for generating ideas and thus embeds the know how needed to master this specific task. It is the physical configuration of the tool and the action possibilities it offers that contribute this know how. The computational and mechanical tool supports students' engagement with idea generation as a "procedurally realised routine". When students interact with the tool to generate ideas, they embody this procedural routine to the extent that the bodily experience becomes experiential knowledge or "know of", i.e., "the knowledge realised in the experience of a phenomenon" (Dohn & Klausen, 2020, p. 28). This is evident in quotes from students who report that, after generating ideas with the tool, they did not use the physical tool but followed the steps provided by the tool in their cognitive work.

Dohn and Klausen (2020) discuss whether practical knowledge is "rule-following" or "builds on holistic recognition and attunement" to situations (p. 27). Based on the findings of the present study, I would argue that, in practice, practical knowledge is realised in both ways and seems to be connected with personal preferences, background and experiences. This latter point must be studied in more detail, though. However, the students who reject tangible tools, seem to be rejecting the decomposed, mechanical, and procedural method of generating ideas, instead preferring a more abstract, non-linear approach. Students who struggle with the task of generating ideas, conversely, seem to embrace the tool exactly because it embeds idea generation as a procedural routine and the know how needed to master the task.

Dohn and Klausen (2020) mention a fifth form of knowledge, namely episodic knowledge that is tied to memories of events. Above it was illustrated how a student recalls his time in primary school as he sits cutting out circles during the intervention. He indicates that this is possibly the reason for his outright rejection. A possible interpretation is that episodic knowledge has a bearing on the way students perceive learning activities, tools and materials later in life and how they choose to engage with these.

11.3 Implications for learning (with) CT in HE

The CT method developed in this study, *computing with concepts using tangible, computational tools*, is a CT unplugged activity that provides computational scaffolding for students' idea generation and work with abstract concepts. Some students rejected the tangible materials and the computational practices introduced because of a perceived mismatch with personal preferences and educational level, i.a. This is a cause of some concern, especially in connection with lifelong learning and the acquisition of 21st century competencies. It is disturbing that tangible, computational things are rejected, and that learning preferences seem to be fixed with some students in HE. Keeping in mind Papert's ideas, versatility with regards to materials and technology, rather than conventions, is important to support learning.

The CT method developed was partly successful in integrating CT but in an implicit way as a computational scaffold for generating ideas and working with abstract concepts. For CT to be of wider use to students, a broader reason for working computationally should be formulated. This might also help overcome some students' rejection of tangible, computational things. If CT is to be taught and used more explicitly in humanistic subjects in HE, more time would be required than the 2- and 3-hour slots accorded in this study. This further requires teachers, students and other stakeholders be convinced of the benefits of teaching and learning CT. The results of this study might serve as a means to illustrate and provide evidence of the usefulness of CT as a tool for learning other subjects.

The design principles contributed by this thesis are narrow ones. They show one possible direction to take; the review in chapter 2 illustrates that there are several. Pluralism in CT methods is an advantage since this can inspire the actual operationalisation in the classroom. However, consensus in conceptualisations of CT is needed to establish a joint base and vocabulary on which to build. The idea that CT can be operationalised in different ways (and not only as programming activities) is particularly important because it is a springboard for creating diverse CT activities that include students in all subjects and at all educational levels.

CT with computational things is a budding area where more research is needed to realise the potential envisaged by Papert and test the potential of embodied approaches to cognition and learning.

12 Conclusion

With the overall aim of investigating how CT with computational things can 1) be made relevant and useful to teachers and students in the humanities in HE and 2) support students in acquiring the competences needed for creative problem-solving within their subject, this thesis asked the following main research questions (RQs):

1. *What CT competences are especially relevant for humanistic subjects and how can they contribute to students' professional development?*
2. *How can computational things be made relevant for humanistic subjects in HE?*
3. *What design knowledge (design principles and design patterns) can support the integration of CT with computational things in humanistic subjects?*

Answers have been provided in the form of the contributions outlined below that offer insight regarding opportunities as well as barriers to the integration of CT with computational things in humanistic subjects in HE. The contributions are empirical and theoretical, offering practical guidance as well as suggestions for theoretical underpinnings in relation to the integration of CT in humanistic subjects. In addition, the thesis uncovers and discusses methodological issues related to design-based research (DBR), including undertaking research in naturalistic settings. The main contributions of the thesis include:

1) Empirically tested design patterns

This contribution is a response to RQs 2 and 3. Adopting a theory- and challenge-driven approach, design patterns were developed, tested, evaluated and refined in collaboration with practitioners from two different humanistic study programmes at the University of Southern Denmark (SDU), namely Philosophy and Media Studies. The practitioners identified pedagogical challenges that formed the basis for the design of a solution that involved CT with computational things. In this way, solutions were contextualised within the humanistic subjects in question. Design patterns were tested in two iterations and adapted to and tested in a third humanistic study programme, namely IT Product Design, also at SDU. The design patterns offer a solution to the pedagogical challenge experienced by the participating practitioners: students have difficulties understanding the abstract concepts of their subjects and using these to independently generate ideas and problem formulations for projects and exam papers. The design patterns communicate the context, learning objectives, materials and tasks contained in the solution that was developed, a non-STEM CT method which constitutes a second contribution.

2) A non-STEM CT method: Computing with concepts using tangible, computational tools

This contribution provides answers to RQs 1 and 2. The non-STEM CT method supports students in working towards the learning objectives of their humanistic subjects using computational things as tools, i.e., learning with CT. The theoretical underpinnings of the method are situated, interactive, embedded and embodied cognition and learning (cf. theoretical contribution below). The CT method is situated in the humanistic subject in question with the computational tool offering a decomposed version of key categories of abstract concepts within the subject. The method adopts a CT unplugged format with an analogue, paper-based tool. This tool allows students to physically manipulate and rearrange the abstract concepts represented. Students can select and combine concepts and build on these combinations to generate ideas and problem formulations; thus, students compute with concepts.

The empirical testing revealed that many students welcome the mechanical and systematic investigation of abstract concepts that the CT method makes possible. The tool supports idea generation, including divergent thinking by facilitating the easy substitution of abstract concepts in a combination made by students. In addition, the tool supports students in sharing, discussing, providing, and receiving feedback on ideas created. The CT competences made relevant to humanities students in the task of computing with concepts are abstraction, decomposition, data generation, mechanisation (the concept most often used in connection with CT is *automation*) and modelling.

The tool can potentially support students in building 21st century competencies by offering novel, situated and embodied ways of thinking and working as well as new tools for working. However, the paper-based materials of the tool pose a barrier to engagement for some students who reject such materials for learning in HE. Likewise, some students object to the linear, computational method if offers.

3) A theoretical framework for design and analysis of activities that support students' situated, interactive, embedded and embodied cognition and learning with computational things

This contribution elaborates the answers to RQs 2 and 3. The theory-driven approach in this study revolved around designing for students' situated and embodied cognition and learning. To support this, preliminary general-substantive, and general-procedural design principles were formulated based on notions of situated and embodied perspectives. Simultaneously with the design process and empirical testing, further theoretical studies were undertaken to reflect the decisions made in the design process and to identify theoretical lenses with which to understand phenomena uncovered in data analysis. Likewise, a retrospective analysis of the computational tool developed was undertaken. On the basis of this, the thesis contributes a theoretical framework for students' situated, interactive, embedded and embodied cognition and learning with tangible, computational things. This contribution includes refined, specific-substantive as well as specific-procedural design principles. These design principles aim to communicate the theoretical underpinnings as well as the challenge-driven approach that is to contextualise the CT activity in specific humanistic subjects.

In the framework, materiality functions as a construct that bridges situated, embodied and computational perspectives. Materiality is understood as the properties of representation formats that impact, i.e., enable, shape, obstruct and or delimit, use. The computational tools developed are identified as manipulatives, i.e., tangible, external representations of abstract concepts that students can interact with physically. In their capacity as external representations of abstract concepts within a subject, the tools become firmly situated within the subject. Furthermore, the tools offer persistent referents to the concepts represented and the combinations generated. It is this trait that supports students' sharing, discussion, and feedback.

In addition, the physical configuration of the tool offers interaction possibilities that can potentially embed students' cognition and learning and support a back-and-forth movement, where the student changes the state of the tool, which leads to new discoveries and ideas, i.e. interactive cognition and learning. Finally, students' physical, sensorimotor engagement with tangible, computational things can lead to the embodiment of the algorithmic processes, these can offer. I.e., in subsequent cognitive work, the student has internalised and can make use of the algorithmic processes without utilising the tool.

Computational things can be further situated in humanistic subjects by making possible the more competent participation in activity and practices that are valued within the domain, such as independent idea generation employing key abstract concepts. The key is to design authentic tasks that merge the computational thing with such valued activity and practices.

However, if students do not acknowledge that the tool constitutes a valid representation of their humanistic subject or find that the tangible materials and/or algorithmic processes are not the right way of doing, e.g., Philosophy or Media Studies, materiality becomes a barrier instead of an opportunity. The computational things act as constrainers and obstruct students' cognitive work, rather than enable and support it.

The conclusion is that materiality matters in the integration of tangible, computational things in HE.

4) Methodological insights

This thesis also contributes a number of methodological insights in relation to undertaking DBR and research in naturalistic settings. It is rewarding to collaborate with practitioners on both the design and testing of interventions since this builds bridges across research and practice. However, matching of expectations and clarification of roles are important for successful collaboration and should be explicitly put on the agenda to secure this. It is also recommended to include students as collaboration partners to avoid blind spots as the one mentioned above of some students rejecting tangible materials in HE. However, this finding illustrates the strength and value of DBR with respects to testing new methods and tools and gaining insight into how these are perceived by teachers and students, before a broad implementation.

It is also recommended to continuously evaluate data collection methods to ensure that these are feasible in the light of the naturalistic setting in question and the research questions posed. Starting out with several data collection methods can secure that some data are collected, should a method fail. In the present study, video data collected during the first intervention did not have sufficient audio quality to be the object of analysis, this was remedied in later interventions, and other sources of data were available in the first intervention, so that this could be evaluated and inform subsequent interventions.

With respects to collaborative design involving practitioners, it is necessary to acknowledge a time constraint in relation to how much time can be allocated to the design process. There is a need to act on the part of the practitioner to have things ready for a new semester. However, DBR scholars advise to stay in the design process and to develop and test alternative designs. In this study, design students and a design teacher were added as a fourth case to produce such alternative designs, albeit after the testing in cases 1 to 3. This provided insight into time efficient ways to produce multiple design alternatives, and it is recommended to involve such designerly thinking early on in a DRB-study.

A final methodological issue to be mentioned here is transparency in all phases of a DBR-study. Researchers are recommended to not only document interventions and changes made from one iteration to the next, but also the design process, as well as the process of creating design principles and patterns. Such documentation practices enable the tracing of ideas, inspiration, underpinnings etc. and make possible the explicitation and communication of process, contexts and conditions. This in turn will provide peers with the necessary information to assess one's work and determine the usefulness and reusability of any design knowledge representations developed.

Limitations and further research

This thesis offered a specific non-STEM CT unplugged method underpinned by situated, interactive, embedded and embodied perspectives on cognition and learning. As such, it does not offer a general solution to or model for the integration of CT with computational things in humanistic subjects in HE. However, the knowledge contributed can inform future efforts to integrate CT unplugged in non-STEM domains.

An important issue for future research is some students' rejection of tangible, computational tools. To better match expectations with students, two strands of research are suggested. Since the CT method offered involves implicit CT, future research should develop and test activities in which students work with CT in more explicit ways, i.e., CT as content intertwined with the non-STEM domain in question. Likewise, future research should involve students as co-designers, so that their perspectives can be represented from the outset.

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14 Appendices

14.1 Signed co-author statement – publication 3

University of Southern Denmark
Faculty of Humanities

Co-author statement in relation to the PhD thesis

This form must be filled in by the corresponding author and signed by both the corresponding author and the co-author(s). If a co-author disagrees with the information offered by the corresponding author, the co-author submits a separate form.

PhD student: Inger-Marie Falgren Christensen
Title of thesis: Computing with concepts using tangible, computational things – Developing design principles and patterns for the integration of computational thinking with computational things in humanistic subjects in higher education

Paper/manuscript (title, journal): Christensen, I.-M. F. and Markauskaite, L. (second, revised version). Creating Reusable Design Knowledge in Interdisciplinary Education: Current Methodological Practices and Issues. In I-M. F. Christensen, L. Markauskaite, N. B. Dohn, D. Ripley & R. Hachmann (Eds.), Creating Design Knowledge in Educational Innovation: Theory, Methods and Practice. Routledge.

Corresponding author: Inger-Marie Falgren Christensen, Department of Media, Design, Education and Cognition, SDU, DK

Co-author: Professor Lina Markauskaite, Sydney School of Education and Social Work, The University of Sydney, AU

Detailed description of the collaboration leading to co-authorship (why was the paper co-authored, who took the initiative, who contributed what and why, etc.?):

The book chapter was conceptualized in connection with special interest group (SIG) meetings that were conducted online from August 2021 to June 2022 and provided a forum for joint discussions between researchers from the University of Sydney and the University of Southern Denmark. The SIG was established due to Corona restrictions in place that prevented Inger-Marie Falgren Christensen from taking up a position as visiting scholar with Professor Lina Markauskaite at the University of Sydney in the last half of 2021 as planned. Instead, online collaboration opportunities were investigated, and a common research interest in design-based research, including the theoretical, methodological, and practical issues involved in the creation of design knowledge was identified and pursued by establishing the SIG. From the onset of the SIG, it was agreed to aim for a research output in the form of a joint book with co-authored chapters that allowed junior and senior researchers to collaborate across institutions and benefit and learn from each other's competences as well as reflect on and disseminate previous or ongoing theoretical and/or empirical studies.

The two authors had already explored the issues involved in creating reusable design knowledge in connection with a conference abstract and found the preliminary results so interesting that they decided to pursue these in a book chapter. The chapter introduces the notion of design knowledge and reports on an integrative literature review, the purpose of which is to examine what kinds of design knowledge are created and how this design knowledge is created focusing on interdisciplinary education. The chapter concludes that methodological awareness is needed to enhance the methodological robustness and practical usefulness of design knowledge.

Approximate percentage(s) of the PhD student's contribution(s) within any relevant category below:

1) Intellectual and analytic work: _50 %

Comments:

2. Production of empirical data (indicate contribution to individual figures, tables, supplementary data, etc.): __50_%

Comments: This concerned creating a search matrix, retrieving and screening literature and preparing illustrations of the process for the book chapter

3. Writing process: _50 %

Comments:

4. Any other relevant collaborative activity (please specify): %

Comments:

Signatures

___Inger-Marie Falgren Christensen_______ I. Christensen
Name Signature (corresponding author)

___Lina Markauskaite__________________ L Markauskaite
Name Signature (co-author)

14.2 Project brief for students at the Professional Apprenticeship

The brief below was shared with all students embarking on the Professional Apprenticeship module to solicit students for the project.

Tangible Interaction for Creativity

[SOCIAL INTERACTION DESIGN – LEARNING DESIGN] – February-March 2022

This project will conceive, build, and evaluate digital-physical prototypes for systematically generating and testing ideas.

You recently met Inger-Marie in DR1 and used her cardboard tool. She is a PhD student working with computational thinking and idea generation tools for different humanistic subjects, exploring how students' idea generation can be "automated".

As a next phase in this project she is collaborating with Robb to explore how tangible and embodied interaction can improve user experience and offer a more flexible tool.

This project should feature several short design loops of concept development, digital-physical making, testing, and redesigning.

There are good chances of this process resulting in an opportunity to participate in an international conference via publication of this project's written deliverable(s).

14.3 Evaluation questionnaire

I prepared the questionnaires and received the teachers' feedback and suggestions for changes. I then revised the questionnaires which were made available to students shortly after an intervention had ended. Questions were tailored to each intervention and followed the learning objectives formulated for the intervention asking students about their perceived outcomes. In addition, we asked about students' experiences in relation to the different phases of the intervention, including using materials/tool and engaging with peers around this.

The questionnaire for Philosophy included three initial open-ended questions to solicit any information the students wanted to share regarding 1) what worked well, 2) what did not work, and 3) suggestions for improvements.

For the next set of items in the questionnaire, Likert-type scales (Croasmun & Ostrom, 2011) were used and students were asked to respond to a series of statements. We provided five answer options from "Strongly agree" to "Strongly disagree" and in addition the option "Don't know". These questions probed students' experiences using the idea generation tool and whether they found this easy or difficult, supportive of or a barrier to generating ideas. This also including students' experiences collaborating with peers on the activity.

In the last part of the questionnaire, the items were formulated as questions with five answer options from "To a high degree" to "Not at all" and "Don't know" that probed students' perceptions of connections between the tool, the components of the good problem formulation, combinatorics and idea generation, such as, e.g.: "To what extent did it help you generate ideas for problem formulations that you could explore combinations of topics, question words, theories and methods by turning the disks of the tool?"

We included both positively- and negatively-worded statements to avoid response bias since negatively-worded statements can help ensure that students read statements carefully before responding instead of just automatically ticking boxes (Croasmun & Ostrom, 2011). This negative and positive wording is illustrated below with an example from Philosophy, iteration 1:

- Positively worded: The tool inspired me to explore different ideas.
- Negatively worded: The tool was a barrier and did not help me generate ideas.

The questionnaire for iteration 1 at Philosophy can be seen below. The questionnaire has been translated from Danish.

Evaluation of the ide generation tool for exploration of potential problem formulations

Dear Students,

You have now tested the idea generation tool for exploration of potential problem formulations. We would like to hear about your learning experience, and therefore we hope that you will answer the questions in this evaluation questionnaire.

Via the evaluation questions, we would like to collect your feedback on both the idea generation tool and the activity, so that we can improve both.

Thanks in advance and best wishes,

………………………………………………………

1. Name 1-3 things about the activity with the idea generation tool, you think worked well.
2. Name 1-3 things about the activity with the idea generation tool that you think did not work.
3. If you have suggestions for improvements of the activity and/or the idea generation tool itself, please write them here:

Read the following statements and indicate whether you agree/disagree (Likert-type scale with five options from “Strongly agree” to “Strongly disagree” and “Don’t know”):

1. It was easy to figure out how to I was to use the idea generation tool.
2. The turning disks of the tool made the task of composing a problem formulation more concrete to me.
3. The tool inspired me to explore different ideas.
4. It was an advantage to help each other use the tool.
5. I will use the tool from now on.
6. It was difficult to figure out how I was to use the tool.
7. The turning disks of the tool contained abstract concepts that made it difficult to get started composing problem formulations.
8. I will not be using the tool in the future.
9. The tool was a barrier and did not help me generate ideas.
10. I would have preferred using the tool alone.

(Likert-type scale with five options from “To a great extent” to “Not at all” and “Don’t know” for the questions below)

11. To what extent did you become aware regarding what components should be included in a good problem formulation as you were working with the tool?
12. To what extent did it help you generate ideas for problem formulations that you could explore combinations of topics, question words, theories and methods by turning the disks of the tool.
13. To what extent did working with the tool give you an overview of the theories and methods you can include in your bachelor project?
14. To what extent did working with the tool make you aware of the connection between question word and choice of theory and methods?

You have now completed the evaluation questionnaire. Thanks for your help :-) Click “Finish” to save and send your answers.

14.4 Reflection questions

Reflection questions used at Media Studies. Quoted from Christensen (2023a):
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?

    - About the media system and its surroundings?
    - About generating problem formulations?
    - Other?
- What is your next step? How do you move on?

Tailored reflection questions used at Philosophy. Quoted from Christensen (2023a):

- 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?

Tailored reflection questions used at Design Research 1:

- What have you learnt?
    - About generating paper ideas/problem statements?
    - About critically analysing design?
    - About research approaches in design?
    - About empirical foci in design research?
    - About concepts in design research?
    - About connecting the theoretical with the empirical?

14.5 Interview guide for semi-structured interviews

The interview guides used in connection with Media Studies iteration 1 and 2 are placed below. The interview guides for Philosophy and ITPD (Design Research 1) were similar to the ones used at Media Studies, but with questions regarding phases tailored to the specific interventions carried out.

The interview guide used with the teacher from Media Studies are also inserted below. I used similar interview guides for all teachers, but in each case, I tailored questions to reflect the different phases of the intervention in question, included questions concerning observed phenomena, and/or probed into the design process, as explained above in section 6.4.6.

Interview guide for students, first and second version

Below, the interview guide used at Media Studies, iteration 1 is shown, translated from Danish. This iteration had three rounds of interventions:

1. How many and which rounds of the Media Systems Game have you participated in?
2. Describe how you used the idea generation tool

a. In the individual phase in which you were to generate ideas (explore and delimit)
b. In the phase where you were to share and discuss ideas with each other
c. In the plenary session following up on the group work
d. In the final, individual reflection

Describe where in the idea generation tool you started. On what turning disk?
How did you proceed?
How many ideas/or problems did you explore/delimit?

e. Note to myself: Compare to responses on reflection questions and image of completed tool – probe as relevant.

3. What became possible using the idea generation tool – in relation to idea generation, exploration of idea, angling, delimitation?
4. What was not possible?
5. Can you describe how you worked in the group during the different phases of the activity?
6. To what extent did the tool direct, constrain, support your idea generation?
7. How has round 3 of the Media Systems Game influenced the idea, the topic, the problem, you are working with in your synopsis?
8. Can you share your overall experience of the game – all 3 rounds.
9. Anything else you want to share?

Below, the interview guide used at Media Studies, iteration 2 is shown, translated from Danish. This iteration had two parts. Changes compared to the interview guide for iteration 1 are marked in red.

1. Did you participate in part 1 where you were to cut out the cardboard model and AG (the teacher) reviewed the different layers of the model? How did that work?
2. Have you used the cardboard model in the interim period? For what? Did you bring the cardboard model on May 5?
3. Describe how you used the cardboard model on May 5?

   a. In the individual phase in which you were to generate ideas (explore and delimit)
   b. In the phase where you were to share and discuss ideas with each other. When you were to share and discuss your idea. When the others shared ideas and you were to discuss these.
   c. After the break, a person from each group was to join another group. What did you do, and how did this work?

d. In the plenary session following up on the group work
e. In the final, individual reflection

   Describe where on the cardboard model you started. On what turning disk?
   How did you proceed?
   How many ideas/or problems did you explore/delimit?
   What role did the cardboard model play?

f. Note to myself: Compare to responses on reflection questions and image of completed tool – probe as relevant.

4. What became possible using the cardboard model – in relation to idea generation, exploration of idea, angling, delimitation?
5. What was not possible?
6. To what extent did the cardboard model direct, constrain, support your idea generation?
7. How has the activity with the cardboard model influenced the idea, the topic, the problem, you are working with in your synopsis?
8. How did you experience the act of cutting out the cardboard model and assembling it? Material and process?
9. Can you share your overall experience of the two parts?
10. Do you have ideas for improvement?
11. Anything else you want to share?

Interview guide for teachers

Below, the interview guide used with the participating teachers is shown, translated from Danish. The version below was used when interviewing the teacher from Media Studies after iteration 1:

1. What was the intention of the collaboration – contributing classes and students for the interventions? What did you hope to achieve and why?
2. Try to describe what happened during the activities with the idea generation tool. What did you see the students do with the tool, in relation to each other, in connection with generating ideas?
3. What happened in the plenary session?
   - How would you characterise/describe the ideas, students presented? Abstract/loose or specific/concrete or?
   - How would you characterise students use of concepts in relation to the subject/the model? (use relevant, specific concepts, use few/do not use concepts?)
4. What did the activity with the idea generation tool make possible?

5. What was not possible?
6. How are the ideas and students' level [ståsted] after the activity compared to previous cohorts?
7. What is your experience of the entire intervention (across all parts of it)?
8. How would you describe you own role in the different phases – how do you experience it? The collaboration with the researcher/me? Advantages and disadvantages of contributing classes and students for research?
9. Do you have suggestions for improvements/changes to the intervention, tool, activity, facilitation?

14.6 Overview of data collection methods and data collected

Table 14.1 below provides an overview of data collection methods and data collected.

Table 14.1 Overview of data collection methods and data collected

Case	Number of participating students	Video observation	Participant observation
Media Studies, iteration 1, spring 2021			
Intervention F2F with idea generation tool	15	Video recordings from 5 groups	Field notes
Philosophy, iteration 1, spring 2021			
Intervention with idea generation tool – online via MS Teams	15	Video recordings from 5 groups	-
Design Research 1, autumn 2021			
Intervention with idea generation tool F2F Follow up session - hybrid	28 17 students F2F 19 via Zoom	Video recordings from 3 groups Video recordings from plenary	Field notes
Media Studies, iteration 2, spring 2022			
Part 1: lecture with idea generation tool disks Part 2: generating, sharing and discussing ideas with tool	29 30	Plenary: both sides of class 8 different group sessions were recorded	Field notes
Philosophy, iteration 2, spring 2022			
Intervention with idea generation tool F2F	8	Video recordings from 3 groups	Field notes
Professional Apprenticeship Project: Tangible interaction for creativity			
Student evaluation of idea generation tool and proposals for alternative designs	7	Audio recordings of 7 sessions	Field notes

Table 14.1 continued

Case	Collecting student products / Written reflections	Evaluation questionnaire	Semi-structured interviews
Media Studies, iteration 1, spring 2021			
Intervention F2F with idea generation tool	Reflections collected from 11 students	Questionnaire not administered	4 interviews (Zoom): The teacher and 3 students
Philosophy, iteration 1, spring 2021			
Intervention with idea generation tool – online via MS Teams	Collected from 8 students	Responses from 4 students	4 interviews (Zoom): The teacher and 3 students
Design Research 1, autumn 2021			
Intervention with idea generation tool F2F Follow up session - hybrid	Collected from 8 students	Questionnaire not administered	6 interviews (Zoom): The teacher and 5 students
Media Studies, iteration 2, spring 2022			
Part 1: lecture with idea generation tool disks Part 2: generating, sharing & discussing ideas with tool	Collected from 23 students Collected from 21 students	Questionnaire not administered	Interviews with 4 students (Zoom). Teacher F2F
Philosophy, iteration 2, spring 2022			
Intervention with idea generation tool F2F	Collected from 6 students	Questionnaire not administered	Interviews with 2 students (Zoom). Teacher F2F
Professional Apprenticeship Project: Tangible interaction for creativity			
Student evaluation of idea generation tool and proposals for alternative designs	Collected from the 7 participating students	Questionnaire not administered	N/A

14.7 Video memos created for thematic analysis

Table 14.2 below shows a snippet of a video memo. Three students are working together to input data into and generate ideas using the idea generation tool. Below that follows Table 14.3 that provides an overview of the number of video memos created for thematic analysis.

Table 14.2. Extract of memo created during video observation of group 1 from the Design Research 1 intervention

<table>
<tr><th>Segment name</th><th>Start time</th><th>Observations</th><th>Reflections/ notes</th></tr>
<tr><td>Using tool to share idea</td><td>12:49</td><td>Students are labelled A, B and C from left to right as they appear in the screen shot below.

Student A picks up her idea generation tool and brushes eraser fluff off it.

Student A: So cool.

She places the tool on the table in front of her.

Students B and C stops talking and turn their attention to student A.</td><td>Visual support for sharing idea</td></tr>
<tr><td colspan="4">

Student A: For the Futures, I could do (points to each circle of her tool in turn with her pen) research through design, and then the user/participants – who are you designing for and then back casting.</td></tr>
<tr><td>For, through or into??</td><td>12:58</td><td>Student B: Isn't it – or is it research for design then?

Student A: Is it into? A starts turning the orange circle with forceful movements

Student C: I get confused about them all the time.

Student B: I think research for design (points to student A's orange circle) is if you are making something new for..

Student A: Ah, yeah.

Student B: the field of design, while into design – you look at what is there – describe what it does. I think.

Student C: Ok, wait, I', gonna.. cause through design would be</td><td>Seems to be a good discussion here on what is contained in the different research approaches depicted on the orange circle – tool as foundation – conversation starter.

Exploring abstract concepts</td></tr>
</table>

		Student B: You make something and look what happens. Student C appears to be writing this explanation on her orange circle as she says: make something… (laughs), look what happens – like through user testing? Student B: Yeah, yeah. And then you have research into design which I think is, like you look, what does design currently do? Like you don't actively participate in the design, but you just look at it. Student C adds the new explanation to her orange circle, spelling it out loud: analysing existing design. Meantime, student A has brought out her laptop Student B: I think for design is if you're creating something for the design sector which is not a thing. You create a theory or something that designers can work with. I think that is research for design. Where you are trying to create a framework they can orientate themselves in. I think. B puts forward her explanation a bit hesitantly. Student C: Yeah. Yeah, I would say framework more than theory. Seems to be struggling with understanding the concepts. C: But I am not sure whether I am wrong when saying that. (laughs) Probably.	

Table 14.3. Memos created for data analysis

Case	No. of participating students	Number of memos
Media Studies, iteration 1, spring 2021		
Intervention F2F with idea generation tool	15	- Audio quality not sufficient for creating memos
Philosophy, iteration 1, spring 2021		
Intervention with idea generation tool – online via MS Teams	15	5 memos
Design Research 1, autumn 2021		
Intervention with idea generation tool Follow up session - hybrid	28 17 students F2F 19 via Zoom	2 memos + field notes elaborated
Media Studies, iteration 2, spring 2022		
Part 1: lecture with idea generation tool disks Part 2: generating, sharing and discussing ideas with tool	29 30	Field notes elaborated 8 memos + field notes elaborated
Philosophy, iteration 2, spring 2022		
Intervention with idea generation tool	8	3 memos
Professional Apprenticeship Project: Tangible interaction for creativity		
Student evaluation of idea generation tool and proposals for alternative designs	7	- Only audio recorded

14.8 Codes and themes developed in iteration 1

Table 14.4. Higher and lower order codes used in the theoretically driven coding

Higher order code	Lower order codes (in vivo codes)	Description
Automation/mechanisation	- Tool aids, but does not give idea/spit out idea - Tool provides perspectives/building blocks/puzzle pieces - You need to formulate idea - Creative freedom - Not just one answer	How do students perceive the contribution of the tool versus their own efforts in generating ideas?
Idea generation ↓ Converging and diverging	- Building blocks/puzzle pieces - Combinations - Concretise/make specific - Delimit - Expand/open up - Locked/zoomed in on idea - Pin down idea/clarification in relation to exam	How does idea generation unfold?
Role of tool in the different phases	- Gave us the framework - We moved on – tool did not play as big a role - Had it in the back of our minds/the tool fell into the background - Tool created a discussion	Students' accounts of the roles of the tool – what the tool was used for/or not – in the different phases of an intervention

	- Tool makes you engage in idea generation - Made us talk more concretely about ideas	
Situatedness ↓ Subject relevance		Students' perceptions as to the relevance of the tool for their subject - situatedness
Materiality and embodiment ↓ Tangible and visual	- Potter with the tool - Having a concrete tool - Concretise - Having something physical - Visualise - keep track of ideas - Made it more concrete what I could contribute as feedback - Creative/creativity	Students' accounts and perceptions in relation to materiality – physical configuration of the tool
Using the tool/algorithmic processing	- Match idea to tool - Followed your instructions - Intuitive - Three steps - Answer the question posed by each disk - Build it up – choose one from each circle	Students' accounts of interacting with the tool for generating ideas

Table 14.5. Higher and lower order codes used for the open coding

Lower order codes / In vivo codes	Higher order codes created	Description
- Foundation stone and basis for thoughts - Starting point and launch pad for discussion	Foundation for thoughts, idea generation and dialogue	Students' accounts of the tool as a foundation for thoughts and a launch pad for discussion
- Framework of relevant perspectives - Framing - Template	Framing and framework	Students' accounts of the tool as a framework delineating the subject/guiding their work with abstract concepts
- Dialogue was Alpha and Omega - Interplay between us - Great to talk about ideas/angles - Talk more genuinely - Sparring makes a world of difference	Importance of dialogue	The significance students attach to the possibility for dialogue with peers
- No limitations - Not being able to create data/did not know enough - What is a topic/subtopic, what is a method? Where to input the different things? - Difficult to use in Philosophy - Not good at using tools in general - Preferred free conversation - Not knowing the next step	Limitations and frustrations	Students' perceptions of limitations in relation to using the tool or account of frustrations in the process
- Prefer face to face - Confusion - Technical difficulties	Online versus face to face	Students' perceptions of learning environments.
- New way of finding idea	Potentials	What did the tool make possible?

- New knowledge on how to approach the idea generation process		
- Sparring with fellow students - Giving input - Receiving input - New thought processes - Boosting each other - Challenge each other - Inspiration	Social/peer learning	Students' accounts of sharing and discussing ideas with peers and how this helped them explore alternatives.
	Timing	Students' perceptions of the timing of the idea generation activity in relation to the exam/current stage of bachelor project.
- Difficult/overwhelming/stressful - Easy with tool/relief - Fear - Worth it	Views on generating ideas independently	Students' expressions of affect in relation to generating ideas without and with the tool.

Table 14.6 below lists the themes arrived at in the analysis of data from iteration 1, explains what codes the themes are derived from and/or the subthemes they contain, and provides a definition of each theme.

Themes were named and defined according to Braun and Clarke's (2012) guidelines that themes should have a singular focus, be related but not overlap and address the research questions directly. In the process of reviewing codes and themes from iteration 1 to prepare for data analysis in iteration 2, the name of theme 3 was slightly changed to make it more precise and to delineate it better from theme 2, see below.

Table 14.6. Themes from the analysis of data in iteration 1

Theme	Subthemes/codes	Definition
1. Problem-solving: what is the problem?	What are the bounds of the subject?/framing and framework Subject relevance/situatedness Views on generating ideas independently/affective dimension Potentials	Captures students' accounts of the problem in focus and the solution the tool is perceived to provide. Some students find it overwhelming to generate ideas. The tool helps students discover the boundaries of their subject and frames their idea generation, situating it in the humanistic subject in question.
2. Algorithmic processing: computing with concepts	Using the tool/algorithmic processing Converging & diverging	Outlines students' engagement with algorithmic processes. Students intuitively and systematically investigated different possible combinations in a stepwise process where each disk constitute a step that asks students to assess data and make a decision.
3. Interacting with a tangible, computational thing (name of theme changed from Using a	Tangible & visual Role of tool in the different phases	Focuses on students' experiences in relation to materiality and embodiment. The physical configuration of the tool made idea generation more tangible and concrete, which again made it possible to visualise and keep

computational thing: a tangible tool)		track of ideas. In the sharing of ideas and discussion phase, some students had internalised the tool, not using it but having it in the back of their minds.
4. What is automated (made mechanical)?	Automation/mechanisation	Captures students' perceptions of the distribution of tasks between themselves and the tool. The tool provided perspectives, puzzle pieces or building blocks for idea generation, and systematised the idea generation process. Students experienced that they had to formulate the ide/problem statement themselves.
5. A conversation tool: a tool for visualising, sharing and discussing ideas	Foundation for thoughts, idea generation and dialogue Importance of dialogue Social/peer learning Online versus face to face	Outlines students' experiences of the tool as a foundation for thoughts and a facilitator of conversation and peer feedback.
6. Rejection of tangible tools for HE (observation during data collection: *non use of tool*)	Timing Limitations and frustrations Online versus face to face	Explains how, in a few cases, students did not use the tool and captures the different reasons provided: wrong timing, mismatch with subject, perceptions of or preferences in relation to learning in HE.

14.9 Codebook for analysis of data in iteration 2

Table 14.7. Code book created for analysis of data in iteration 2

Code name	Description
Deductive coding	
Automation/mechanisation	How do students perceive the contribution of the tool versus their own efforts in generating ideas?
Foundation for thoughts, idea generation and dialogue	Students' accounts of the tool as a foundation for thoughts and a launch pad for discussion.
Framing and framework	Students' accounts of the tool as a framework delineating the subject/guiding their work with abstract concepts.
Idea generation - Converging and diverging	How does idea generation unfold?
Importance of dialogue	The significance students attach to the possibility for dialogue with peers.
Improvements	Ideas or suggestions concerning how the tool or activity can be improved.
Limitations and frustrations	Students' perceptions of limitations in relation to using the tool or account of frustrations in the process.
Online versus face to face	Students' perceptions of learning environments.
Potentials	What did the tool make possible? What can the tool be used for?

Problem-solving: what is the problem?	Problems or challenges that the tool and activity appear to be solving.
Role of tool in the different phases	Students' accounts of the roles of the tool – what the tool was used for/or not – in the different phases of an intervention.
Social/peer learning	Students' accounts of sharing and discussing ideas with peers and how this helped them explore alternatives.
Subject relevance	Students' perceptions as to the relevance of the tool for their subject – situatedness.
Tangible and visual	Students' accounts and perceptions in relation to materiality – physical configuration of the tool.
Timing	Students' perceptions of the timing of the idea generation activity in relation to the exam/current stage of bachelor project.
Using the tool/algorithmic processing	Students' accounts of interacting with the tool for generating ideas.
Views on generating ideas independently	Students' expressions of affect in relation to generating ideas without and with the tool.
Open coding using in vivo codes	

14.10 Adapting the idea generation tool for Design Research 1

In this appendix, the process of adapting the idea generation tool and activity to the new context of Design Research 1 (DR1) at ITPD is described.

The intervention at ITPD was planned and conducted in autumn 2021. In a series of planning meetings between the practitioner and me, the adaptation of the tool to the course was discussed and prototyped. This happened by decomposing the tool used for Media Studies, turning the circles around to reveal the empty back of each, upon which the teacher was asked to consider the categories of concepts she wanted to include, the actual concepts to be contained within each category, and which category to place on which circle. I also reminded the teacher of the possibility to only label a circle with category name and then leave the input of specific concepts to students themselves, as well as the possibility to leave out a circle or include an additional one.

In between our first and second planning meetings, the teacher made a prototype and I read two papers (Frayling, 1994; Leshem & Trafford, 2007) provided by the teacher to introduce me to the notions of design research applied in the course.

There was no existing resource or model that encompassed all the different categories of concepts that the teacher wanted her students to include in their generation of research questions for exam papers, and thus the teacher based her prototype on a decomposition of a successful exam paper and discussed this prototype with the course co-ordinator and other experts in the field at SDU. I was presented with the result and made a master model in MS PowerPoint that could be used for printing physical copies for students. The physical model can be seen below in Figure 14-1.

The tool has the same number of circles as the tool for Media Studies. The inner circle contains the category, research approach, and circle two contains empirical foci. Note how the concepts on circle two are phrased as questions for students to consider. Circle three are for theoretical concepts. In the demo version depicted below, circle three contains actual concepts but it is left blank in students' version to allow them to discuss theoretical lenses they find interesting and then add these to the tool. Having inserted concepts in circle three, students can assemble the tool and select a concept from each disk to generate ideas. On the outer circle, students can write notes on research questions or problem statements that they arrive at on the basis of the combinations generated.

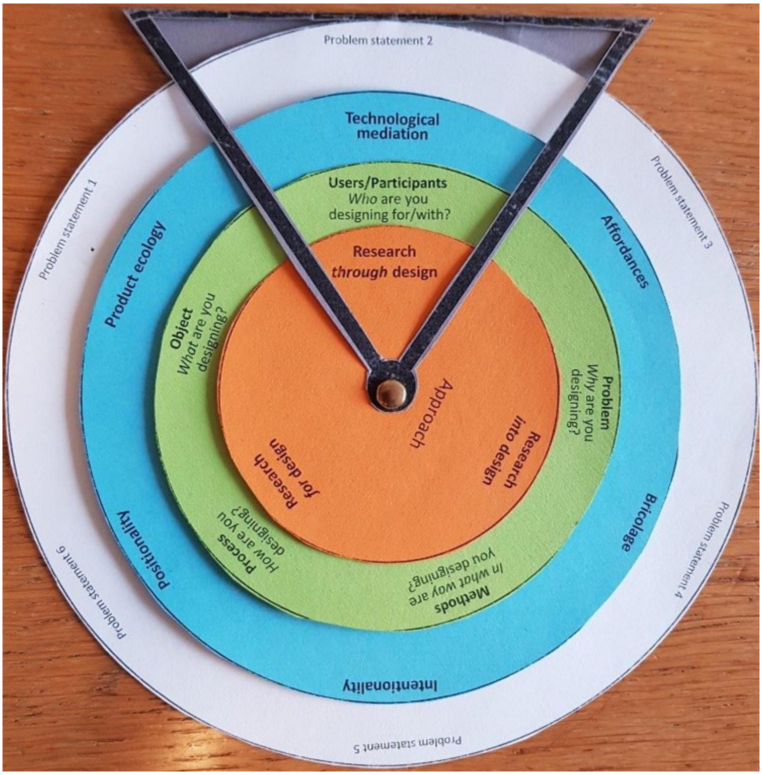

Figure 14-1. Demo version of the idea generation tool for Design Research 1

A 3-hour module in two consecutive weeks at the end of the course were agreed upon for the intervention. These two 3-hour modules facilitated by the teacher were each followed by afternoon writing sessions where students could get started on their exam papers. The first module was set aside for students to familiarise themselves with each category of the tool, to discuss and gain understanding of the concepts included on circles 1 and 2, and to discuss and fill in concepts in circle 3. The second module was set aside for students' idea generation using the assembled tool.

There was a different distribution of roles between the teacher and me since I acted more as consultant than co-facilitator and only participated in outlining the interventions but did not participate in the detailed planning of each module. I was present during interventions, introduced my study, asked students for permission to collect data and demonstrated the tool. Apart from that I undertook participant observation and was available to answer questions about the use of the tool. The teacher undertook all detailed planning and facilitation of learning activities. This proved quite interesting for two reasons: 1) the teacher facilitated the activities more fluidly and did not restrict the time used for subtasks or answering students' questions, and 2) the teacher chose to develop and introduce a new tool and activity, "Diagramming student conference papers" prior to introducing the idea generation tool. This new tool and activity were based on the categories of the idea generation tool and was used to support students in decomposing design research papers from conference proceedings. The hope was that students, by analysing exemplars, would gain an understanding of the desired contents of exam papers and the categories, the building blocks, to use when formulating their own research questions and writing papers.

First the teacher introduced the categories of the tool and provided examples. Then, in groups, students were to select papers of interest from conference proceedings and analyse them using the hand-out shown in Figure 14-2 below.

Following this, students were provided with sets of materials, asked to cut out the circles and, in groups of three, discuss what theoretical concepts to insert in circle 3. In the 3-hour module the following week, students were asked to generate ideas using the tool and to share and discuss these ideas with fellow students. Initial and final reflection questions were also part of the planned activity as explained in section 6.4.5.

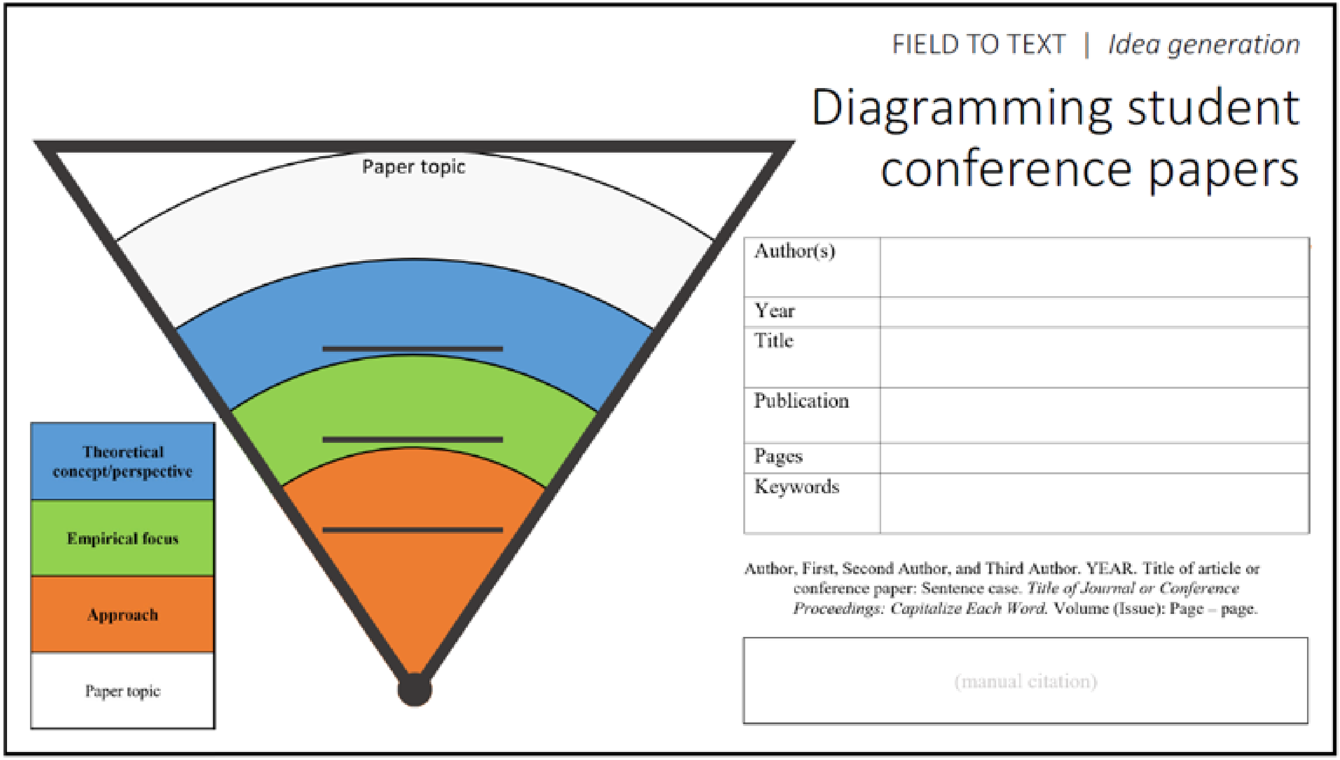

Figure 14-2. Decomposing conference papers - getting familiar with tool categories

14.11 Thematic analysis of data from the intervention in Design Research 1

This appendix contains details of the thematic analysis of data from the Design Research 1 (DR1) intervention, i.e., case 3, including the final list of codes used. The purpose is to illustrate how the themes created in the analysis of data from iteration 1 unfolded in the intervention at DR1, ITPD.

14.11.1 Final list of codes

The table below shows the final list of codes used for the thematic analysis of data collected in the DR1 intervention. The codes all derive from the code book created upon the analysis of data from iteration 1, see Table 14.7 on p. 270. New codes were also created. These are marked in italics in the table below. However, the new codes could all be fitted in as subcodes to already existing codes.

Table 14.8. Final list of codes used in the analysis of data from the DR1 intervention

Code name	**Description**
Automation - mechanisation	How do students perceive the contribution of the tool versus their own efforts in generating ideas?
Foundation for thoughts, idea generation and dialogue - *Communication tool* - *Levels of discussion* - *Negotiating meaning* - *Overview* - *Structure*	Students' accounts of the tool as a foundation for thoughts and a launch pad for discussion.
Framing and framework - *Steps/stepping stone*	Students' accounts of the tool as a framework delineating the subject/guiding their work with abstract concepts.
Idea generation - *Converging and diverging* - *Fall into place – get aligned*	How does idea generation unfold?
Importance of dialogue	The significance students attach to the possibility for dialogue with peers.
Improvements	Ideas or suggestions concerning how the tool or activity can be improved.
Limitations and frustrations - *Obstacle/constrainer*	Students' perceptions of limitations in relation to using the tool or account of frustrations in the process.
Online versus face to face	Students' perceptions of learning environments. **Not used during coding**
Potentials - *Analysis tool* - *Teaching tool*	What did the tool make possible? What can the tool be used for?

Problem solving - what is the problem?
 	
- Blackboxing
- Own practice
- What is the task?
- What projects did we do?
- Which concepts?
    - Personal concepts
    - Understanding abstract concepts
	Problems or challenges that the tool and activity appear to be solving.

Role of tool in different phases	Students' accounts of the roles of the tool – what the tool was used for/or not – in the different phases of an intervention.
Social - peer learning	Students' accounts of sharing and discussing ideas with peers and how this helped them explore alternatives.
Subject relevance	Students' perceptions as to the relevance of the tool for their subject – situatedness.
Tangible and visual *- Power of colours*	Students' accounts and perceptions in relation to materiality – physical configuration of the tool.
Timing	Students' perceptions of the timing of the idea generation activity in relation to the exam/current stage of bachelor project.
Using the tool - algorithmic processing *- Play*	Students' accounts of interacting with the tool for generating ideas
View on generating ideas (independently)	Students' expressions of affect in relation to generating ideas without and with the tool.

14.11.2 How the themes unfolded in case 3

All the six themes that were presented and discussed in chapter 3, were found to be present in case 3, and thus the themes were consolidated. Below follows a presentation and discussion of new phenomena discovered during data analysis that provide a more nuanced insight into the six themes or that point to further themes.

Problem-solving: what is the problem?

The analysis of data in case 3 uncovers that these students also appear to be struggling with multiple problems other than those of understanding the abstract concepts of their subject and generating research questions on the basis of these. Again, much negotiating takes place between students regarding how to interpret the task presented to them. Since students are required to write exam papers that involve a project they have undertaken earlier in the semester, it also poses a problem to remember what projects they did and what was involved in each of them. In addition, students have difficulties understanding how to write a scientific and a humanistic paper respectively.

On par with the findings from the first iteration at Philosophy, the ITPD students also have difficulties understanding the categories of abstract concepts present on the different circles of the tool. Much discussion goes on in relation to what is a concept and what is a method. I observe students' pointing indirectly to problems such as: I don't know if that is a theory, is this a concept or a method? The very subtask of writing concepts into the blue circle becomes a problem. Students try to remember what concepts they have come across and struggle to make sense of these once the actual terms have been found.

Indeed, "figuring" out the tool becomes the problem or task that some students identify:

> Student E: What did we have to do? Student G (tool in one hand): We have to figure this one out, right (taps on the tool with a pen she is holding in the other hand). Everybody agrees.
>
> Student F: So, we have to figure out the blue one. What kind of concepts.. She folds away the outer circles to look at the text in the middle of the blue circle.
>
> (Video memo DR1 intervention, group 2)

Tool obstructs and constrains

When the tool becomes the task for students to "figure out", the tool becomes an obstacle that obstructs their cognitive efforts and sidetracks them from the actual task of understanding the abstract concepts of their subject and generating ideas with these. A further indication that the tool acts as an obstacle instead of an enabler for some students is found in this quote:

> Student: It feels like, ehm, to use an analogy, it's like, I'm eh an Olympic sprinter running in hurdles race and someone's giving me this new device to which I have to wear, which helps me jump over the hurdles easier. But keep tripping over this device because I don't
>
> Interviewer: Yeah.
>
> Student: I don't know how to use it, but it'd just be easier if I was to just do it on my own, if that makes any sense.
>
> (Interview with DR1 student 5)

Algorithmic processing – computing with concepts

The tool cannot solve the problem of distinguishing between theoretical concepts and methods. However, the tool might have brought such questions out into the open and focused students' attention on the importance of these abstract concepts for generating research questions and problem statements. In this way, the tool and activity bring into play the algorithmic processes of abstraction, decomposition and combinatorics. One student explicitly mentions the modularised, physical configuration of the tool:

> So, it makes sense the way this, eh, circle is designed. Ehm, it's easy. So, the fact that it's modular, it makes it very easy to, eh, to play around, right? So, while you keep the same starting point, you can still change the next ones, right? So, you might decide on one thing, but then you can always [...] change the other ones, right? So, it's like in the process you could solidify some-thing, but then the other things are still modular. Ehm. So, that was very nice.
>
> (Interview with DR1 student 3)

When analysing the data, it is obvious that the learning design incorporates algorithmic processes in an implicit manner. Students use vague formulations that non-the-less point to the task of computing with concepts:

> Eh. So, for me, it was really helpful to first break down: what is a concept, what is an empirical focus, what is an approach, and then how do they interrelate with each other? And there I think for me personally, that it was very, very helpful [...] it was really helpful also not to be overwhelmed by the amount of concepts, but I could take the ones that are most interesting to me. The ones I already know I, were applied during a project and I could put them [...] on there and be like, okay, and now I'm focusing on that and I'm just ignoring the other ten, I know.
>
> (Interview with DR1 student 1)

Interacting with a tangible, computational thing: embodiment and mechanical idea generation

During the analysis of data from case 3, further indications of students' embodying the mechanical process of generating ideas that the tool offers, were found. The quotes below illustrate how students, after the first idea generation with the tool, did not use the actual physical tool. Instead, they had in mind "the steps" that the tool offers, and one student explains how the idea generation process was automated or mechanised, i.e., "just seemed to happen".

She [the teacher] made us write the problem statement. So, I did that. And then I went with that to her and explained, basically went through the steps of the tool while explaining what I'm planning on doing. So, kind of not the tool physically itself, but me explaining my idea went through the same steps as the tool. (Interview with DR1 student 1)

So, I think it was rather that [explaining how she arrived at the idea for her second paper]. I don’t think I actually thought about pulling out the tool, because it sort of just seemed to happen with number two assignment. (Interview with DR1 student 2. My translation)

But then in the paper I needed also to make a problem statement. So, in order to create that problem statement, I thought about the steps, eh, that we had in this tool. (Interview with DR1 student 3)

A conversation tool, an analysis tool, a teaching tool: making tacit knowledge explicit

The theme *A conversation tool: a tool for visualising, sharing and discussing ideas* was again a richly represented theme. In addition, new tool uses were indicated or made explicit in the data.

Student 5, mentioned above, thus related how the tool could work as a teaching tool and help make what could be labelled tacit knowledge explicit and present for first year students:

I have a feeling that it would be. It would work well with younger students, maybe […] with students who are less experienced, eh, students, academically. […] No, but looking at that tool, I think that would have been something fantastic for early, first year students to have and bachelor's, because I remember when I was there and so many people would be struggling for even like in second year, people were struggling for like how to write this paper or what should I call it? Like I don't get how to kind of approach it […] and… It would be hard to it, like cause it would be some of my friends and it would be hard to explain to them at the time. Like, I couldn't quite put it into words myself, but that tool would do everything you'd need it to do for them. So, I think that would be a great teaching tool.

(Interview with DR1 student 5)

In addition, a student explains how she helped some of her peers generate ideas:

I think, I also helped some of my class mates a bit with generating some ideas, where I also just, you know, helped.. went directly to that tool and said: well, you try to follow this here tool (laughs), because it actually makes a lot of sense. (Interview with DR1 student 4. My translation)

In effect, the tool became an analysis tool in case 3, since students were to create problem statements that would help them investigate already completed design projects:

The teacher also provides examples that analyse student projects using the idea generation tool (the tool used as analysis tool). (Field note from 24 Nov. 2021)

The tool made it easy for me to differentiate between approach and empirical focus, which is something I struggled before this. I felt like it gave me a good tool to look back at the projects I did on a more meta-level and see what I did. (Reflections, DR1 student 1)

Student D: I think this tool (lifts up the tool from the table with his left hand, then places it on the table again) is meant to understand a paper. What is this paper about (he points in front of him as if indicating an imaginary paper). (Video memo DR1 group 2)

Because of the retrospective nature of the task with which they are faced, many students were preoccupied with their own practice and previous projects:

Student B: I think what we most commonly do is through design, right? (looking at the other two as if for confirmation) Because we make something, and then we look what happened.

Student A: I did my dissertation on for design.

Student B moves on to the green circle and empirical focus and starts reading the text, indicating how she feels about each of the options. She turns the circle and points to the different options as she reads them out loud: How are you designing? Uh, I don’t like that one. What are you designing? I can work with that. I can work with what am I designing and why am I designing and who am I designing for.

Student C: I like the Problem, Why are you designing?

Student B: Yes.

Student C: In what way are you designing?

> Student B: Yeah, I think I am a big fan of the Object. What are you designing?
>
> Smiles and laughter.
>
> Student B: I know how to do that. I know how to talk about what I am doing.
>
> (Video memo DR1 group 1)

As also mentioned above, there are indications that the tool makes tacit knowledge concrete and present:

> I think it [the tool] is good, eh, but it is also because it relates so much to design research that we have had with teacher J. Ehm. And also really nice to have kind of a division into.. that.. because sometimes, you can, because design research is so theoretical that it is, sometimes you can feel that it gets kind of ehm (exhales), well a bit fluffy, or how can we say. Sometimes, it can be difficult to draw out: What is it, we have learned like, or what is it that we can do with it? You know, like seize on to it. Ehm. And I think the orange [circle] does that very well, really. Like, oh yes, that is actually, if you, like, were to roughly split it up, then that is actually sort of what it teaches us. Ehm. So, I think, it was actually very nice (laughs), like to get it down on paper, like, oh yes, it is in fact [down on paper] (laughs). (Interview with DR1 student 2. My translation)
>
> So, yes, well, it was that there was something in between us that we could work with, when before, it was just up in the air. (Interview with DR1 teacher. My translation)

Blackboxing

A very interesting phenomenon that is visible in the data is the blackboxing of concept category labels. Since these labels (research approach, empirical focus, concepts) are placed in the middle of the circle, they are hidden once the tool is assembled, except for the label on the top, orange circle. This blackboxing is interesting because it is normally associated with digital devices, and CT unplugged is recommended as a starting point for learning programming to avoid blackboxing and to support students' computational thinking.

> What was difficult and challenging? Why?
> It was difficult to see what the blue one represents since once you cut you don't see what you are supposed to write. Also not everything fits in the design of the circles. (Reflections, DR1 student 6)

> Student A starts reading from the orange disk: so, approach is design into, for and through research.
>
> Student B: Yes.
>
> Student A: And the next one is (she pulls one end of the orange circle out, so she can look at the category label on the green disk) empirical focus. (Video memo DR1 group 1)

Easy to use and familiar

Some students point to the tool being easy to use and familiar:

> It [the tool] was easy to assemble, it looks familiar which makes it easy to start working with. (Reflections, DR1 student 2)
>
> The design of the tool was easy to use and give me a good idea how to generate my paper. (Reflections, DR1 student 8)

Rejection of tangible tools for HE

The theme *Rejection of tangible tools for HE* was more richly represented in case 3. This is caused, in part, by my persuading a student who rejected the tool to let me interview him. The interview brought forth a more nuanced understanding regarding what might cause rejection of tangible tools, especially the following quote is enlightening and points to the idea that tangibles are for young children and do not belong in HE:

> Ehm. (Pause). They were, I've never done anything like that before, so it was different and I was a bit surprised, I think. When I'm going into a lecture and I'm sitting there cutting things out, it almost took me back to being in primary school, which was a bit strange. So, I think that's, maybe that was a possible reason for me, just rejecting it before I'd even tried it ehm. (Interview with DR1 student 5)

Student 5 explains that the tool felt very alien to him and calls the activity and tool a "strange method of working". He further explains how he prefers his own system and method which is not a linear process, and how he prefers to work individually to generate ideas and write papers. The tool, he says, makes something that comes natural to him, very complex:

> Student: found it so (pause) confusing. I've I've never
>
> Interviewer: Right.

Student: worked like that before. So, the idea of like placing. What was the first disk for? That was eh the sort of the method of like design through research, design for research, right?

Interviewer: Yes. Yes, exactly. That was the a approach.

Student: Yeah.

Interviewer: Which one. Yeah.

Student: So, I found it weird sort of aligning these and especially the concepts. That's that's what I found weirdest.

(Interview with DR1 student 5)

Non-use of tool

I observed several instances of non-use of the tool with students not engaging with the planned subtasks, but instead discussing more general concerns related to their studies both with peers and the teacher. This was reinforced by the teacher's more fluid facilitation and adoption of topics brought forth by the students. Consequently, not all activities were carried out as planned. This leads me to conclude that facilitation and timing of subtasks are important for the successful use of the tool.

> There are indications that if there is insecurity about the overall aims of a course and the exam, e.g., this can take attention away from specific learning activities and the introduction of new tools. Perhaps students need an overview – a more holistic picture of what is needed – matching of expectations.
>
> Very little tool use at all during the GoPro groups sharing and discussing of ideas. It seems here that the teacher and I have directed the students' attention away from the physical tool.
>
> My video observations here indicate that students' (successful) use of the tool requires rather firm facilitation to take place. Also, my impression it that we ended up with two sessions with too many sub tasks that distracted students. Fragmented session that perhaps confused students more than benefitted them. (Field note from DR1 intervention 1 Dec. 2021)

Suggested improvements

There were suggestions to laminate the individual components of the tool to make it more durable. One student wanted more space to write details on the concept selected, e.g., on an extra circle. Students asked for questions/criteria/a guide to be inserted in the tool that could help them determine: is this a concept?

The teacher and I, furthermore, discussed the idea of introducing the tool from the start, perhaps even in connection with students' design projects. Students could use the tool to analyse projects immediately upon completion, writing a blue circle of concepts for each project, and singling out the empirical focus of each project on a green circle.

14.12 Thematic analysis of data from iteration 2 at Media Studies

This appendix contains details of the thematic analysis of data from iteration 2 at Media Studies, including the final list of codes used. The purpose is to illustrate how the themes created in the analysis of data from previous iterations unfolded in iteration 2 at Media Studies.

14.12.1 Final list of codes

The table below shows the final list of codes used for the thematic analysis of data collected in iteration 2 at Media Studies. The codes all derive from the code book created upon the analysis of data from iteration 1, see Table 14.7 on p. 270. New codes were also created. These are marked in italics in the table below. Most new codes could be fitted in as subcodes to already existing codes.

Table 14.9. Final list of codes used in the analysis of data from iteration 2 at Media Studies

Code name	Description
Automation - mechanisation	How do students perceive the contribution of the tool versus their own efforts in generating ideas?
Foundation for thoughts, idea generation and dialogue - *Theoretical starting point*	Students' accounts of the tool as a foundation for thoughts and a launch pad for discussion.
Framing and framework - *Overview* - *Focus* - *Connections*	Students' accounts of the tool as a framework delineating the subject/guiding their work with abstract concepts.
Idea generation - *Converging and diverging* - *Locked on idea* - *The power of examples*	How does idea generation unfold?
Importance of dialogue	The significance students attach to the possibility for dialogue with peers.
Improvements	Ideas or suggestions concerning how the tool or activity can be improved.

Limitations and frustrations	Students' perceptions of limitations in relation to using the tool or account of frustrations in the process.
No value at university	Students' and teacher's view on tangible materials and handicraft in university teaching and learning.
Online versus face to face	Students' perceptions of learning environments. **Not used during coding**
Potentials - *Analysis tool* - *Mapping tool*	What did the tool make possible? What can the tool be used for?
Problem solving - what is the problem? - *Adopting/working with abstract concepts* - *Difficult subject* - *Too many options-directions*	Problems or challenges that the tool and activity appear to be solving.
Role of tool in different phases - *Cutting and pasting*	Students' accounts of the roles of the tool – what the tool was used for/or not – in the different phases of an intervention.
Social - peer learning	Students' accounts of sharing and discussing ideas with peers and how this helped them explore alternatives.
Subject relevance	Students' perceptions as to the relevance of the tool for their subject – situatedness.
Tangible and visual - *Importance of format*	Students' accounts and perceptions in relation to materiality – physical configuration of the tool.
Timing	Students' perceptions of the timing of the idea generation activity in relation to the exam/current stage of bachelor project.
Using the tool - algorithmic processing - *Combinatorics* - *Decomposition* - *Play* - *Randomisation*	Students' accounts of interacting with the tool for generating ideas
View on generating ideas (independently)	Students' expressions of affect in relation to generating ideas without and with the tool.

14.12.2 Changed framework conditions

When I contacted the teacher at Media Studies to plan for the second iteration of our intervention, she informed me that the framework conditions for the course *Media institutions, industries and systems* had changed. She no longer had 12 3-hour lessons at her disposal, but only eight. The remaining lessons were to be co-taught with students and teachers from other humanistic study programmes. This meant that less time could be set aside for the intervention. On this background, it was decided to discontinue the Media Systems Game, since rounds 1 and 2 (the activities not reported in this thesis) failed in making the three, different layers of the Media Systems model visible and present to students and did not support students in generating ideas for cases independently.

The teacher and I developed a new introductory activity with the aim of making the 3 layers of the model tangible to students. This activity was placed in the first 3-hour lesson with only the students from Media Studies. The students were provided with sets of materials (similar to those handed out to students in connection with iteration 1) and asked to cut out each circle in turn as the teacher conducted a short lecture on this particular layer of the model and the concepts present in this layer and gave practical examples. The teacher had colour-coded the accompanying slides using the colours from the tool. Each brief lecture ended with a buzz meeting, in which students discussed reflection questions provided by the teacher to support students understanding, see Table 14.10.

Table 14.10. Reflection questions for each part of the lecture on the Media Systems model.

Layer	Reflection questions
Media system levels (orange) One media institution, an industry, the entire media system	Look at the three media system levels and (in groups of two) find at least one more example within each of the three levels.
Media systemic actors (green) Legislators, organisations, companies, citizens	1) Why are they together in this layer? 2) What separates them? 3) Other thoughts on this layer?
Macro structure variables (blue) Technology, culture, religion, macro economics	4) Why are they together in this layer? 5) What separates them? 6) Other thoughts on this layer?

In the final lesson with the Media Studies students, the activity with the idea generation tool from iteration one was repeated. However, two rounds of sharing and discussing ideas were included instead of the original one, to allow students to share and discuss their ideas with two different groups of students.

14.12.3 How the themes unfolded

In this iteration at Media Studies, better audio quality was ensured in the video observation by supplementing the GoPro cameras with dictaphones. This made it possible to create video memos as described in section 6.5 and this provided good insight into students' use or non-use of the tool.

The final list of codes used for the analysis of data from the iteration 2 intervention at Media Studies, can be found in Table 14.9 above.

All the six themes discussed earlier were found to be present, and thus the themes were further consolidated. Below follows a presentation and discussion of new phenomena discovered during data analysis that provide a more nuanced insight into the six themes or that point to further themes. All quotes presented in this section have been translated from Danish by me.

Theme 5. Tool as conversation tool was a thin theme

In this intervention, theme 5. Tool as conversation tool appeared as a thin theme. Most students did acknowledge the importance of dialogue and the benefits of social and peer learning, but the tool was not broadly articulated as the foundation for this. The reason is likely that for some students, the tool worked more as a theoretical tripwire or obstacle, than an enabler. It forced them to consider and integrate theoretical perspectives. However, some students failed to acknowledge the words on the different circles as useful concepts, lacking a definition and/or explanation of the terms to be able to use them in their idea generation. In the video observations, I saw how some students came to a halt in their idea generation and abandoned the tool because they were unsure about the meaning of the concepts on it. In these cases, the tool did not function as a conversation tool and students did not enter into discussions on the abstract concepts themselves. Another reason appears to be students' preoccupation with media content.

In the data, a tension between students' preoccupation with media content and concrete cases on the one hand and theoretical perspectives on media systems on the other is visible. This confirms the teacher's statement that students have difficulties understanding the media systems perspective (cf. chapter 3) and in this case, also of working at that particular level. Some students, do however, remember to integrate theoretical perspectives, the tool acting as a reminder and becoming more of a mapping tool than an idea generation tool, as illustrated in the quote below:

> D asks: But where on the disk is it (D points to his tool on the table).
>
> A: Where on the disk we are? […] I'm actually a bit in doubt about the orange (he has picked up the tool and turns the orange circle) […]
>
> D seems to be turning the relevant concepts on the blue and green circle inside the marker triangle: Culture and citizens actually, right?
>
> E: Yes. Culture, citizens and then the entire media system.

> D: And the entire media system. (Video memo MS2 part 2 group 2)

> So, in that way, I have used it to visualise and then perhaps also, like, explain to myself, what direction I want to go. Sort of being able to map, okay, well, I would like to stick to this here level, delimit myself to this, right? (Interview with MS2 student 1)

Different attitudes towards tangible materials and handicraft

The new part 1 that was added to the intervention brought much focus on tangible materials and handicraft with students being divided between two different positions. Some students found it time-consuming, distracting and unnecessary, whereas others found it fun and related how it enhanced their learning to have something that visualised the components of the model; it provided overview and focused attention. The negative comments resulted in the new code "No value at university" (see Table 14.9) and themes 3 and 6 were further nuanced.

> The cardboard model took too much time and was a disturbance in relation to the subject-related content and unnecessary for my learning […]. I would prefer to leave out the activity and spend the time on classic teaching with more time for discussion and immersion in the subject. (Reflections MS2 part 1 student 11)

Decomposition in focus

The algorithmic process of decomposition was much in focus with some students indicating that they prefer the stepwise process enabled by the tool while others found it confusing to work from the parts towards the whole like students did in part 1:

> Had a giant flow of ideas with the wheel, when I was finally "forced" to think along those lines. Before the lesson, I had no ideas for the exam, now I have 5+ suggestions. (Reflections MS2 part 2 student 12)

> It was easy to put together new combinations of the different layers with help from the wheel. The wheel also made it easy to remember what parameters one was to work from. The wheel made it easy to discuss the different compositions. (Reflections MS2 part 2 student 26)

> We should have gone through the circles first, you see, before we began cutting any out. Because, I felt, it became a bit eh.. Like, then you were just quickly on to the new circle. And then, well ok, now we are to cut that one out, and now we are to assemble it [the

> tool]. So, I think that if you had been through it [the model/tool] first, and what it was to lead to, that it would become this circle named so and so and so. And then for each, like we also did, like for each circle we made, we could like talk about.. Because, we have just been talking about this, eh, how they work as a whole, eh, and then we can talk about, ok, well, the individual circle can this and that. (Interview with MS2 student 2)

Suggested improvements

Students suggested several improvements to both parts 1 and 2. There were suggestions to spend more time on each layer (both for review and for buzz meetings to find own examples and cases) in part 1 and to add a concluding sub-task in which the connections between the concepts on the circles could be reviewed and the use of the wheel for analysis could be illustrated. One student recommended to go through the circles and how they work as a whole before cutting them out, cf. quote above.

More time was demanded for the concluding reflections in part 2 that students find educational and a task in itself. With regards the tool itself, there was the specific suggestion to make the "environment" level green because this makes sense and to then give the actors a different colour. In addition, a student wanted more space for writing on especially the white circle, but also the other ones. This student also called for the possibility to document selected combinations, e.g., using pins to indicate which idea fits what concepts.

Finally, it was suggested to place parts 1 and 2 closer together, so students would not forget tool or concepts in between the two activities.

14.13 Thematic analysis of data from iteration 2 at Philosophy

This appendix contains details of the thematic analysis of data from the iteration 2 intervention at Philosophy, including the final list of codes used. The purpose is to illustrate how the themes created in the analysis of data from previous iterations unfolded in iteration 2 at Philosophy.

14.13.1 Final list of codes

The table below shows the final list of codes used for the thematic analysis of data collected in iteration 2 at Philosophy. The codes all derive from the code book created upon the analysis of data from iteration 1, see Table 14.7 on p. 270. New codes were also created. These are marked in italics in the table below. However, the new codes could all be fitted in as subcodes to already existing codes.

Table 14.11. Final list of codes used in the analysis of data from iteration 2 at Philosophy

Code name	**Description**
Automation – mechanisation *- Guide (rettesnor) – guideline* *- Direct (styre)*	How do students perceive the contribution of the tool versus their own efforts in generating ideas?
Foundation for thoughts, idea generation and dialogue *- Joint point of departure*	Students' accounts of the tool as a foundation for thoughts and a launch pad for discussion.
Framing and framework *- Overview* *- Focus* *- Doing the wheel*	Students' accounts of the tool as a framework delineating the subject/guiding their work with abstract concepts.
Idea generation *- Converging and diverging* *- The power of example*	How does idea generation unfold?
Importance of dialogue *- Community feeling*	The significance students attach to the possibility for dialogue with peers.
Improvements	Ideas or suggestions concerning how the tool or activity can be improved.
Limitations and frustrations	Students' perceptions of limitations in relation to using the tool or account of frustrations in the process.
Online versus face to face	Students' perceptions of learning environments. **Not used during coding**
Potentials *- New format* - Additional circles	What did the tool make possible? What can the tool be used for?
Problem solving - what is the problem? *- Completing the circles* *- Reviewing – remembering theories etc.* *- Understanding abstract concepts*	Problems or challenges that the tool and activity appear to be solving.
Role of tool in different phases	Students' accounts of the roles of the tool – what the tool was used for/or not – in the different phases of an intervention.
Social - peer learning	Students' accounts of sharing and discussing ideas with peers and how this helped them explore alternatives.
Subject relevance	Students' perceptions as to the relevance of the tool for their subject – situatedness.

Tangible and visual - *Getting it down in writing* - *Handwork - handicraft*	Students' accounts and perceptions in relation to materiality – physical configuration of the tool.
Timing	Students' perceptions of the timing of the idea generation activity in relation to the exam/current stage of bachelor project.
Using the tool - algorithmic processing	Students' accounts of interacting with the tool for generating ideas
View on generating ideas (independently)	Students' expressions of affect in relation to generating ideas without and with the tool.

14.13.2 Changed framework conditions

When, in autumn 2021, I contacted the teacher with whom I had planned and conducted the intervention at Philosophy in iteration 1, he notified me that he was not to teach the bachelor seminar series in the spring, and that he did not know who would be taking over. Since, at that point, I was busy adapting the intervention for Design Research 1, I did not pursue the matter further. However, in February 2022, I was approached by the teacher who was to take over the seminar series. He asked whether I would come and do the workshop on problem formulations since he had heard from the previous teacher that it had been a very profitable session with tools connected to the problem formulation phase. I agreed since I was very interested in seeing a physical model of the tool used. Furthermore, I knew the teacher and had worked with him some years previously on course development which facilitated the collaboration. However, instead of simply doing the workshop myself, I persuaded the new teacher to collaborate on the planning and delivery of the workshop to help him gain knowledge on both the activity and tool and in the hope to connect research and practice more firmly.

As in the case with Media Studies, framework conditions for the seminar series for bachelor students at Philosophy had also changed. Workshop sessions were now only 2 hours which meant that the idea generation activity had to be tweaked to fit the new time constraints. I discussed the activity step by step with the new teacher and demonstrated the tool to explain how it worked and the intention of supporting students' systematic idea generation. In addition, I showed the teacher a few video segments from iteration one, so that he could see students engaging in the activity with the online model of the tool and shared evaluation and analysis results. Together we revised the time plan and activity, incorporating the improvement suggested in chapter 3 that the teacher presents exemplar problem statements that outline the components of topic, theory and method in philosophy. The purpose of this activity was to support students in the task of inputting data into the topic, theory and method circles of the tool. Something that had proved difficult in iteration 1. The final design pattern can be seen chapter 9.

14.13.3 How the themes unfolded

All the six themes discussed earlier were found to be present, and thus the themes were further consolidated. Below follows a presentation and discussion of new phenomena discovered during data analysis that provide a more nuanced insight into the six themes or that point to further themes. All quotes presented in this section have been translated from Danish by me.

Changed framework conditions

The changed framework conditions impacted the intervention in different ways. Both students and the teacher indicated that two hours were not enough to satisfactorily complete the activity. Also, I observed that only few students reached the subtask where they were to generate ideas. Student spent much time cutting out the circles and then helping each other fill these out with concepts. The task instructions specified to first fill out the circles and then assemble the tool. This was done to make it easier for students to write text on each circle. However, this delay in assembling the tool might have impacted students' perception of interaction possibilities:

> Student A mentions that she is thinking about what the teacher said about applying a new angle. One or other interpretation of Platon. That could be interesting.
>
> B agrees: Yes, it could. If you could find something topical today. Not necessarily topical, but a new angle.
>
> A: Yes.
>
> B: But I have difficulties believing that we can.
>
> A: Yes, and..
>
> B: Not that it is not possible. But you need to be creative to do it.
>
> My reflections:
>
> The students have not yet assembled the tool. Would they have seen the possibility to be creative and find new angles if they had assembled the tool?
>
> (Video memo Philosophy2 group 1)

The power of example

In response to the problem seemingly perceived by the students in iteration 1: what is a theory, what is a method etc., the teacher had made available two examples of problem statements in which the different categories of concepts were explicated, and we had also prepared a handout that provided examples of completed circles. These two tweaks to the activity contributed to students' perception of subject relevance and worked as enablers for some students. However, there is also evidence in the data that such examples can be adopted as unproductive(?) loopholes:

> Also, the examples that were already provided and showed what it (a topic) could look like especially in Philosophy. It was incredibly useful that you could see something, what had already been thought of. Yes, so I sort of think it made.. that you like could continue your idea generation. Like that you could continue considering what could be something within Philosophy. (Interview with Philosophy2 student 2)
>
> D: I think that thing about methods.. I get a bit (he writes on his green circle).
>
> F has picked up the handout and is studying it. F: If nothing else, one can just steal those from here (the handout) and use them as inspiration. Because, I don't know either what I could eh could come up with.
>
> D refers to what the teacher initially gave as examples and says he talked about phenomenology.
>
> (Video memo Philosophy2 group 2)

The wheel as joint problem to be solved

As was apparent in case 3 above, the tool seemed to be the very thing around which students' problem-solving revolved:

> Overall, I think that it was very educational to discuss with my fellow students, and the wheel seemed ok in relation to giving us a joint problem to solve. However, I think that there was too little time to properly utilise the tool. It seemed like a good idea, but more time was needed for discussion, understanding and simply just gathering your thoughts. (Reflections Philsophy2 student 3)

In addition, some students seemed to perceive the completion of the circles as a goal in itself and highlighted the importance of having a finished tool. Here the algorithmic process of data generation is in focus as an imperative step in the process of generating ideas:

> So, my wheel is not.. It is almost. Like, lack two topics, I think, and then it will be completely filled out. But actually, it made me feel that I was sitting with a fairly completed tool. Really, I could imagine that there were others who have been sitting, and then there have been fairly many holes, or perhaps it has looked half-finished, and that in itself is not sufficient. But, it also makes the further work with it harder. Towards the end, in any case. So yes, I also think, it was good or lucky that I were together with two others with whom I had established a reasonable rapport where that was concerned, like. So, we got something written down and talked about it. And we got something more written down, so it looked fairly finished in the end […] It becomes very clear that the less or more you put into the tool, the more or less ehm you get out. Or will it be possible for you to generate, I think. (Interview with Philosophy2 student 1)

Community feeling

In this iteration, theme 5 was firmly consolidated. Students remarked on the importance of dialogue, explained how the tool formed a joint point of departure for discussion, and also indicated how much they were inspired by fellow students and how their input brought their learning forward. The teacher and students talked about community, and "community feeling" was added as a subcode, see Table 14.11 above.

> Well, I don't know if I.. I still think I have felt it more like a collective introduction to it. Like, that we have helped each other think of topics and angles […] But.. but well, I, like think it was rewarding to sit together (i fællesskab) and have the feeling that together, we found.., yes generated eh. Like because, anyway, I was personally very open towards the others' ideas. Also, because, we had sat down and said, well, now, now we try to cultivate each other's ideas and each other's themes and such. And there were also some things that were further away from my own thoughts about what to work with. But, I feel for sure it had value. So, I think I had more of a sense of community than of me having to sit and work on my own project. (Interview with Philsophy2 student 1)

> The experiment, if you can say that, or working with that [tool], was to be evaluated based on eh the entire eh what can we say, the entire process, right? So, so, it wasn't just. Like, you could, it

> isn't just that you could sit with it alone and then get, then get it. Well, perhaps you could also benefit from that. But, but, it was also about sitting together (i fællesskab) with it and that which gave rise to discussions. (Interview with Philosophy2 teacher)

Terminated chapter or new format

It was not until iteration 2 at Philosophy that a physical model of the idea generation tool could be tested. This resulted in interesting comments from students and teachers. For example, the word "handwork" and "handicraft" was used and provided deeper insight into students' perceptions and experiences in relation to materiality, the tangible and visual element, theme 3, but also theme 6. Rejection of tangible tools for HE.

A student who found the activity with the idea generation tool helpful in relation to "kickstarting something bachelor-related" goes on to explain her impression regarding how a couple of fellow students saw the task:

> I have also like talked with a couple of my, a couple of my fellow students, who sort of had the opposite perception of it and perhaps felt.. I don't know, I think. Anyway, there were a couple of them who found it a bit difficult to come to terms with the task. And I think like the idea of cutting and pasting (klippe-klistre) got somewhat, I don't know. Perhaps it wasn't.. Yes, I don't know. I think, I think, it was a bit difficult for them to take in the task. That perhaps it was a terminated chapter in educational contexts. (Interview with Philosophy2 student 1)
>
> Interviewer: Yes. Did they like express difficulties in relation to connected this thing about cutting out the disks and assembling the tool with the fact that they were on a bachelor programme at university?
>
> Student: Yes, yes. But again, I think that that is also on of the strengths of it. And it, like, I think this thing about completely disregarding something and like, doing something that does not at all look like what we usually do, even though, of course, we have a lot of group work and the like. But this element is, like, so fundamentally different that one has perhaps been forced to think about it in new.. Like, think a new format, and in that format, you also have to perhaps think a bit differently. So, that's what I think, anyway. I don't think we will agree on, like the quality of it. But, like, I can, I can.. I think I can understand what it is they find difficult. (Interview with Philosophy2 student 1)

Distracting handiwork:

> But then again, it is perhaps also a bit of a stake, right, because it distracts. Does it also have a distracting function, right? Like, it might turn into a Christmas bazaar or something, if they don't like eh catch the task precisely as it could be. (Interview with Philosophy2 teacher)

A student clearly expresses his view on the tool and activity both during the group work and in the individual reflections:

> C: I don't think that mine [the tool] will work at all.
>
> B: Oh, I think it will work. Don't be so critical of yourself. Don't let perfectionism..
>
> C: I don't think I am cut out (egnet) to do things like this.
>
> C takes out the metal clip and assembles the tool again, this time adding the marker triangle.
>
> C: I can't quite see the point of it.
>
> …
>
> C: One hole at a time.
>
> Laughter.
>
> B: Back to kindergarden
>
> C looks at his assembled tool and shakes his head.
>
> (Video memo Philosophy2 group 1)

> Did you come to a halt in the process? Where and why?
> Yes, since I can't see the purpose of the tool, at least not in relation to Philosophy. (Reflections Philosophy2 student 6)

Unblackboxing

The students have cut out the explanation that is provided on each piece of coloured cardboard and tells what category of abstract concept goes on which circle. Students consult these cardboard pieces now and then and seem to use them as a guide as they fill concepts into the different circles (see Figure 14-3) – this means that blackboxing is avoided. (Video memo Philosophy2 group 2)

Figure 14-3. Avoiding blackboxing by cutting out and saving concept category descriptions

What is mechanised?

The data seem to suggest that what was mechanised or put into system via the activity and tool was data generation, idea generation, peer learning and work with the problem formulation for one's bachelor project. A student reports how the tool and activity helped him "skip a few steps" so he was "forced to perhaps not overthink things too much" but instead within a short timeframe "to get quickly going" (Interview with Philosophy2 student 1).

Another student explains that it was nice to have a guide:.

> Like how can we approach this? Because it can be very abstract and broad. And how do we get it concretised? That's the impression I got from some of my fellow students that it was nice to have something to be guided by. (Interview with Philosopohy2 student 2)

This student also explains how the tool "directed his idea generation because [...] These things that we could delve into were like lined up".

The teacher's impression was that the students found it "inspiring that they, so to say, had been forced to listen to each other's things, right?" And goes on to explain that "the presentation of and listening to others had been systematised through the work with the tool." He further calls it a "more directed way" of working with the problem formulation and "a way of further systematising the work that goes beyond the method for that sort of thing that one gets through literature" (Interview with Philosophy2 teacher). In an email comment at the end of the semester, the teacher explains how he "encouraged the groups to use the principle of the tool to home in on a problem formulation".

Two students mention, however, that the tool does not provide the actual problem formulation.

Embodiment

The embodiment perspective was also present in the data:

> Well, like, something had to be put down on the paper. Like, like it all. It is very nice to have this here talk about it. But it is also helpful to get it down in writing, so that you can like gather it, because one can have many ideas that sort of come to mind. But then it is also important to hold on to it when you are in it, and I thought that was good. Having this tool, so that you could sort of say: Well, yes, it could be like this. And yes, and see how different methods or theories could play together with different problems. Well, we didn't have time to spin [the circles]. But you could yourself consider how they could play together. So yes, it was probably, yes, it all, the thing that it like started some thoughts. Then afterwards, that you like remember and think further about it. (Interview with Philosophy2 student 2)

> It was easy to formulate your thoughts down onto the tool that, at the same time, made it easier to find out what thoughts and considerations one had had. (Reflections Philosophy2 student 4)

Suggested improvements

A student suggested to add time to:

> in some way or other get some of what you have been using the wheel for, to get that onto the computer […] Because, […] then I could pull out a document and show you some quite concrete connections, I have made. (Interview with Philosophy2 student 1)

There were other suggestions related to the time issue and agreement that two hours were not enough. One student suggested to provide students with sets of materials and have them cut out and assemble the tool before class and to arrive with ideas but acknowledged that this might impede spontaneity. There is also the added risk that students forget to cut out and assemble the tool. The teacher would have liked time for a closing plenary in which students share the ideas they have come up with. Also, he found that more time is needed when "handicraft" is involved, and students have to find out: "How are we like to sit and work with eh it [the materials/the tool] in this manner here".

Both the teacher and students suggested new categories of concepts for circles (philosophers, great thinkers, periods in the history of philosophy, concepts within a selected theory) which leads me to the idea of also providing blank circles where students themselves can decide on the category of concepts. One might even consider letting the students themselves create external representations and physical configurations that suit their preferences and areas of interest.

14.14 The professional apprenticeship project

14.14.1 Evaluating the tangible, computational tool

Session 1 of the Professional Apprenticeship project: Tangible interaction for creativity

The lead teacher guided students' evaluation by providing the following questions on each their poster. Students wrote their responses on post-its and added these to the relevant poster. Students shared and discussed their responses in plenary.

1. Initial impression – anything you remember?
2. What did you recognise?
3. What surprised you?
4. What did you not understand?
5. Left blank for other comments

The evaluation was rounded off with a task in which the lead teacher asked students to work with the scenario: If you were to give the tool to somebody else tomorrow, and you could only change one thing, what would that be? It could be colour, interactivity, shape etc. Who would you give the tool to?

Students was given time to study the tools developed in this study and reflect on the task. They wrote their responses on post-its that they added to a sixth poster. Students' suggestions for changes are listed below:

- Bigger, write more
- Colours and their connection to the components on the disks – which was which? Choose colours which can show importance/hierarchy
- Materials – more durable
- Space for own questions
- Digital – goes more in detail
- Change shape: make it possible for the user to construct own shape from building blocks
- Allowed me to structure my thoughts – narrow path (visualised by the selections inside the triangle) – but other, not chosen components are still visible and distracts and your selection can quickly disappear as

the disks are not locked in place. Can you lock selection and hide the rest? Different modi.

- Adding space for notes
- Timing
- Universal – blank canvas that can be used for any education
- Have the tool but combine with digital tool for notes, elaboration etc.

The first session ended with the sharing of examples of creativity sparking and aids for decision-making. The lead teacher had asked everyone to bring two images in print; one showing what sparked one's creativity, and the other showing what helped one make decisions. The sharing was followed up with a joint mind mapping of the input provided. These exercises constituted a springboard for the sketching of ideas which was the topic of session 2.

14.14.2 Design constraints and students' sketches

The lead teacher gave students the following task for session 2:

Based on session 1 (the analysis of creativity sparking and decision-making aids, and experiences with and analysis of the idea generation tool), produce at least 50 quick sketches of ideas to redesign the current disc tool &/or create a totally new tool. Consider the design opportunities from multiple angles. As an imagination stretching exercise, we ask that everyone should produce sketches that address each of these challenges (one at a time):

1. Tool inspired by something from your own culture
2. Tool that uses a micro:bit output or input that you have used before
3. Tool that uses a micro:bit output or input that you have seen or heard about
4. Science fiction style solutions - no-budget limits!
5. Large scale tool
6. Wearable tool
7. Biological tool
8. Invisible tool

"There is no such thing as a bad idea!"

Note:

- Use a sheet of single-sided A4 for each sketch
- Give each sketch some kind of title
- On each sketch include some indication of the inspiration for the sketch e.g., which experience, or example, or theory etc. is the idea responding to? Or inspired by? Etc.

Below, a couple of student sketches are included to show some of the results of this exercise (Figure 14-4 to Figure Figure 14-8):

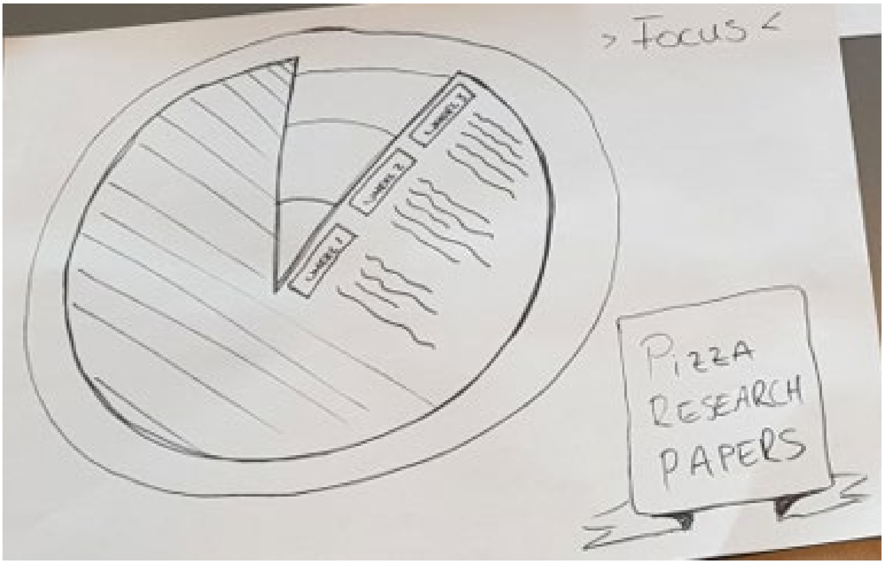

Figure 14-4. Biological – edible idea

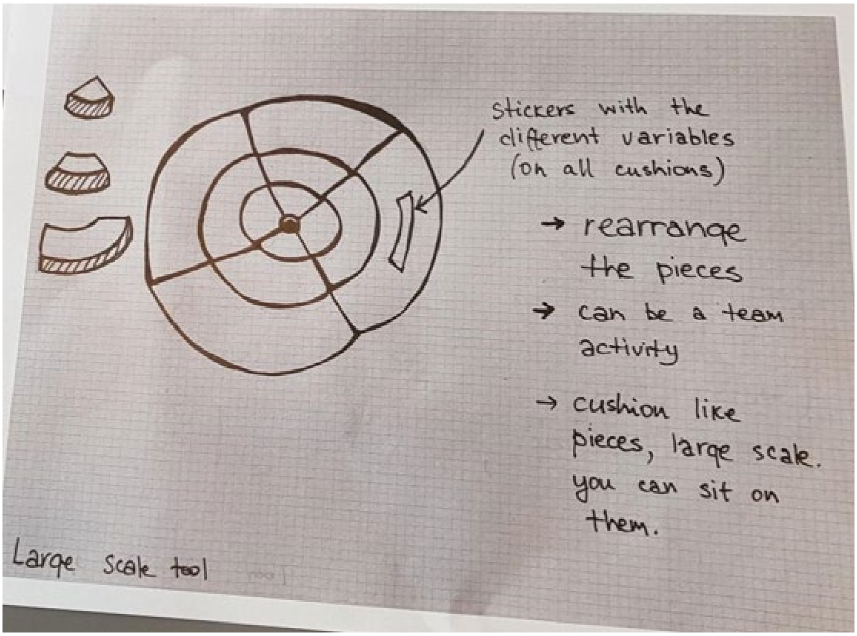

Figure 14-5. Large scale tool

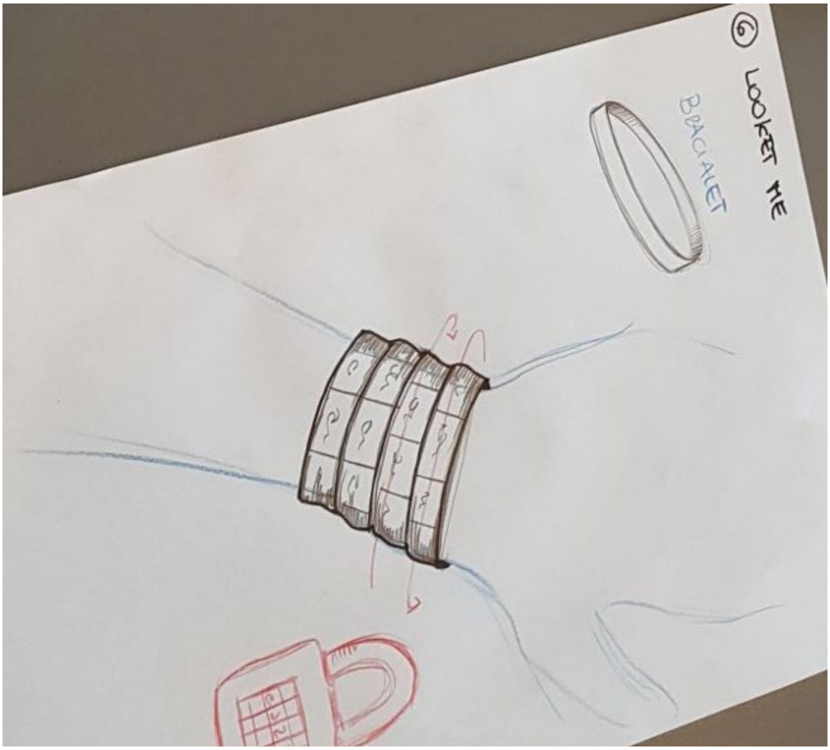

Figure 14-6. Wearable tool

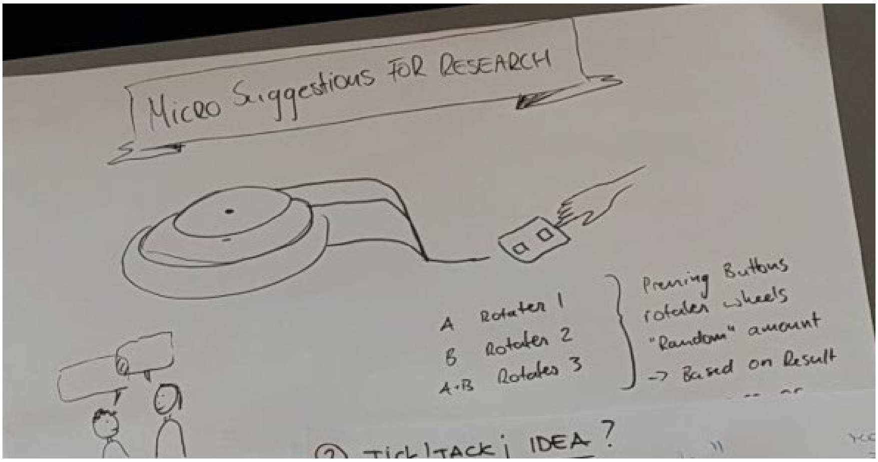

Figure 14-7. Tool using micro:bit to add randomness to idea generation

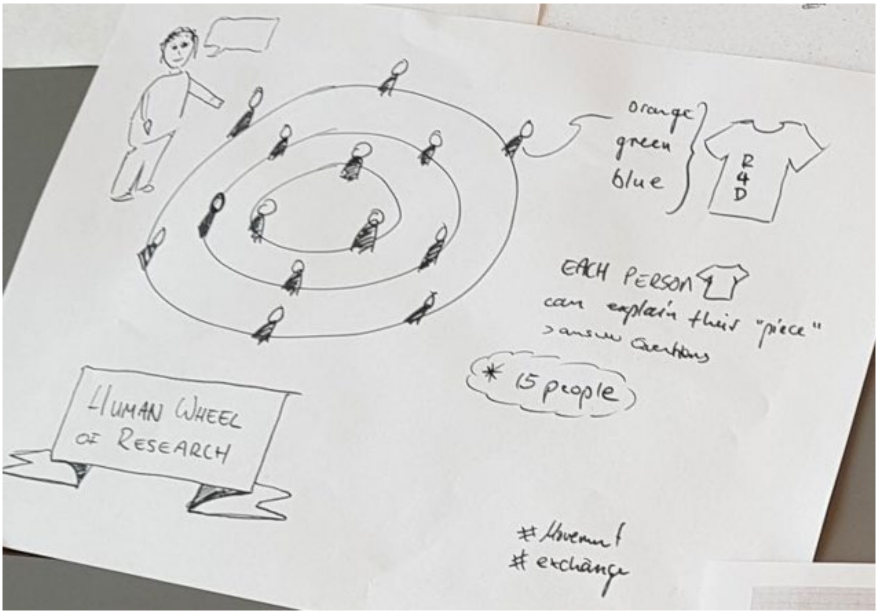

Figure 14-8. Human wheel of research - each person in the wheel wears an orange, green or blue t-shirt and can answer questions within the category of concepts represented by the t-shirt colour. Large scale tool with full body interaction