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Computational Thinking Utilizing Visual Arts, or Maybe the Other way Around

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Abstract: This paper is a theoretical discussion about the extent to which school subjects can contribute to teaching students computational thinking. Or is it the other way around and, perhaps surprisingly, how computational thinking might transform existing school subjects? The discussion takes as its point of departure the national experimental project Technology Understanding, which is the Danish response to a worldwide interest in bringing digitalization to students in primary and secondary schools and the Danish governmental initiative regarding implementation of digital literacy as a new school subject and as an integrated part of existing school subjects in primary school (Ministry of Education 2018). Visual arts education is one of the subjects chosen for the integration of technology, and this paper follows up on the ministry's intention by considering visual arts as the starting point for computational thinking. At issue is how visual art may be informed by computational thinking and how computational thinking may be informed by visual art. I argue that teaching students to understand algorithms and data processes can be inspired by practices from contemporary art and the ideas of new materialism (Barad 2008). Contemporary art may be characterized as conceptual, distributive, and interventional in life practices, and programming principles may illuminate how human activities and algorithms intertwine. I also argue that the teaching of contemporary art can be inspired by principles from programming and algorithms. These practices can illuminate how artistic concepts may be planned and designed for human interaction. However, programming for contemporary art requires openness regarding use, while programming for data processes requires the opposite. Thus, the integration of computational thinking into visual arts education is more than a means for understanding programming and algorithms; the dynamic also works in reverse. This paper will bring a wider societal perspective to bear on teaching computational thinking by bringing school subjects into the center of discussions and drawing on current discussions of STEAM education and contemporary art.

Keywords: visual arts education, technology understanding, computational thinking, STEAM

1. Introduction

In light of increasing digitalization worldwide and nationally, the Danish government decided to respond to its powerful influence on society by incorporating digital literacy into the school curricula (Ministry of Education 2018a). From 2018 to 2021, a national experimental project (tekforsøget.dk) is testing a newly-developed school subject called *Technological Understanding* as well as the integration of the subject's learning objectives into selected subjects in 46 schools across the country (Ministry of Education 2018b). Leaving aside the details of the new school subject for now, this paper will address one of the existing school subjects that has been chosen for integration of technological understanding in the national project: visual arts education in grades 1-3. Visual arts education in Danish schooling (K-12) started integrating information technology (IT) in the late 1980s when computer graphics became a part of visual arts education and programming activities became more commonplace in the work among a handful of visual arts education scholars, developers, teachers, and students (e.g. Nielsen 1987, Skov 1988) that led to inclusion of computer graphics inthe curriculum (Billedkunst 1991 p.12). Since 1991 IT has been considered as one of a range of media available for artistic expression (Rasmussen 2017). Danish art pedagogy is driven by learning through visual practice as well as developing skills within a broad field of art and visual culture, and it includes a critical perspective on visuality as a core learning objective (Buhl and Skov 2018). The role of technology in the school subject is double: it is the tool for artistic expression when students experiment with devices and applications, and it is the topic for artistic expression when students inquire and explore the societal implications of man-machine in a world of social media, algorithms and mobile technology.

As part of the initiative of technological understanding, visual arts education is at another inflection point in its relationship with technology. One aspect of this is the relation between computational thinking and art practices. In order to discuss this relation, I will investigate the term computational thinking and ask how it informs teaching visual arts education, and I will address current discussions of the arts in relation to the so-called STEM disciplines. Furthermore, I will discuss how practices in the school subject may inform computational thinking by drawing on conceptual currents in contemporary art, and I will explore how computational thinking may inform the school subject. My purpose is to determine whether and how technological understanding in visual arts education may add new dimensions to contemporary school education.

2. Perspectives on computational thinking

The term *technological understanding* is broader than *computational thinking*, and the two terms represent a division in the way scholars approach the issue. Caeli and Bundsgaard, for example, contrast teaching children "to think like computer scientists" with teaching them "to understand computers" (2018). They refer to two contrasting positions among computer scientists represented by Jeanette Wing and Peter Denning. Wing argues that "Computational thinking is a grand vision to guide computer science educators, researchers, and practitioners as we act to change society's image of the field" (2006 p. 35). She acknowledges the origin of computer science in math and takes it to another level of abstraction, emphasizing that computational thinking goes further than programming a computer. According to her, computational thinking is first and foremost a mode of problem solving that applies to real-life problems and is characterized by conceptualizing and abstraction on multiple levels, complementing and combining mathematical and engineering thinking. She regards it as a fundamental skill needed to live in modern society. Wing advocates for computational thinking in education as a formal skill in a particular language of the future, and asserts that a computer science major can do anything for a career, including work in the arts. From her perspective as a computer scientist, the skills involved in and the benefits of computational thinking are evident, but from other perspectives the picture may be more mixed.

According to Denning (2017) school teachers are not entirely comfortable with the idea of computational thinking. He claims that three questions repeated among teachers reveal the concerns that teachers have: 1. What is computational thinking? 2. How do we measure students' computational abilities? 3. Is computational thinking good for everyone? (2017 p. 34). To answer the first question, he takes an historical view, identifying scientist and educator Seymour Papert as the inventor of the term in his book *Mindstorms* (1960), in which he used it to refer to the skills children develop from programming. Denning also highlights computer scientist Al Aho's definition from 2011: "…computational thinking is the thought processes involved in formulating problems so their solutions can be represented as computational steps and algorithms," as well as Aho's explanation of the crucial importance of a computational model to formulating an operational definition of the term. In Aho's interpretation, designing an algorithm means designing a way to control any machine that implements the model so that the machine produces a desired effect in the world. Furthermore, Denning explains that Aho's term *computational model* applies to all fields in the humanities, law and medicine. Denning concludes by asserting the importance of making a distinction between the nature of algorithmic steps and human judgment. The nature of the first one is not arbitrary but a series of steps that control a computational model; human judgement is not a series of controlled steps. To the second question about how we measure students' computational abilities, Denning explores the difference between assessing students' knowledge about abstraction and their ability to perform it in design activities. Here Papert's ideas of "doing" are relevant. To the third question about the value of computational thinking for all students, Denning suggests that many "thinkings" are applied to education such as science thinking, economics thinking, systems thinking, logical thinking, rational thinking, network thinking, ethical thinking, design thinking, critical thinking, and, one could add, artistic and visual thinking. Denning's point is that computational thinking may be overrated, since each academic field claims its own way of thinking, and he concludes that "computational thinking primarily benefits people who design computations and that the claims of benefit to non-designers are not substantiated" (2017 p. 38). With this he casts doubt on the idea that computational thinking is generally applicble across the school curriculum a view that supports the new Danish school subject Technological Understanding but not the idea of its integration into existing school subjects.

While Wing emphasizes teaching children the logic and practices of programming and algorithms in order to solve problems, Denning suggests a more holistic approach that includes a user and designer perspective on how to judge whether there are "problems to set" (cf. the pragmatist Donald Schön's (1983) concept for identifying what the actual problem in a problem is) that computational thinking may solve or not as well as the understanding that computational thinking may not be the answer to everything. The two perspectives are applied to the Danish context by Caeli and Bundsgaard (2018) who join others' warnings about Wing's too narrow approach to computational thinking that neglects the history of computing in education. In line with Denning (2017), they revisit the history of technology education, but from a Danish perspective. They suggest that the perspectives represented by Wing and Denning can be traced to similar discussions about technology as a fixed or general orientation in previous educational initiatives. They encourage those engaged in current discussions about technology education to learn from history and advocate an approach that teaches a fundamental rather than an instrumental understanding of algorithms and data processes. Caeli and Bundsgaard, then, align with the Danish governmental initiative regarding the implementation of technology understanding as a new school subject and as an integrated part of existing school subjects in primary school (Ministry of Education 2018) because this initiative embraces an approach of fundamental understanding in which computational thinking, programming, and designing algorithms are contextualized, problematized and discussed. However, the question remains: how is this fundamental understanding reached? Is it through knowing skills or doing skills? Is it through abstraction or designing? The learning objectives of the new school subject and its integration into existing school subjects address computational thinking, programming, construction, and design, and the selected school subjects represent a broad swath of the curriculum, which makes it possible to foster an ongoing discussion of societal perspectives on technology. The implementation of technological understanding in schooling will show which perspectives dominate and whether the term *technological understanding* means thinking like computational scientists in order to solve problems or thinking about the implications of solving problems through computational modeling. As one of the selected school subjects, visual arts education can contribute significantly to this discussion because of its particular perspective on technological understanding and can, moreover, mediate the diverse interpretations of computational thinking by drawing on its creative approach to production.

3. Computational thinking: STEM or STEAM?

The role of visual arts in technological understanding is asserted by scholars who argue for an expansion of the four STEM disciplines Science, Technology Engineering, Math to include a fifth, Arts, thereby adding an 'A' to make STEM into STEAM. The choice to combine technology with a subject outside the obvious STEM disciplines indicates a governmental choice to address technology in ways that are both transdisciplinary and subject-specific. STEM education is the obvious response to teach the kind of computational thinking that originated from math and computer science. The STEM disciplines offer a contemporary response to real-life problems that must be addressed in an interdisciplinary fashion, but scholars argue that visual arts and STEAM approaches hold the potential to innovate science education in both K–12 and postsecondary education (e.g. Segarra et al. 2018) and suggest that the relationship between art and technology is a complementary one (Boy 2013). Discussing art and technology requires us to define what art means in relation to STEAM. Colucci-Gray et al. (2015) review the emergence of art in a UK discussion of STEM, arguing primarily that technological progression will never take place without involving the arts. The authors refer to three interlinked arguments from a Culture Learning Alliance (CLA) report: that studying the arts improves cognitive scores (including those in math and literacy), that it leads to innovation, and that it motivates young people to engage in STEM subjects and careers. They also report that participation in the arts can enhance high-performance teamwork, change management, intercultural communication, observational skills, and adaptability. Furthermore, the arts as a part of the humanities provide an intellectual framework for thriving in and understanding a changing world (CLA, 2015 p.11). Colucci-Gray et al. (2015) conclude that the three arguments provide weight to an economic imperative for STEAM as a necessary approach to improving the labor market.

However even arguments based on a single purpose like economic growth depend upon the twin approaches of viewing the arts as a means to reach that goal (an improved labor market) and as important in their own right (for understanding a changing world). From a Danish perspective, the twin approaches of viewing the arts can be traced back in time (Buhl, 2015) to the first law of schools in Denmark (1814) in which drawing was a significant activity that had a clear purpose: preparing boys for future craftsmanship and girls for crafts (Pedersen 2004).

Studies of the first law of schools show that drawing was a necessary skill for executing daily work, so the practical purpose of acquiring drawing skills was obvious. This early 'technology' was followed by an artistic approach to visual arts education, and the next significant trend was based on pedagogical reform ideas that developed in the late 1950s. Its focus was on the child's personal expression, explained by the need for general education, coined in the German term Bildung. The contours of a division in the way we think about the visual arts (in terms of utility or personal development) are drawn here and emerge repeatedly in various forms up to today's discussions of visual practices: either they are for utility or they are for appreciation. In late 1970s the communicative aspect of visual practice became part of the school subject. Visual activities came to be considered a particular language that comprises an important component of children's development and general education, and a critical approach to the images in mass media began to be applied along with the activities already performed. This development was only reinforced by the introduction of electronic media into the curriculum in 1991 and has been supported by research (e.g. Flensborg 2002). Digital technology has been a part of the Danish curriculum in visual arts education ever since, and technology projects in developing schooling include visual arts education (e.g. Buhl and Hemmingsen 2004, Flensborg 2004, Holm Sørensen and Levinsen 2010, Rasmussen 2017).

Later on, the twin approaches of viewing visual arts education as either utility or personal development became evident in matters of discussing learning objectives. An approach to visual arts education as social practice was added into the curriculum in 2009 through the term visual culture. Visual arts education took on a third path, towards visual practices drawing on contemporary arts to promote an understanding of a changing world. This addition was in line with international currents of developing a new and transdisciplinary approach to visuality that also included digital media (e.g. Mitchell 1994, 2002, Sturken and Cartwright 2009). Along with this development, the Danish school system encountered a new set of imperatives based on unsatisfactory scores in international reports of school children in reading and math skills. These measures grew out of developments in international school systems and the Program for International Student Assessment **(**PISA**)** 2000-2012, which did not include visual arts skills. The result is that visual arts education has been all but excluded from the Danish discourse in educational science, where evidence has entered the discourse and resulted in a paradigm shift. The paradigm shift has consequences for visual arts education that are revealed in the learning objectives of the new school reform (Danish Ministry of Education 2013, 2014) which added the subject, but only in the service of other school subjects. Thus, the 'utility' approach of the subject was revitalized in an instrumental manner and based on political rather than pedagogical arguments. IT and media, already part of the visual arts curriculum, now take a new form as a cross-disciplinary topic.

The new Danish school subject called technological understanding, then, is only the latest addition to technology in visual arts education, in which computational thinking appears as one among other learning objectives for the subject. The question that presents itself is whether the utility, or the personal development or the social practice approach to visual arts will be dominant, or they will find a way to co-exist? Colucci-Gray et al. (2015) note that there is a lack of clarity in the very meaning of the 'A' in STEAM education. They suggest that "three uses of the term [STEAM] are evident: as supporting creative pedagogies; reflecting diversification of what counts as 'science'; and a resistance to technicist [sic] and economically focussed accounts of education" (2015 p.30). Their suggestions align with the idea of including art in STEM learning practices but outside art as a school subject. In the current economic and cultural climate, it is unlikely that visual arts will be acknowledged to have a function in its own right, and the endeavor of advocating for STEAM education exemplifies that. The question is whether that goes for the Danish technology understanding project too or an integration of technology understanding into visual arts' curriculum will be successful?

In this paper, art is discussed only as the visual arts, but the discussion draws on the history of the Danish school subject's pedagogy in which the instrumental function and the general education function are intertwined and in which technology is a tool, a thinking mode, and a topic for critical thinking. Visual arts education in Denmark has cognition, cultural and critical dimensions and is influenced by currents of contemporary art. Contemporary art includes the idea of concept development as a mode of "programming" social art practice and enacting a relation between concept and viewer. This way of thinking draws upon design as well as inquiry and critical approach to art activities, and the artist's or the art student's design concepts invite the audience to be participants in realizing an art work. In order to develop and conduct an artistic concept, a pedagogy for imagination, innovation, planning and experimentation are required. Inquiry and critical pedagogy suggest that the purpose of artistic activity is to develop towards citizenship and democracy. These are contemporary interpretations of instrumental functions and general education in visual arts education. It is suggested that art has the potential to be a model for computational activities based on the fact that creating an algorithm can be compared to conceptualizing a contemporary work of art. Likewise, the view of art works as social projects that try to solve real-life problems may also shed light on teaching technological.

4. Signifiers of contemporary arts

This paper follows up on the ministry's intention by taking visual arts education as a starting point for computational thinking. It is argued that teaching the understanding of algorithms and data processes can be inspired by practices and ideas from contemporary art. Contemporary art can be seen as participatory, networked, social, self-organized, conceptual, distributive, and relevant to life practices. Computers challenge how we understand art, because the technology as a 'materiality' constitutes meaning (Andersen and Pold n.d.). Andersen and Pold assert that digital technology is more than a topic for interpretation in the arts; rather, digital technology changes the ways of making art, for instance, by following the logics of algorithms and data processing. The digital interface is both technical and cultural and represents the result of a historical development that gradually led to its current use, but it is still under the influence of human decisions. In a contemporary art perspective technology and programming principles illuminate how human activities and algorithms intertwine and offer insight into the conditions under which artists work. Ideas of new materialism (e.g. Barad 2003) take this idea of intertwinement one step further by suggesting a post-human and performative approach to computation as material practice in order to go beyond human and nonhuman dichotomies. Sociologist Karen Barad questions the givenness of differential categories of "human" and "nonhuman" and examines practices to identify how boundaries are stabilized and destabilized in order to argue for a levelling of human and nonhuman agency (Barad 2003 p. 808). By this she suggests a new approach to a relation where human intention and actions do not control the material. New materialism offers a framework for understanding how contemporary art concepts are the result of actions and agency similar to those at play in the design of algorithms for data processing. However, the idea of programming for contemporary art participation involves an openness towards use, while programming for data processes requires the opposite. Thus, the integration of computational thinking into visual arts is more than a means for understanding programming and algorithms. Contemporary art promotes understanding of the human and nonhuman 'agencies' based on artistic 'algorithms' for meaning-making with and without the involvement of digital technology. This opens a wider societal perspective on teaching computational thinking and artistic practice because the asymmetry between man-machine where man has the control of the machine is levelled.

5. Visual art education instrumental, human judgement or social material practice?

When we engage computational thinking in visual arts education, we develop new perspectives to understand and practice art as a social and material enactment of human and nonhuman actions that constitute meaning. Producing a clay figure is neither an act of artistic inspiration nor a matter of transforming hidden meaning into material expression; it is instead a *negotiation* of meaning making. By applying a socio-material perspective to activities in the school subject, the learning objectives in art education will change from traditional and modernist ideas like the following: when children make art they are creating original works, the production process consists of individualized and personalized expressions, development of technical skills means manipulation of a medium, such as canvas, clay, or paint, or works of art are finished and fixed pieces that are produced in school (Buhl 2017). Furthermore, technology used for art production will go beyond digital applications that re-mediate analog practices like painting and facilitate development of new art processes by which students design concepts for visual social practices of meaning making. Art practices offer the possibility to design open-ended algorithms that invite participation. But what happens to the human judgement in a new material understanding of computational thinking and art practice? What happens to Denning's claim of the societal perspective? Technology as integrated into the school subject may take on a new role and transform visual arts education to a point at which technological understanding is neither a tool for artistic expression with which students experiment using devices and applications nor a topic for artistic expression through which students inquire and explore the societal implications of man-machine in a world of social media, algorithms and mobile technology. Contemporary art currents and new materialism theories suggest a third path on which technological logics and social inquiry are integrated learning modes. This may be the rationale behind the Danish initiative of technological understanding in visual arts education.

6. Conclusion

The merger of technology and the subject of visual arts raises some concerns with regard to learning and new thinking patterns. Technology educators Mayes and De Freitas (2013) discuss three interconnected learning paradigms that sum up how technological education is approached: the associative learning paradigm referring to programmatic learning and training programs, the cognitive learning paradigm referring to individual and constructive learning activities and the situated learning paradigm referring to social and practice activities. Lessons learned from previous initiatives (c.f. Caeli and Bundsgaard 2018) call for serious consideration of which learning paradigms to draw on. For one thing, pedagogical traditions from different disciplines will challenge both transdisciplinarity and collaboration because they are rooted in different ideas about what constitutes knowledge. This paper's discussion suggests that technological understanding may hold potential to bridge computational thinking and visual arts education following a so-called third path in schooling. But the realization of the third path is influenced by professionals from other domains of knowledge and stakeholders following other agendas in and outside school than what emerge from developing art pedagogy. Thus, the conclusion of this paper is formed by unanswered questions: What will be the role of technological understanding in visual arts education? Will visual artscontinue to be marginalized from STEM education and if; is that good or bad for the students' ability to cope as future professionals and citizens? Will we witness a regression to old behavioristic learning practices from computer science, or will we succeed in formulating problems, solving problems and contextualizing problem solutions based on critical, social and democratic negotiation? Will technological understanding become an addition to a modernist art paradigm or will new theoretical developments of levelling human and non-human 'agency' transform art pedagogy into socio-material art pedagogy and provide new art - and new technology practice? Only time will show.

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