A Framework for Computing Education: Hybrid Interaction System

The need for a bigger picture in computing education

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ABSTRACT

This theory and philosophy paper deals with the question how computing education can be framed. Against the background of the explosion in the field of computer science, the question arises as to what should be taught - and this answer is ultimately related to the normative questions as to why should be taught.

The framework presented in the paper is intended to discuss this question from the perspective of educational theory. Our approach does not start by trying to capture “the nature of the discipline” as is usually done, but by asking what we need for “educating the nation’s young”. This does not mean that educational considerations should exclude the discipline, certainly it is still the primary reference, but not the only one. In our framework, education is understood as transformation of self-perception and world-perception. Based on this understanding of education, more precisely *Bildung*, we approach the question of what is a useful general educational perspective about computing, and what and above all why it should be taught in schools. Our answer is a didactic model that pursues the central idea of a reciprocal interaction between a human and a digital artefact.

CCS CONCEPTS

• **Social and professional topics** → *Model curricula*;

KEYWORDS

Philosophy and Purpose of Computing Education, Framework, Bildung, computing education, Hybrid Interaction System, reciprocal interaction, self-perception, world-perception, digital artefact

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1 INTRODUCTION

In this paper, we discuss the question of how computing education can be framed in the classroom. Our approach does not start by trying to capture “the nature of the discipline” as is usually done, but by asking what we need for “educating the nation’s young”.

As in open source, where there is “yet another tool” to solve some particular problem, we think that despite a lively discussion and ongoing tradition in computing education there are yet some issues to solve. This does not imply that existing approaches are invalid. But necessarily all educational approaches reflect a discussion on current issues, and they are tied - probably implicitly, to “people’s hopes and expectations for educating the nation’s young” - and these naturally differ, so that education is a contested field [4, p. 17].

In addition, “all scientific observations are “theory laden” (Kuhn, 1962 [18]). That is the choice of what to observe and how to observe it is driven by an organizing conceptionexplicit or tacit of the problem or topic” [4, p. 62]. One such “organizing conception” is the assumption that computing education models are derived from a discussion of the discipline.

To repeat: Our approach does not start by trying to capture “the nature of the discipline” as is usually done, but by asking what we need for “educating the nation’s young". However, it must be made clear that the discipline with its concepts and fields of knowledge should not be completely ignored. Rather, the question “What do learners need to cope with in their future lives and how can they develop into self-determined and responsible citizens” should be addressed. In our opinion, this question is closely linked to even concepts of discipline, because computing has a direct and conspicuous impact on our everyday and professional lives. The goal is a mature, self-determined participation and to prevent human beings to be controlled by technology. We will explore how far this idea guides the development of a framework for computing education that hopefully adds to the debate, helps to explicate so far implicit assumptions, to ask new questions, and to get new perspectives for so far overlooked or under-attended aspects and goals of computing education.

The reader might think this approach must be even more “contested” [4, p. 17]: How can we be able to define what the nation’s young need? Isn’t it easier to define the nature of the discipline, or at least agree on core ideas of the discipline? However, even then there would be the follow-up question of why such core ideas are valuable for educating the next generation, and should be learned by everybody at school.

To sum it up: The classic approach in the debate on computing education is to think about the discipline and argue for valuable elements of the discipline, with the implicit assumption that aspects valuable in the discipline are also valuable in society and for the future life of current school kids. In this approach the argumentation is reversed: Asking what kids need - with the implicit assumption that aspects of the computing discipline will occur. And this implicit assumption (well not so implicit now that we talk about it) is our "organizing conception" that guides where to look in order to find suitable answers.

The paper is structured as follows

(1) The notion of *Bildung* as the starting point for conceptualising computing education
(2) Introduction of the model
(3) Contextualising the model in different strands of research - includes a discussion of related work
(4) Summarising the model (based on the discussion in the prior section)
(5) Preliminary conclusions for the model, and future work / open questions

2 *BILDUNG* AS STARTING POINT FOR CONCEPTUALISING COMPUTING EDUCATION AT SCHOOL

In this section, we want to find an overarching principle to answer the question of what kind of education should be aspired to (in the current situation). The focus is on answering the following question: What is the goal of (computing) education and why should students learn certain contents? To do so we need to touch upon educational theory. We do not give a general account of this field of research but rather present the context or frame within educational theory we rely upon.

We focus on aspects that are best described with the term *Bildung* within the German and Scandinavian tradition of didactic (see e.g. [43]; as is also done in the debate in other domains like e.g. music education [23], or chemistry education [32]).

Let's start the discussion by quoting a similar discussion in science education [13]. The authors of that summarising article point out a general impression that "the content of school science and its related pedagogical approaches are not aligned with the interests and needs of both society and the majority of the students [...] One key problem seems to be that few science programs around the world teach how science is linked to those issues that are relevant to students' life, environment, and role as a citizen" [13]. We believe discussing this problem of "linkage" is also worthwhile for computing education.

In order to remedy the situation the article discusses models of science teaching, including educational theory. The aim is to find out what learners need to cope with in life. What are the contents, abilities and skills you need in everyday life? Such a theoretical foundation they claim is specifically "found in the central European tradition of *Bildung* in its contemporary interpretation as *Allgemeinbildung*" [13, p. 1643].

The reader might look into that paper for a first starting point in the discussion of *Bildung* and *Allgemeinbildung*, as well as in the paper of Hopmann [15, p. 115] who states that:

> the word as well as the concept of *Bildung* is hardly translatable to English. Stemming from medieval mysticism and romantic Weltanschauung, the word combines elements of education, erudition, formation, experience, and whatever else is used in English to denote the process of unfolding individuality by learning. [...] The Didaktik tradition connects to the whole development of this concept, from Socrates' innate ideas to first and foremost Wilhelm von Humboldt's understanding of Bildung as grasping as much world as possible' and as contributing to human mankind' by developing one's own unique self (Humboldt, [1792] 2000; cf. Gonon, 1995; Klafki, 2000a; Luth, 2000). *Bildung* is more than mastery of contents or development of competencies and abilities, more than "knowing something" or "being able to do it".

The important insight is the last sentence of the quote: there is more to computing education than teaching and learning of knowing something and being able to do something. *Bildung* denotes the idea of individualisation, self-fulfilment and the ability to develop one's own innate capabilities - and only thus allows to participate in society as an autonomous, self-determined and also responsible citizen.

Biesta summarises the overarching goals of education in this sense (including *Bildung*) within the following three dimensions: Qualification (learning knowledge, skills, etc), Socialisation (enculturation to society), and Subjectification (develop one's own personality, autonomy, and responsibility) [1].

Within the above-outlined tradition of *Bildung*, Marotzki [21] points out the reflective and reciprocal nature of *Bildung*. And this nature of *Bildung* is central for our conceptualisation: *Bildung* is a **transformation** of the individual. Learning - as defined in opposition to *Bildung* - is merely equipping the individual with knowledge and the ability to do something, whereas *Bildung* is the innate development of one's own capacities [21].

The additional contribution of Marotzki is to work out that such *Bildung* is based on interaction with the world, e.g. in our case interacting with digital technologies and ideas from computer science. In so doing, something is learned, and if that learning gives the individual a new perspective of the world, the learner itself is transformed and can reach a new perception of oneself, and in that development also increases the innate capacity for freedom, which can be operationalised as a higher variety of choices how to act (here Marotzki refers to Bateson's ideas of learning1, learning2, and so forth - maybe Gregory Bateson is more familiar to English speaking readers).

In summary, in our model, learning is not conceptualised as learning facts and skills only, but as learning a point of view on the world. As a consequence, education / *Bildung* is conceptualised as relational and that is the core idea we learn from Marotzki: education as interaction: By interacting with the world we transform the world (literally, and our view on the world), and at the same time our self is transformed, too.

In a more practical representation of the consequences, we use the wording introduced by Tiefel, who operationalizes three core consequences of *Bildung* for empirical studies. These are useful to add some depth and detail in the model: Henceforth, *Bildung* (including education, and learning1 and learning2) always and simultaneously addresses the following three dimensions [38]:

WV A transformation of the individual's perspective on the world (We call it worldview)

SV A transformation of the individual's perspective on herself (We call it selfview)

H A transformation of the individual's choices to act, leading to new (We call it habits)

3 INTRODUCTION TO THE MODEL OF HYBRID INTERACTION SYSTEMS

As outlined in the introduction, we discuss the question of *Bildung* in a way that we assume aspects of computing are likely to occur. To do so, we describe and analyse how people interact with computational artefacts. By computational artefacts, we mean essentially the same as digital artefacts [27] or different forms of computer technologies.

At the core of the model is the interaction between the two actors: the human being and the technology. This shall be referred to by the term "hybrid". Both parties have their own characteristics and intentions that influence the interaction.

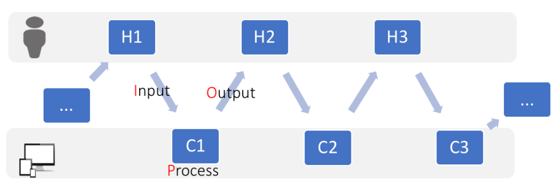

Figure 1: The IPO model in the context of hybrid interaction

The interaction can be understood as a chain of actions that goes back and forth between the two parties: "...human action followed by computer action followed by human action...". Globally, it is difficult to work out a so-called starting point. Who controls whom here and who is controlled by the other? [26] This question cannot be answered clearly and generally. Rather, individual interaction sequences have to be taken care of and analysed in context.

Overall, both parties are actors which are shaping and at the same time are being shaped by the Hybrid Interaction System. The roles and nature of one of the actors cannot be fully understood without the framework or context of the Hybrid Interaction System which they are part of.

Let's discuss the implications of this conceptualisation in some more detail: A common principle often used in the context of teaching about artefacts is the Input-Process-Output (IPO) model. It describes a basic principle of data processing, see figure 1. But this principle does not account for the whole picture. Analysing digital artefacts based on the IPO-model would mean to consider interaction only as isolated steps, e.g. H1 (human interaction 1) followed by C1 (computer interaction 1) to H2.

This would lead to a conceptualisation, in which interaction would be pre-defined because the interaction is driven by algorithmic processing only. The user would thus only have limited and predefined options for action. The human user would have to adapt to the given interaction. For the designer, it would mean that he would have to estimate all possible actions and reactions at design time and build the artefact according to these models. However, this contradicts the image of an adequate IT system. There are no (or not so hard formulated: not only) predefined interaction processes. However, it must be acknowledged that the extent to which a system is changeable and open to a variety of interactions depends on the artefact itself. However, especially in the sense of self-determination, artefacts should be considered and developed in relation to an open interaction and influenced by both actors. In the sense of education, people should be able to act independently. Human and technology act as equal parties of action, influencing each other. Thus, a designer no longer creates an informatics system with fixed processes, but rather an interaction context in which human and machine can act. Both actors have the chance to develop further in this system. Only in this way a designer can create an adequate IT system that is prepared for interaction.

Interaction can be seen as relation (remember: an important term within our view on *Bildung*): We are shaping the computer, by giving input in form of data, commands, or even programs - and in turn we are being shaped by the output from the computer, when e.g. specified navigation steps are followed by a digital form or requested data is entered by us (e.g. when filling out a flight reservation form). In order to see the nature of this dynamic relation, we have to widen the picture (as we have already done, implicitly) and discuss interaction pathways, see figure 1.

Bildung is then to become aware of this dynamic relationship, and not only (blindly) being part of the relationship or system. In fact, the term system seems appropriate here. It is a system of two different kinds of actors, hence a hybrid system, and it is defined mainly by the interaction between the two, hence we speak of a Hybrid Interaction System.

So for *Bildung*, the core is in big contrast to all classic approaches we are aware of, not to reflect on the computer itself (or algorithms, or programming, or computational thinking all of them isolate the technical actor from the hybrid interaction pathway), but to reflect on the system as a whole. This implies to reflect on the role of humans in light of everyday and ubiquitous and calm computing [41] and the role of the computational artefacts in this system, who can be seen as actors, too (for this terminology and the implication see e.g. [20], but we will not follow these implications in this paper, that has to be done elsewhere.). The greatest and probably most important new insight is that there is also the need to reflect on what we are as humans. That is, computing education is also art, its core is not (only) educating about computers and the associated academic discipline, but to learn about oneself. This is perhaps the most difficult but to the same extent the most important part of the approach: it is about individual further development in the context of the Hybrid Interaction System. By looking at the interaction between humans and digital artefacts, both actors change and evolve. In the sense of the threshold concepts, it can be seen as a kind of "conceptual gateway" or "portal" [22]. Through this way of dealing with the interaction with digital artefacts, the learner can develop further and become a self-directed actor in the Hybrid Interaction System.

As a systems approach, it is of course not only about one part, the human, but also on the other core parts: the computational actor, and the process of interaction, too. Figure 2 gives an overview.

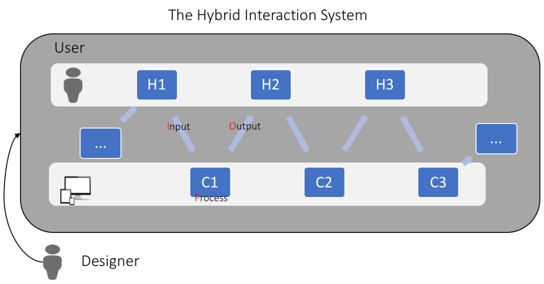

Figure 2: The context of the Hybrid Interaction System

4 CONTEXTUALISING THE MODEL IN DIFFERENT STRANDS OF RESEARCH

In this section we will contextualise the model, thereby adding some depth, and discuss related research. The chapter can be divided into three subsections. First, approaches of computing education are considered, see 4.1. Afterwards, our approach is related to discipline and professional context, see 4.2. This chapter concludes with a debate on future work and life 4.3.

4.1 Discussion on computing education

There is an abundance of papers on the nature of computing education, Tedre et al. [35] give an overview, and suggest some major strands in the debate of computing education.

Note, all of them are indeed as claimed above thought from the discipline, and all focus on the technical actor. There is no awareness of the Hybrid Interaction System (HIS) in this overarching and therefore abstracted overview - but that also suggests that the notion of HIS is not considered as central in the historical developments up to the 2000th. There are of course in detail more recent work, we will very briefly mention two:

Computational Thinking: In detail, it is not clear what it is, some see it as the same as the classic algorithmic approach and the algorithmic idea of problem solving, some contextualise it in the programming paradigm [35]. From our model, the notion would be not to design a technology (only), as phrased in this often quoted remark: a computational solution that can be effectively carried out by a computer or a human actor [44]. This notion blurs the differences between humans and technologies because the focus is on the solution. In the HIS model it would be crucial and interesting to analyse and reflect on how a solution differs depending on the actor (the human or digital artefact); and overall the idea would be not to design for either of both, but for and (!) within a Hybrid Interaction System. The consequences of this change on perception of designing and using computational solutions seem manifold, and thus need to be discussed in detail elsewhere - it cannot be done here. With this example, we only want to highlight how the framework of HIS can lead to different perspectives and insights into the debate about computing education.

Information Process: The concept of an information-oriented approach [3] to computing education is an example of focusing the subject matter on "information processes" of all kinds, and aiming at training for computational problem solving as described by Tedre et al. [36]. It [3] frames the discussion about the nature of computing in the different sciences and assigns a certain place to computing within the different areas of science. In summary, the argumentation on defining the core of computing education again starts by thinking about the academic discipline: The study of information processes is at the core of the academic discipline and hence no surprise also the core of computing education is defined in the same way. This perspective would be enriched by taking HIS into account. In its current implementation at school e.g. UML is introduced as a tool for object oriented modelling, and students have to learn the rules of UML. From a HIS perspective they should learn in addition to understand that UML is meant as supporting and enforcing a way to think about the problem of OO modelling - and that besides to UML in computing other tools exist and that progress in computing is tightly interwoven with progress in tools and technologies, because the tools shape the thinking and in turn are shaped by using them to think. In summary, from the HIS perspective this could and would need to be supplemented by the idea of interaction, and how the role of humans changes in this new science. Thus, the focus is no longer on the process of information processing. It's about the interaction between the two actors, but still transporting, processing and modifying information. It is, therefore, a different accentuation of the viewing angle.

This discussion reflects what has happened in science education already: Looking at the didactic approaches, it becomes apparent that the academic discipline is repeatedly used as more or less sole reference point for determining content for the school. A look at other science education shows, however, that an essential step has been taken if the academic discipline is regarded as a reference discipline, but not as the central source of origin from which all discussions about goals, contents, topics and methods can be derived.

This can't be done in this paper, but most likely traces of HIS thinking can be found within the classic view also because also there educational discussions are needed to reflect on the role of science in society, the relevance for everyday life, and the relevance beyond job training.

While the goals mentioned seem relevant and agreeable, the underlying assumption that everyday users would be enabled to transfer abstract principles to concrete use experiences, or even to use academic perspectives in everyday life, is (unfortunately!) too optimistic. Instead, scientific research on learning frequently demonstrates the problems of such transfer, applicability, and change of everyday conceptions with appropriate scientific ones; see e.g. Tedre and Denning discussing computational thinking [35], or the discussions on conceptual change [7].

There is a fundamental question underneath these discussions in computing education that is based on the tension between "education for all" and "Computer Science (the academic discipline) as basis for the curriculum". While this tension is hard to solve, often a (too) quick consensus emerges on the complementary nature of computing education and digital literacy. For example, in a more recent study (as successor of [12]) it is stated that "One of the main goals of this study and report is to clarify and describe the differences between computer science and Digital Literacy, particularly in the context of education." [24, p. 8]. Digital literacy is defined as fluency with information technology, Computing as the science behind information technology [24, p. 9]. Data shows that digital literacy is taught in Europe either as subject in its own, or integrated into other subjects [24, p. 15].

In the report of the royal society on the state of computing education in England after the restart (where ICT and computing were set as different subjects) shows that "the image of computer science can be a barrier to implementation where school senior leaders perceive the subject as specialist' rather than mainstream'." [34, p. 33]. It concludes that "the qualifications framework for computing pupils aged 14 16 is a cause for serious concern" [34, p. 35] and recommends "to ensure that the range of qualifications includes pathways suitable for all pupils, with an immediate focus on information technology qualifications at Key Stage 4." [34, p. 35].

One major issue (that these sources show or indicate) preventing the discipline of computing education research to solve some of the above mentioned issues (terminology, role of CS education and broader education (*Allgemeinbildung*) is in our perspective the idea that computing education and digital literacy are conceptualised as complementary and not as continuous.

The idea of complementarity suggests the notion of being able to competently reach one's own goals in using computational devices without any idea about what happens; e.g. without any understanding of data, algorithm, client server, the cloud, artificial intelligence, access rights, and so forth. But, if there is no understanding, and no explanation than technology becomes magical, and incomprehensible. But if you do not understand the technology you are using, you loose your self-determination. This means that competent handling is only possible in combination with knowledge of the computer. Only by taking a close look can actions be understood and questioned. Without knowledge, actions are perceived as given. This would limit our own ability to act and in our opinion would hinder or even prevent responsible and self-determined action.

On the other hand, it would not be right "only" to deal with computing topics such as algorithms, data structures or protocols. In the context of schools, there should always be a general educational interest in the sense of *Bildung*. In other words, the focus should be on the learner's ability to act and individual development, not just a pure (lazy) knowledge of concepts.

These two directions of argumentation show that ICT and computing education are not complementary fields. Rather, they flow into one wire and areas each other.

4.2 Disciplinary and professional context

If one considers computing and its origin, Tedre and Apiola distinguish three traditions, which bring with them different principles, goals, approaches and methods. Computing has its beginnings in three different but interwoven traditions: the theoretical tradition, the technical tradition and the scientific tradition [16, p. 100]. Depending on the observance of these traditions, a different image and different strands of computer science and thus of computer science teaching emerge. Tedre and Apiola emphasise the different accentuations of the traditions and plead for a conscious consideration of the origin of science itself. However, there is a debate in various sources about a new accentuation of computer science, which can be seen in our didactic approach: A relational framing of interaction. This describes a new role for the computer scientist (and user). It is no longer just about understanding the problem and understanding the solution with the aim of training the machine, which leads to a solution and thus to new follow-up questions. Rather, it is about a new relationship between human and machine, which brings with it a transformation of the relationship between both actors. The computer scientist no longer analyses and models an artefact, but an interaction.

There are a number of approaches that (also) focus not only on the digital artefact itself but also have a wider view of computer science, namely on hybrid interaction:

Peter Wegner formulates for example: "The paradigm shift from algorithms to interaction is a consequence of converging changes in system architecture, software engineering, and human-computer interface technology. Interactive models provide a unifying framework for understanding the evolution of computing technology, as well as interdisciplinary connections to physics and philosophy. The irreducibility of interaction to algorithms enhances the intellectual legitimacy of computer science as a discipline distinct from mathematics and, by clarifying the nature of empirical models of computation, provides a technical rationale calling for computer science a science." [40, p. 91]. A consequence of this approach is to not reduce the question of the solubility of a problem to the mathematical problem but to take into account the contribution of human input in such interactive computations. The idea is that humans can receive input from the machine and process it in different ways than algorithmic computation - and if they feed in the results the overall interactive system supersedes algorithmic computability. This model can be seen as the first outline of a Hybrid Interaction System: Roles of humans, of machines, and their interactive relationship are to be considered in such a model.

Another approach that is interesting in this context is that of Gerhard Fischer [8]. He deals with the role of humans in the context of software development. In his opinion, many new media are primarily conceived with the idea of users as consumers; but for personally meaningful activities, the possibility for people to act as designers (in those cases where they so desire) should not only be accessible to a small group of "high-tech writers", but to all interested persons and groups. For this, he describes different levels of design involvement [8, p. 2]. This perspective adds to the nature of the human input in such a Hybrid Interaction System: Using and designing as a continuum of different types of interaction.

Douglas Rushkoff also deals with the interaction and handling of digital artefacts. In his book “Program or be Programmed” he deals with the context of the role of technology in everyday life from a more normative or moral perspective [26]. “The debate over whether the Net is good or bad for us fills the airwaves and the blogosphere. But for all the heat of claim and counter-claim, the argument is essentially beside the point: it's here; it's everywhere. The real question is, do we direct technology, or do we let ourselves be directed by it and those who have mastered it?” [26] It is clear that the role of interaction is connected with the question of self-perception, the worldview and the associated patterns of action.

Wicker in CACM [42] argues in the context of legislation of smartphones that a “data-centric focus ignores an equally important issue: the nature of the relationship between smartphones and their users”. He summarises that “Phenomenology, AI, and extended cognition thus suggest that when we interact with “external” objects such as our smartphones, cognition is taking place in a system that includes both our persons and the phone. [...] we actually offload cognitive functions from our (internal) selves onto the phone.”[42] This notion could be seen as the counterpart to the first model in this section, where Wegener discusses the role and capacity of the machine that would be enhanced by human interaction. In this perspective, vice versa the human cognitive capacity is enhanced in the interaction process. Thus interaction pattern should be better explainable and describable when they are contextualised within the framework of a Hybrid Interaction System, in which both actors (the technical and the human) are taken into account.

In summary, a comparison of the different approaches shows that the interaction between humans and artefacts is often at the centre of attention. There is an increasing focus on the different levels of interaction, the understanding of roles and the mutual effects. Unfortunately the digital world of automation, algorithms and virtualization is often understood in public debate as the other, in contrast to the real analogue world. Accordingly, there are real jobs for real people in the analogue world, which disappear into the digital world of computers and are thus outsourced - automatically, like a black box hidden and no longer accessible to people. The view of Hybrid Interaction Systems, in which humans and machines interact, designs a different perspective in which technology is not set against the human, but is seen or designed as a cooperation of human and machine. A Hybrid Interaction System can only be completely described and recorded if both the qualities of the human actor and the qualities of the digital actor are understood as a unit - as a system. And this can be understood as the new core, i.e. the “big picture”

Here, however, the question arises whether this principle of interaction in the hybrid sense does justice to this. Is it sufficient to concentrate on individual interaction steps or should the individual actions not be seen much more in the context of the entire interaction (H1 - C1 - H2 - C2 -....)? An interaction is shaped by the previous experiences and characteristics of the person, the technical actor and the context in which the interaction takes place. Here, several dimensions meet that influence the interaction. Therefore, the view that a ready-made system that is “prepared for all” interactions is obsolete. Rather, the design time blurs with the time of use [8]. In the interaction itself, we change the digital artefact and also the digital artefact us. We react to a so-called output, which then has an influence on the next human action. Through this action, which only arises during the action, we, in turn, change the artefact. This leads us to the conclusion that a developer no longer creates a technical artefact, but rather a Hybrid Interaction System that encompasses the chain of interaction between human and artefact. From a designer perspective, it is clear quite long that designing information technology means to design interaction, and that while ”we shape technology, technology shapes us” [19, p. 141].

For figure 1, this means that the designer no longer only has an influence on the technical artefact, but also designs the Hybrid Interaction System, see figure 2. But this should not lead to the misconception that the designer now designs the interaction and then understands it as a product. A Hybrid Interaction System must be understood as a dynamic and changeable system in which, as we have just said, design and working (or use) time are blurred - see for example [8].

Overall, one important aspect is to perceive the process of interaction as reciprocal, with effects on both actors, and on the process itself. This perception is a prerequisite to be able to really understand what is going on, and thus to be able to act in a responsible and self-determined manner.

4.3 The debate on future work and life

After looking at the Hybrid Interaction System in the context of the discipline in the last section, the view is now to be broadened. The didactic model presented here is intended to analyse computing processes from the context of general education. This raises the question of what the future of learners will be like? What do they need for their future private and professional life? Thus, in this chapter, the didactic model is set in the debate on future work and life.

According to a report by the World Economic Forum [9, p. 3], 65% of the present primary school children will have professions in the future that do not even exist today. The consulting firm cognizant has prepared a study thinking in this direction with possible new job profiles that will emerge in the next ten years and will shape future professional life [25]. Among the 21 job profiles presented are, for example, “data detectives” who make data speak for itself and reveal the knowledge and secrets contained therein, and “man-machine teaming managers” with the following job description: “developing an interaction system through which humans and machines mutually communicate their capabilities, goals and intentions, and devising a task planning system for human-machine collaboration. The end goal is to create augmented hybrid teams that generate better business outcomes through human-machine collaboration” [25, p. 30]. The “Man-Machine Teaming Manager” has the task to work effectively with and in Hybrid Interaction Systems.

The important role of technical actors in everyday life is undisputed. Digital artefacts are used, explored and evaluated on a daily basis and in almost all situations. There are many approaches that analyse and try to understand the perception and understanding of technical actors. ICILS [2], for example, focuses on the use of the technical actor, i.e. a kind of external view, whereas the standards recommended by the GI [11] are more oriented towards internal concepts, the principles of action. [1]

But the question arises, what does it mean to understand the digital artefact in the interaction? When can a learner interact competently with it? If the two approaches of ICLS and GI standards are combined, two different perceptions of the digital artefact can be identified. The dual nature is described in various literature. According to the dual nature of technical artefacts, however, two different perspectives of explanation and understanding belong together: One perspective aimed at the structure or architecture (where these principles of action recur - it‘s the so-called analytical perspective) and another at the function or relevance, the interpretive perspective, i.e. the benefits (where the ICIL study and often the debate on digital education are focused).

The dual nature can, therefore, be seen as an essential characteristic of technical artefacts. However, this does not depend on the technical actor itself but describes various points of view. Besides Kroes [17] and De Ridder [5], other approaches can be found in which the idea of duality is recognised (within part different aspects and concepts). A quick view in different works of computing education where this duality was also recognised can be found in [28].

However, both perspectives are connected - they are not detached from each other. They are always linked together, albeit sometimes only implicitly. That is, a person may shift attention on one of the two sides of the duality. A very important aspect of this is that during the process of "doing" computer science, like e.g. exploring, using or designing, the view of the duality is changing. In some phases, the focus is more on the interpretative perspective of the system, and questions about the intended use or importance will be considered. If the focus is on the analytical perspective, questions about the structure, e.g. some specifics of the mechanism to be implemented, are discussed.

The dual nature of digital artefacts, in summary, requires to be able to perceive or focus on a) the architecture (structure, mechanics, ..), b) the relevance (intention, function, meaning, interpretation, context), and c) the connection of the two roles. In addition, this can and probably needs to be done on the level of a feature of the digital artefact, and on the level of the artefact as a whole. Note, being able to perceive and analyse the digital artefact from within the different perspectives is only a first step. If, for example, one is able to understand and perceive that some processes are of an algorithmic nature, this does not mean that the algorithm itself is understood or perceived correctly.

It might be surprising, but to correctly understand the architectural (analytical) perspective, e.g. the workings of algorithms, data, protocols, ... is probably the easier part. This part of the duality can be objectively decided upon. But the differentiated interpretation of the relevance, the impact and effects (the interpretive perspective) is probably much harder; and there is no way to objectively decide on the rightful interpretation and critical reflection [5, 17].

Figure 3 graphically illustrates the duality in relation to a digital artefact. It should be mentioned one more time that an interaction (which can represent an exploration, a design,...) usually does not address **the** artefact as a whole, but mostly refers to single features.

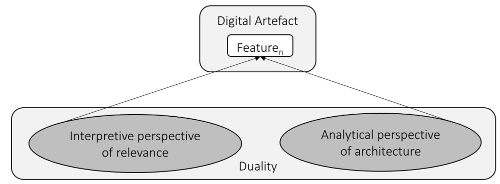

Figure 3: Dual nature of digital artefacts

To conclude this section, we would like to summarise once again the core message of what our framework means in the context of future work and life: The human actor and its actions are understood and developed in the context of this Hybrid Interaction System and the relational *Bildungs-* perspective and as such cannot be reduced to which knowledge has been acquired.

In interaction, people should shape and evaluate their own role in a self-determined and responsible manner. The role of the human being should not be characterised by an adaptation to digitisation. Rather, the active participation and development of interaction are to be focused. Aims in this context are therefore an enlightenment that enables people to act in a self-determined, reflected and personality-forming way in their interaction with technical actors.

5 SUMMARISING THE MODEL

In the last subsections, the model was analysed and described in more detail in the different strands of research. Figure 4 summarises the key statements once again.

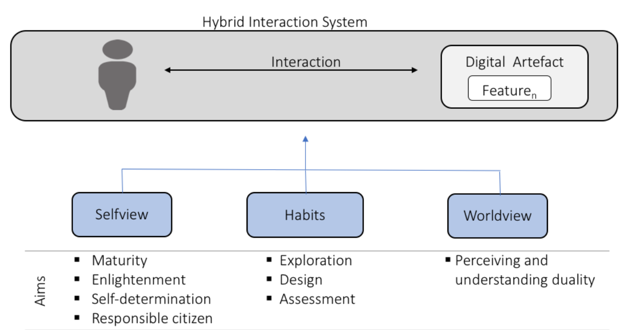

Figure 4: Formation of Hybrid Interaction Systems

The understanding of digital artefacts as Hybrid Interaction Systems comprises a number of concepts and aspects, which are summarised in the following section. Section 6 then summarises the intention and core message once again and refers to the school context (and thus teachers and learners).

At the core of the approach is the interaction between two actors: the human being and the technology. Both are actors which are shaping and at the same time are being shaped by the Hybrid Interaction System. The roles and nature of one of the actors cannot

[1] To our knowledge, however, there is no theory of working principles and no pragmatic list of the most important examples. We cannot, therefore, build on the concept of working principles.

be completely understood without the framework or context of the Hybrid Interaction System which they are part of.

The technological actor, the digital artefact has to be addressed in terms of its general nature. We perceive the nature of digital artefacts as a dual nature, see figure 3.

In general, interaction in the sense of the Hybrid Interaction System should be considered on different levels, for example on a global or local level. Based on individual conflicts between digital artefact and humans, conclusions can be drawn about global effects. Questions like "What are the effects of my actions? What are my possibilities of action and influence?" can be considered.

With reference to the human actor, the article and the basic concept of the approach repeatedly referred to the understanding of *Bildung*. The interaction is characterised by the goals of self-determination, responsible action and the maturity of the learner. It is, therefore, a kind of enlightenment in the sense of interaction itself and the students. In the interaction itself (which can represent a kind of exploration, design or assessment, for example) they should be able to act in a self-directed manner and thus pursue their own goals in the Hybrid Interaction System. So the human actor and its actions are understood and developed in the context of this Hybrid Interaction System and the relation a *Bildungs*- perspective and as such cannot be reduced to which knowledge has been acquired.

It must be repeated that the aspects and concepts mentioned here must always be understood in terms of *Bildung*. It is about a relational understanding of *Bildung* and includes the transformation of the individual perspective of the world and of oneself (WV and SV). But also the behaviours and the way of interacting, i.e. the habits (H), change or consolidate.

6 DISCUSSING THE MODEL

This theory paper aims to outline a didactic approach that can answer the questions of what computing education is and how it can be framed in school. A new characteristic of this approach is that it addresses this question from an educational theoretical point of view and does not take the discipline as a starting point. The model of the Hybrid Interaction System is intended to answer the question "Why do students learn?" This answer is important both in the research context and concretely for the school. Teachers and students should be able to question the setting in class and see an implication for their lives.

A central challenge for teachers (of computer science) is the examination of the overall context of the teaching content. That is our main concern, so to speak: How can we handle, name and make this overall picture tangible? In other words, how can content in computing education be conveyed in a real, true and comprehensive context so that implications for every day, competent action arise? Our first feeling here was that the problem is probably that a coherent overall picture is not made conscious at all and that the right language, the right concepts and a coherent model or framework for such an overall picture is missing. And this is probably due to the rapid developments and paradigm shifts in computer science as an academic discipline, but also in computer science, or better: technology and IT as everyday experience (see 4.2).

This, so to speak, constantly changing role of IT and thus current topics in computing is a challenge, because it also changes the needs and the relationship of users, but also of experts to digital artefacts and IT. So what and why exactly should be taught in class? It was also the concern of Schwill's fundamental ideas that the topics cannot be transferred to school at such a rapid pace [29, 30]. However, we do not prefer the way of thinking about computing in school from a disciplinary point of view. The question is, what are the skills you need in everyday life at these frantic speeds? What are problems and contents that enable learners to develop their personality? However, this question should not give the impression of being less complex - it only conveys a different accentuation, namely in the sense of the term *Bildung*.

So our main idea is to propose not to teach and focus on one of these relationships or the concrete application. Instead, we propose to educate in a way that explains and visualises such a relationship and is thus open to criticism, reflection and thus to development of new forms of relationships. We focus on the interaction with digital artefacts in a kind of overall system. The focus is on the reciprocal interaction between humans and digital artefacts, which provides a framework for personal development and the abilities and skills related to interaction.

This includes the disclosure of the interaction itself, the understanding and the role of the digital artefact through different perspectives and thirdly the view of the different patterns of action within this system. Focused ideas are that on the one hand one's own role in the digital world changes / solidifies / sharpens and on the other hand the transformation of the relationship to discipline and IT is influenced. These two transformations can be seen in the understanding of the mutual relationship of interaction: The system of human and artefact is influenced, determined and changed by the interaction. This view of computer science education eliminates the rather depressing and resigned image that people adapt to digitisation. Rather, a general **visual** concept for the design of the digital world is created - the task of computing education should, therefore, be to perceive digital artefacts as designed and designable objects. We determine the environment through our interaction and can thus influence it independently.

This view of the big picture [31] of the Hybrid Interaction System can be seen as a kind of counter perspective to another threatening view of digitisation. This view of full digitisation is described as the beginning of the fourth revolution (cf. e.g. [33]). From the perspective of the labour market and the economy, this was prominently discussed by Frey and Osborne [10] in the context of automation: The increasing outsourcing and automation of intellectual processes through Big Data and AI, which can also kill off the demanding so-called "white collar" jobs instead of the "blue collar" jobs.

In this reduced sense, creating Hybrid Interaction Systems means a kind of optimisation task: adapting people and their user competence to the digital counterpart for better productivity (cf. also [6], [14]). This reduced technology-focused (mis-) interpretation of Hybrid Interaction System leads to focus on mastering the technology and at the same time to similar notions of mastering human behaviour in terms of ensuring that humans behave as intended in terms of the goals of the designer. This means an adaption of human being too technology. In this sense, the idea of mastering the technology (or as it was formulated in some curriculum document: fluency with technology as the ability to use a system competently) becomes to "act in the right" way, with the implicit notion of learn to behave in the pre-determined way, and to adapt to the system.

Note, such adaption might make sense in e.g. some areas of industrial production. But the danger is that such a view is spread to all interactions with digital artefacts, also in e.g. private life. But it's about one's own experience, one's own life - even time spent online is real lifetime. And just as we want to feel at home and familiar in real life, we also want to do so in future hybrid living environments - and not at the mercy of incomprehensible artificial intelligence's.

This latter use in the context of artificial intelligence allures also to the debate in that field of a new computer science (of course, we need to be aware of Tedre/Denning: It may not be enough to think only about this new computer science [45]). Nevertheless: The new computer science and what is so fundamentally different can be explained in our proposed relational framework: As it is usually defined as a new role of computer scientist in relation to the machine: from understanding the problem and understanding the solution to training the machine that will come up with a solution, and hence new follow up questions for responsibility. And also a new relationship between human and machine. This includes the idea of a transformation of the relationship, which must be made conscious and reflected upon - and that is the cornerstone of *Bildung*!

7 CONCLUSION

In this article, we have presented a framework for computer science. In contrast to (many) already existing didactic approaches, we do not derive the model mainly from the academic discipline of computer science. Instead, we focus on the hard to translate theory and idea of *Bildung*. The focus is on the bigger picture of a Hybrid Interaction System, which should have effects on the world-view, the self-view and possible habits of the learners. We call the interaction in the Hybrid Interaction Systems our rationale [37]. However, further work is needed: The approach must still be made manageable for concrete teaching and curriculum development. In the current approach, several dimensions, perspectives and target levels are addressed, which in this form cannot directly lead to concrete teaching. Starting from the rationale, individual components of a curriculum [37] must then be differentiated. Components of a curriculum such as "goals and objectives" or "content" must be clarified, modified or refined on the basis of the approach of the Hybrid Interaction System presented here. The different components influence each other, which leads to a mutual new accentuation (which can also include a congratulation or differentiation of the justification).

It should be noted that this does not mean that existing content has to be completely rewritten. Rather, the model should contribute to increasing the relevance and value of the content in terms of general education (*Bildung*).

These work indicate a first direction for further development and work. This article and the work so far can, therefore, be interpreted as a first accentuation and direction. It is important that further refinements and differentiation's should focus on the core of the framework presented here. The core is the *Bildung* approach that computer science education is to be understood as a relational education. By dealing with interaction in the Hybrid Interaction System, not only the world itself but also the world of the individual and society is actively co-determined and changed. In concrete terms, this means that by interacting with a digital artefact I can create new data myself and thus modify the Hybrid Interaction System. It is therefore not an adaptation to the digital world, but an active participation in shaping the digital world. How far the co-designing turns out to be and what the type of interaction looks like must also be discussed, based on the framework. An active design and influence cannot stop in the use of prefabricated interfaces but must contain an active exploring, designing and changing (i.e. programming). As a consequence, it means that one does not design technology, but society - that one designs, modifies and actively (re)designs a HIS. Here in the article, the focus was on interaction at the individual level in the presentation of the framework. Analyses and differentiation at the level of (peer-) groups and at the level of society would have to follow [31, p. 67]. Especially, if the framework presented here is extended to the societal level, the active participation in shaping society and also ethical questions become more and more central to the approach. As a consequence, this means that further theories and research strands, such as cybernetics, must be discussed.

In conclusion, we want to make clear once again that we believe that this didactic perspective represents a so far often overlooked way of thinking about didactic approaches in computing, but should by no means eliminate other approaches. Rather, the debate should be supplemented. So far, we have seen very diverse reactions to this approach (for example when discussing the approach with pre-service teachers). While most are very enthusiastic about this new perspective, some react a little confused or even angry. We attribute these different reactions in part to different "organising conceptions" [4, p. 62], or "curricular beliefs" [39], as reported for chemistry teachers: FC (fundamental chemistry) is the belief that the subject needs to be organised around the core ideas of the academic discipline, CTS (chemistry, science and technology) is the belief that the school subject should focus on the role and contribution of the subject for coping with everyday life. If someone thinks about K-12 education in computer science only in terms of the fundamental ideas of the (academic) discipline, the idea of HIS really must be very strange or confused. Nevertheless, we hop by explicating the framework to be able to articulate the possibly also in computing different beliefs and organising principles - and this is the first step to engage in a scientific and academic discourse on different assumptions, frameworks and goals of computing education.

We want to end with one additional theoretical concept, further explain why we believe this approach is so important; and why we think there is a need to frame computing education (also) as education about one-self as in *Bildung*: Understanding what defines us as human beings, our role in life and society; and to contribute to self-determination.

The concept is borrowed from research in system theory and the debate on socio-technical systems: A social system is autopoietic: It can be influenced from the outside, but not completely controlled. It is in a way self-organized.

On the other hand, there are systems that are labelled as allopoietic: Such a system is completely controlled by its design, and functions according to its internal mechanics or architecture. It thus

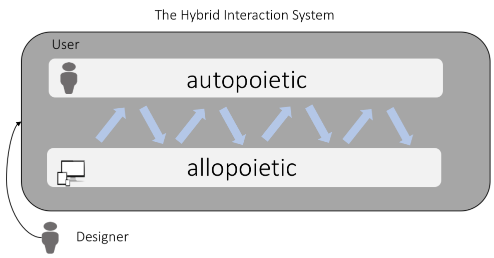

Figure 5: Assemblage of an autopoietic system and an allopoietic system

can be completely controlled from the outside. Usually, technical systems are depicted as allopoietic systems: They should behave as designed and be controlled by the operator (who is outside the system). A Hybrid Interaction System now can be seen as an assemblage of an autopoietic system (the human actor), and an allopoietic system (the technical actor), see figure 5. And this raises several questions: For example, if the technical part of a sociotechnical system like our notion of HIS is controlled by some external designer it might become possible to exert influence on the social (sub-) system in a way that might even change the former autopoietic system in an allopoietic one. In this way, a user as part of a HIS and unaware of these issues indeed might be subjected to far greater external control in everyday life. On the other hand, enabling such users to become designers of their HIS allows them to become self-determined by influencing the technical part of the HIS - the key is the notion that only(!) being able to influence the technical part allows to become and stay a self-determined human being in the age of ubiquitous Hybrid Interaction Systems.

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