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ARIadne –
An Explanation Model for Digital Artefacts

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Abstract. When it comes to mastering the digital world, the education system is more and more facing the task of making students competent and self-determined agents when interacting with digital artefacts. This task often falls to computing education. In the traditional fields of computing education, a plethora of models, guidelines, and principles exist, which help scholars and teachers identify what the relevant aspects are and which of them one should cover in the classroom. When it comes to explaining the world of digital artefacts, however, there is hardly any such guiding model. The ARIadne model introduced in this paper provides a means of explanation and exploration of digital artefacts which help teachers and students to do a subject analysis of digital artefacts by scrutinizing them from several perspectives. Instead of artificially separating aspects which target the same phenomena within different areas of education (like computing, ICT or media education), the model integrates technological aspects of digital artefacts and the relevant societal discourses of their usage, their impacts and the reasons behind their development into a coherent explanation model.

Keywords: digital artefacts, digital literacy, computing literacy, bildung, educational model.

1. Introduction

Today's students and teachers are more and more living in a world full of digital artefacts[2]. One can therefore consider the knowledge to use, transform, create and adapt

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[2] In this text, we use the term "digital artefacts" to encompass digital tools, computer systems of any kinds, parts thereof, and the way they are interconnected by technical means. It includes both software and hardware, as well as data objects, such as digital text documents. It can also refer to techniques and concepts, such as algorithms, functions, or procedures of a software product. When using the term "artefact" we typically do not refer to particular incarnations, such as a particular installation of Microsoft Word on one's computer, and not even to a certain version of a word processor, but rather refer to artefact classes and their distinctions, e.g. what distinguishes a word processor (like MS Word) from a simple editor (like Notepad) or from a text layout system (like LaTeX).

these artefacts to be an essential part of education in general and of computing education[3] in particular.

This "new" relevance for everyone poses a challenge to computing education. While in the past, computing typically was a subject mainly chosen by enthusiasts, with more and more educational systems acknowledging that everyone has to acquire knowledge and skills regarding the digital world, both contents and methods of computing education need to be reevaluated. However, as Guzdial (2021) points out, such a reevaluation has not yet taken place. He identifies several possible target audiences for computing education: There is the rather small group of those whose goal it is to become computer scientists. Then, there is a somewhat larger group of those who need to be versed in certain areas of computing without themselves having a desire to become computer scientists. Finally, there is by far the biggest group of those who are not primarily interested in computing as such, but still need to know enough about it, to know what it is about and how to make good use of it for their individual needs and desires. They also need to develop enough knowledge to avoid risks associated with information technology. While this group of pupils is by far the largest, Guzdial concedes that the majority of computing classes still treat their pupils as if they all wanted to become full-blown computer scientists.

For those pupils who indeed want to become computer scientists, current computing education approaches based on theoretical foundations and concepts of computability[4], on professional software development and on programming methods might indeed be appropriate. For the big majority of the others, however, an approach to the digital world which is less focused on its underpinnings but on properties of existing digital artefacts would most likely way more align with their needs. It would be an approach to the digital world which puts people into a position where they can not only make proper use of digital artefacts, but where they can also shape this world by combining its pieces and by shaping, adapting and creating new artefacts without becoming technicians or scientists themselves. Based on those thoughts, it is our goal to figure out what it is that everyone needs to know about digital artefacts. The fundamental aspects and concepts behind this knowledge and the associated competencies can be quite different from what is traditionally considered to be the foundation of the subject of computing.

The Need for a Model

What can be considered a fundamental aspect of a domain can only be answered with knowledge about what someone perceives as the general idea of the subject matter. While the endeavour to identify a "nature of computer science" has not been taken as systemically as in the sciences[5], a brief literature research reveals several attempts

[3] There is a confusion of terminology regarding whether one should call the subject computing, computer science or informatics and which one of these subsumes the other ones. For simplicity, we decided to use the term computing here.

[4] "Substantive theories" according to Bunge (1967).

[5] See, for example, thoughts on the "nature of science" by Lederman (2013).

to identify the core of the subject through the decades. Shaw (1985), for example, characterizes computer science as being "concerned with the study of computers and of the phenomena connected with computing, notably algorithms, programs, and programming". While this characterization is very much focussed on the computer itself, Hartmanis (1995) defines the nature of computer science more as a way of thinking about the world. He cites personal communication with Donald Knuth, who stated that "Computer Science and Engineering is a field that attracts a different kind of thinker. I believe that one who is a natural computer scientist thinks algorithmically". This notion of a "different kind of thinker" aligns with the of computational thinking as described by Wing (2006), who states that "computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" and suggests that "professors of computer science should teach a course called 'Ways to Think Like a Computer Scientist' to college freshmen"[6]. Protagonists of computational thinking hence perceive computing as an endeavour to identify those problems in the world which can be solved using established computing techniques. This example of two quite different interpretations of what is in the centre of computing education indicates that there might not be one "nature" of computer science, but that there are several possible perspectives. This is reflected by Tedre and Apiola, who identify "Three Computing Traditions in School Computing Education": A theoretical tradition, an engineering tradition and a scientific tradition (Tedre and Apiola, 2013), despite the fact that these traditions largely overlap in practice.

Regardless of whether computing education scientists and practitioners identify a single nature of computer science or several traditions of the subject, what their characterisations all have in common is a notion that what students and pupils should learn is essentially the same basic knowledge actual computer scientists and engineers have acquired, be it with varying emphasis on the more theoretical or more practical aspects. While following such approaches is perfectly fine and indeed represents a great chunk of what computing is about, they hardly help to explore, understand or even (re-)construct the world of digital artefacts teachers and pupils are living in.

Across all scientific and educational disciplines, models provide guidance on how to perceive, explore and scrutinize phenomena. In chemistry, for example, Niels Bohr's atomic model (Bohr, 1913) helps to understand basic concepts about atoms and can explain many effects of chemical reactions. In computing, the Turing Machine (Turing *et al.*, 1936) is a model, which can illustrate the most basic properties of computability. Both models, while not covering every aspect of their respective fields, spurred both science and education by making something which is by nature unperceivable and obscure explorable and therefore available to discourse. They helped to identify what to explore, what to teach and what to learn. In the field of programming education, many thoughts have been made regarding which aspects of rather complex subjects are essential and how they relate to each other. In the 1980s, Du Boulay (1986), for instance,

[6] Computational thinking is a concept with many facets and interpretations. A critical account of the concept can be found in Pears et al. (2021).

identified principles which help novices to understand programming. Later, Beck and Cunningham (1989) introduced CRC cards to convey the essence of object-oriented thinking. On a more systematic level, Schwill *et al.* (1994) introduced the concept of fundamental ideas to computing education and provided a first catalogue of fundamental ideas of software development. Such catalogues, methods and principles, which help to identify the very core of a subject matter and therefore make it accessible, exist in many established areas of computing education.

However, when trying to make the characteristically digital properties of current and potential future digital artefacts the subject of interest, there is not yet any coherent approach or model.

The approach we introduce in this article constitutes a model using which digital artefacts can be perceived from a number of distinct perspectives, and in which these perspectives are interrelated with each other. As a consequence, in contrast to many approaches targeting computing education, our approach does not construct knowledge about the digital world from the bottom-up, starting with basics like binary numbers or fundamentals of programming, but is rather focussed on properties of the artefacts themselves, as well as how they relate to matters of technology and society. We introduce our model as a tool for present and future teachers who want to target digital artefacts relevant to them and their students, to figure out which aspects of the artefacts they want to include into their lessons without losing themselves in irrelevant details. On a broader scale, the model might become part of educational approaches for computing education and for curriculum development. Equally high we consider its potential of a comprehensive explanation model for digital artefacts of being content of computing courses itself. This would provide students with a tool which would make them able to get a grip of whatever piece of digital technology they might get in touch with in the future, even if it has not explicitly been covered during their school days as it may not even have been invented yet.

The model we describe in the following we call ARIadne, where A, R and I refer to the perspectives of architecture, relevance, and interaction, which we will explain in the following sections. The term as a whole is a reference to the mythological character of Ariadne, who found her way through and out of a maze. In this introduction chapter, we motivated the need for an explanation model for digital artefacts. In chapter two, we develop *perspectives on digital artefacts* based on findings and deliberations from the philosophy of technology. In chapter three, we highlight the *genesis* of digital artefacts as an interrelation between the established perspectives over time. Chapter four then completes the model by adding the *interaction* between users and artefacts. In chapter five, we *relate* the ARIadne model to other approaches towards an understanding of digital artefacts. Having unfolded the details of the principle, in chapter six, we *apply it to an example* which is already a subject of existing teaching units. Finally, in chapter seven, we *summarize* our findings and *reflect* on the role ARIadne can have in computing classes and in the related research fields, before, in chapter eight, we highlight *future work* needed for embedding and extending the ARIadne approach to educational contexts.

2. Perspectives on Digital Artefacts

ARIadne defines a number of perspectives one can have on digital artefacts. Each of these perspectives could be the starting point for an exploration of a digital artefact. In this article, we start our argumentation with a perspective targetting those properties of an artefact one is immediately confronted with when using it. We call these properties the **features** of a digital artefact. Features describe what one does with an artefact, how it reacts to outside stimuli, and which visible and manipulable properties it offers in terms of its capabilities. A major feature of an instant messenger would, for example, be its capability to send text to one or more participants of the service. For this feature, the instant messenger provides the necessary means through its user interface, which means it provides the user at least with a text input field and a “Send” button. When text is entered and “Send” is pressed, that text is transferred to the devices of those participants of the service which have been selected before. Other features of the same artefact include the ability to check whether a message has already been read and the ability to have persistent access to past messages even when using different devices.

Dualities

Even though it is possible and sometimes even sensible to describe an artefact solely from a feature perspective (e.g., in a user manual), such a perspective cannot explain how and why something works, what it is actually used for or why it has been developed the way it presents itself today. To answer such questions, further perspectives have to be taken. In the philosophy of technology, a variety of models provides different perspectives on technological artefacts. The ARIadne principle is based on an interpretation of technological artefacts which distinguishes a physical-structural perspective from a social-attributional perspective, or rather points out that, if one wants to understand technology, both perspectives need to be integrated. This interpretation is inspired by what in the 2000s was developed in the duality program (see for example in Kroes (1998); Kroes and Meijers (2006); De Ridder (2007)). The maybe most important concept of this approach is the insight that the “function” of an artefact, which describes what the artefact is used for, is not determined by the physical reality of that artefact, but is rather also socially (or individually) attributed to it. This attribution can be illustrated quite nicely in a thought experiment in which mankind has suddenly disappeared from the face of the earth, leaving behind all its technological artefacts. Aliens, who happened to find these artefacts, would surely have difficulties figuring out what the purpose of the artefacts might have been, as they could only examine their physical properties. Without any contextual information about human physiology, human needs, and human cultural preferences, the actual purpose of many artefacts could not be determined.

Like in the duality program, ARIadne reflects a general dichotomy of a physical-structual and a social-attributional sphere. The former provides a context of formal descriptions of mathematics, as well as a wealth of scientific and technological knowledge. The latter comprises societal discourses that manifest themselves in laws, norms, and institutions, as well as in public media and political debates. The notion of "functions" as it is used in the duality program, however, would be too narrow a perspective for our purposes, we consider many aspects of societal discourse relevant as parts of an explanation of a digital artefact. In this sense, Vaesen (2011) criticized the focus on function in the duality programme. He points out that in the relation between physicality and intention, the function of an artefact is not the only relevant intentional property. In the case of an instant messenger, the social need for privacy, for example, may let users decide whether they want to prefer a certain product over another one or could encourage developers of such messengers to introduce encryption features. The desire to maintain privacy therefore is an important aspect of using instant messengers, even though it is not directly associated with the purpose and function of the instant messenger. Whether some aspect of an artefact is interpreted as a function often is subject of debate. Furthermore, since the term "function" is used with varying connotations within computing, to avoid misinterpretations, we avoid the term in the ARIadne concept by making it a part of the bigger perspective of societal discourses.

The two resulting bodies of knowledge, mathematics, science and technology, on the one hand, and societal discourses, on the other hand, by themselves are far too exhaustive if one is just interested in an explanation of digital artefacts. Just to explain a digital artefact, one would not want to go into the details of electric current or explore the axioms of mathematics. Neither would it make sense to analyse the basics of human societies and political systems, only to explain an instant messenger or a word processor. It is therefore important to identify those specific aspects of both spheres which are required for an explanation. Fig. 1 depicts these aspects in the form of a cloud, as boundaries regarding what is a necessary aspect and what isn't often cannot be clearly defined and may depend on the explanatory context. This being the case, we can still divide the cloud into two distinct parts, which represent two important perspectives of description of a digital artefact:

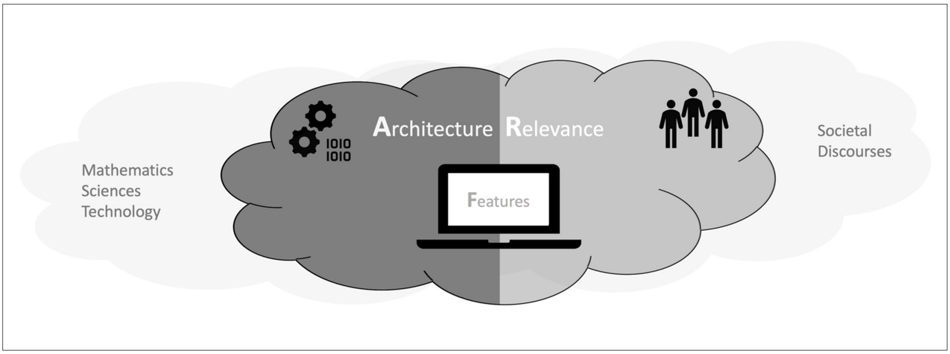

Fig. 1. Architecture and relevance as the core perspectives of an explanation of digital artefacts.

The **architecture** (or structure[7]) perspective describes how an artefact is constructed physically, and how it works internally. An architectural description of an instant messenger, for example, encompasses hardware components like servers on the Internet, the internal data structures which constitute messages and contact lists, as well as formal structures like the algorithms for encryption and decryption of messages or for network communication. Although structures like these are often described in abstract form and are sometimes even declared to be non-physical, they are, of course, implemented physically within the artefacts and are therefore physically effective. The perspective of architecture is that perspective of explanation which engineers – including computer scientists – typically deal with extensively.

The **relevance** (or meaning, usage) of a digital artefact is that perspective of explanation covering the relevant aspects of public discourse regarding the artefact. It includes what in the duality program is called function but also extends to the goals associated with its usage, the purposes and values ascribed to it, as well as societal structures which have a relation to the artefact (such as laws, rules or associations). Much of what is subject to public discourse and therefore is covered in the relevance perspective, goes beyond what technicians and engineers typically talk about professionally. One aspect of the relevance considerations of instant messaging services, for example, would be the observation that their existence is changing people's expectations regarding communication, so that today, among many people, it is expected that friends and acquaintances respond quickly to messages which have been sent to them.

Features as a Bridge between Architecture and Relevance

By defining architecture and relevance like above, we have introduced a clear separation between perspectives and carefully distinguished between aspects of the artefact that can be assigned to either one perspective or the other. There are good reasons for such a separation, as it makes clear that different qualities of the same artefact become important in different perspectives, that these qualities are identified and investigated using distinct methods, that different design competencies are involved, and that, ultimately, different branches of science and education are looking into them. However, in every real-life situation such a separation cannot be maintained, as both perspectives have to be integrated as soon as the features of an artefact become the subject of explanation. In the features, architecture and relevance necessarily meet. This interpretation aligns with a complex model of technological artefacts described by Vermaas (2009, 2013); Vermaas and Dorst (2007), who integrate the basic dichotomy of the duality program (the two perspectives being called "physico-chemical" and "intentional") but define within them more fine-grained "conceptual layers", which are characterized as follows:

7 While developing the concept mentioned here, we frequently discussed the terminology we use to describe our perspectives of explanation. In the end, however, it is not at all important how exactly we call the aspects of our concept, especially since the appropriate terminology often depends on the context it is used in.

Goals “the states in the world that agents desire when using devices.” (Vermaas, 2009), “a state of affairs the prospective users of the device are to achieve with the device” (Vermaas, 2013).

Actions “operations that describe the actions that agents execute when using the device” (Vermaas, 2009), “a deliberate manipulation of the device by a user” (Vermaas, 2013).

Functions “those physical dispositions of an artefact that contribute to the purposes for which the artefact is designed” (Vermaas and Dorst, 2007), “the roles the device should play in its environment for the agent when the agent is using the device” (Vermaas, 2009), “a physicochemical capacity of the device that makes it so that these actions with the device are successful” (Vermaas, 2013).

Behaviors “the physical dispositions of the artefact” (Vermaas and Dorst, 2007), “the way in which the physicochemical state of the device evolves in its environment, when it is used but also when it is not used.” (Vermaas, 2009), “the physicochemical evolution of the device, including the evolution of its structure and the device’s physicochemical interactions with its environment” (Vermaas, 2013).

Structures “the materials of the artefact, the dimensions and geometry of these materials, and their topological relations” (Vermaas and Dorst, 2007), “the physicochemical materials and fields of the device and its environment, the spatiotemporal configuration of these materials and fields, and their mutual physicochemical interactions.” (Vermaas, 2009), “the physicochemical configuration of the device” (Vermaas, 2013).

The “conceptual views” Vermaas and colleagues characterize here are interrelated[8] bidirectionally. This means, artefacts can be explored starting from the goals, the structure or from any intermediate view by jumping from one view to the next. Vermaas’ complex framework can be mapped to the model we developed so far: goals and actions are combined to relevance, structures and behaviours[9] form the architecture. What remains is a conceptual view called “functions”, which is characterized both “intentional”, as well as “physico-chemical”[10]. This characterization differs from the simple model of the duality program in which function was distinctly associated to what is here called “intentional”, as here, on the one hand, function is described as the “physical capability” of an artefact that defines an artefact’s behaviour, while on the other hand, it is described as an attribution of a desired effect an artefact should exhibit when used. These “functions” exactly correspond to what we introduced as **features** before. Features in our model therefore exhibit said inherent dual nature, thereby creating a common point of reference for an explanation in both the perspectives of relevance and architecture. Such a common point of reference can serve two purposes: For once, it allows for the separa-

[8] Often, the term “interaction” is used when trying to describe mutual influences. As we later use this term for a specific kind of relation between stakeholders and digital artefacts, we rather use the term “interrelation” when describing how societal discourses and technological development influence each other in general.

[9] In educational literature, behaviour often refers to the way people react to stimuli or how they comport themselves. Here, however, “behaviour” is used in a technical sense and refers to actions and reactions of an artefact one can observe as a consequence of its programming and modelling.

[10] Even though an illustration in (Vermaas, 2009) suggests functions would belong in the intentional sphere only, the additions made later (represented in the quotes) clearly argue for an assignment to both spheres.

tion of human intention and physical behaviour, as indicated by Vermaas and Houkes (2006) using the term "drawbridge" but, more importantly, it also allows both of them to be "bridged", as described by Erden *et al.* (2008) in the sense of establishing a connection between them.

When one is interested in a comprehensive explanation of a digital artefact, the areas of architecture and relevance indeed have to be "bridged" in this sense. If features were only described from an architectural perspective, the description would literally be meaningless. It would not make clear what the artefact is expected to afford and what its purpose might be. If, on in contrast, features were described only from the perspective of relevance, the attributions made to it literally were baseless, as it would not at all be sure whether an artefact can fulfil the expectations and attributions it is the target of at all. Consequently, for a comprehensive picture, both perspectives need to be integrated. This, however, does not mean that such a comprehensive consideration of all aspects is necessary in each and every situation. Following the metaphors introduced above, features have the potential to be a "drawbridge", which, figuratively speaking, could be raised at any time. Features hence have the potential to represent the respective other side in an explanation when this perspective is not of particular interest. In a professional context, for example, it is not only possible but often even sensible to speak about network protocols or other technical features of instant messengers on the architecture level without having to explicitly describe the social discourse of communication needs and associated hopes and concerns.

Distinguishing Features and Goals

Discussions within the relevance perspective often run the risk of confusing societal and individual goals regarding a digital artefact with the features of said artefact. Despite features, as indicated above, can be discussed on the relevance level and are indeed features because they are attributed to the artefact, their realization remains a technical matter. Only what is technically realized can be a feature. What goes beyond this technological realization can very likely be an important aspect of relevance, but cannot be a feature. The individual goal of using an instant messenger for maintaining friendships, for example, while definitely being a relevant reason for using instant messengers, cannot be a feature of the digital artefact, since features can only be something an artefact can itself perform technically. What a messenger does technically, however, has nothing at all to do with friendships, family, or work relationships but "only" with receiving text messages from and sending them to one or more participants of the service. The relevance perspective comprises what an artefact is used for in a broad sense, while a feature only represents what is done with an artefact during concrete operations.[11]

[11] If this were otherwise, one could solve societal problems in their entirety just by developing technology with the appropriate features. This, however, is not so. Indeed, technology can only ever play a role in complex societal conditions, but does not determinate them. See the discussion about "technological determinism" in the following section.

Having established that features have characteristics of both architecture and relevance, this inherent duality makes them the ideal starting point for an explanation, as the significant aspects of architecture and relevance can be explored starting from here. Functional requirements in software development, which have not yet been met, in this sense, can be understood as hypothetical features which are defined in the relevance perspective but do not yet exist on the architectural side. The term "feature request" used in software development reflects this condition very well. Only when the artefact is revised in such a way that the architecture can then meet the requirement, the requirement actually becomes a feature of the artefact. This also works in the other way around: Properties and the behaviour of the architecture of an artefact, which are made perceivable and manipulable through the user interface, can be interpreted as an affordance. If it inspires users to use the artefact in certain ways, these architectural properties can become a feature, even if they may not have been intended to be so in advance[12].

3. How it Got the Way it Is: Genesis

In the end, not a single aspect of architecture can be explained without at least touching aspects of relevance, and explanations within the relevance perspective cannot ever be made without reference to architecture. Analysing this interrelation is the basis for figuring out why artefacts are the way they are, why they are used the way they are used, and why they play the role they do play in their societal context. While a description of the status quo of an artefact may be possible without analysing any interrelations, an actual explanation of the status quo cannot. For an explanation, it is not sufficient to limit oneself to describing the artefact and its use in its current state, even when taking all the perspectives introduced so far are considered. This is due to the fact that all these perspectives can be interrelated and understood in their complexity only by analysing the history of the ideas behind the development of an artefact. What can be observed and described today is a result of complex negotiation and development processes of the past. This historical perspective we call the **genesis** of the artefact.

An instant messenger with all its features, for example, can only be explained by considering the genesis of the mobile phone, which can be traced back to the 1950s or even earlier if one considered radio communication or landline telephone networks (more on mobile phone history in the example in section 6). For simplicity, assume in the following that the history of the mobile phone only began in the 1990s. Even then, one could analyse how social developments, especially in the field of businesses among commercial travellers or managers, led to a desire to be in touch with others while on the go. At the same time, improvements in microelectronics enabled the de-

[12] As a by-product of a quantitative study carried out in our department, for example, we learned that the instant messenger WhatsApp can be used as mobile, persistent memory for personal notes. A participant told us, she had created a group with herself and someone else as members, only to directly remove that person from the group right away. Into this remaining "group of one" she posts messages which, for her, serve the purpose of a shopping list.

velopment of smaller and smaller radios, which today we call mobile phones[13]. The availability of these devices in turn fundamentally changed people's expectations regarding communication.

An interesting aspect of the genesis of instant messaging services lies in the fact that technical properties originally intended for sending technical messages to customers -the SMS text service -became popular as an important general feature of mobile phones. This popularity and the resulting demand to be able to send text messages more conveniently led to the development of ever better interfaces both in hardware (e.g., better keyboards and displays that could display longer text messages), and in software, (e.g., in the form of reply and forwarding functionalities). Instant messengers like WhatsApp can be understood as a continuation of the tradition of SMS text services and therefore also inherited aspects of mobile phone history. Business decisions beyond those of the instant messaging services themselves played an important role in the development of the services and therefore are part of their genesis, too. It is no surprise that instant messaging services became particularly popular in countries where telecommunication companies charged substantial fees for the use of their text messaging services. The fact that there is no per message fee for internet-based instant messaging services makes them particularly attractive in these countries. This being so, a prerequisite for the services becoming usable at all was the general availability of mobile Internet connectivity. The availability of mobile Internet can therefore, in a way, be seen both as a prerequisite and, together with other service improvements, a consequence of the popularity of said instant messaging services.

Properties within the realm of the architecture of a digital artefact can be analysed and understood when taking complex interrelations and interrelations during its genesis into account. When looking into the architecture of instant messaging services, one can trace back the genesis of their characteristics to influences of social discourse. In an instant messaging service, for example, all participants send their messages to a central server, which forwards them to the respective recipients. This means the messages are at least temporarily stored on servers of the service provider. This architectural decision not only ensures that messages can be delivered even when the recipient is not connected to the internet at the time the message is sent, but also allows participants of the service to replace their phones without losing access to past messages. While this is of course convenient, it also means that the provider itself can read and evaluate the messages. Over time and fuelled by social discourse (e.g., by the Snowden revelations), the desire for privacy increased significantly, resulting in new rules and regulations and in putting pressure on messaging services to introduce technical means like end-to-end encryption. Such an encryption ensures that only those involved in the conversation can decrypt the message. End-to-end encryption is nowadays implemented in all major instant messaging services transparently, i.e. without interrupting the workflow of using the service.

This brief outline of the analysis of genesis of a particular artefact will have to suffice at this point. If one wanted to present the genesis of instant messaging services

[13] Why these mobile communication devices ended up in the world of telephones rather than in the world of radio equipment would be an interesting investigation in itself, in which social conditions, especially in the form of state-owned and monopolistic telecommunications companies, would probably play a major role.

comprehensively, one would not only have to take a closer look at mobile phones but also at other predecessors of these services like Internet chat services, pagers, or e-mail services. To what extent and in which depth an analysis of the genesis actually has to be done depends on previous knowledge and the educational goals.

Artefacts Are Neither ever New ...

A comprehensive analysis of the genesis of an artefact does not only have to consider that it has a history of its own, but also that every artefact is constructed using existing technology, which itself has its history. One does hardly ever reinvent the wheel. Developers of instant messengers, for example, have used existing technologies and techniques for text encoding, encryption and network communication, which were available as ready-made modules. Past interrelations, which led to such modules being the way they are, therefore always influence even allegedly new artefacts. Hence, even when analysing artefacts which supposedly are entirely new or when creating one's own artefact, there still is a genesis which can be analysed, and which has an impact on the artefact at hand. Even if one were to create a new computer program by starting with an empty text file, entering some code, and letting the computer execute that code, there would still be a lot of genesis to consider:

- One uses a programming language, which properties have an impact on the artefact that is created with it, so these artefacts inherit some of the genesis of the programming language.
- When programming, one relies heavily on functionality provided by the operating system. When, for example, a program reads and writes data to and reads it from a local storage medium, properties of the file system, e.g., a hierarchical file structure or file naming limitations, can become an influencing factor on the new artefact.
- The same is true when libraries are used – be they part of the programming language or provided externally – which is the case in virtually any program that goes beyond "hello world."[14]
- Even in the rare case where no library and no significant operating system functionality would be used, professional programming conventions and the implementation of already established algorithms – all of which have their own genesis – sneak their characteristics into the newly created artefact.

Only if someone who had never seen or used a computer at all and who knew nothing about it were to create their own artefacts completely from scratch, without relying on anything that already existed, could that artefact be called entirely new. As this is virtually impossible, a new artefact always "inherits" a lot of genesis from the existing parts it is created of, the system it runs on, and the established knowledge used in its

[14] Of course, the very tradition of using "hello world" programs as a showcase for basic characteristics of programming languages is itself part of the genesis of programming.

construction. MacKenzie and Wajcman (1999) summarize this with a nod to an interesting productive aspect of technological determinism, as

> *„new technology, then, typically emerges not from flashes and disembodied inspiration but from existing technology by a process of gradual change to, and new combinations of, that existing technology. Even what we might with some justification want to call revolutions in technology often turns out to have been long in the making.“* (page 9)

... Nor Are they Neutral

An important consequence of this insight is that the common characterization of technology being neutral is a misconception. A narrative of reasonable, neutral, and inevitable technical properties are a symptom of technological determinism and can, in consequence, lead to a passive relation towards technology in which one neither questions nor attempts to adapt technology to one's own needs and expectations.

The idea behind technological determinism is that social reality and social relations are determined by technological means. The concept is often traced back to Marx (1910). It was particularly popular in major parts of the 20th century and can often still be observed in discussions about the impacts of technology. Bimber (1994) distinguishes a number of interpretations of technological determinism. In the context of ARIadne and the presumed neutrality of the digital artefacts, the *nomological* interpretation becomes particularly interesting. In Bimber's account it is described as the only true determinism as it claims that technological developments are unavoidable and uncontrollable. He cites Heilbroner (1967), who described it as "history [which] is predetermined by scientific laws that are sequentially discovered by people and which, in their inexorable application, produce technology. Only within the limits imposed by this logic may people exercise collective or individual agency and will". When understanding technological determinism this way, technology indeed would have to be considered neutral, as it would be completely culture-independent. It would develop similarly, regardless of where on earth the development takes place and which social system is predominant. Such a view, according to MacKenzie and Wajcman (1999) "promotes a passive attitude to technological change. It focuses our minds on how to adapt to technological change, not on how to shape it" (page 5).

A very common variation of this kind of technological determinism can be found in the idea of "technological fixes", which, according to Johnston (2018), became popular in the early 20th century. While maintaining the general notion of society being determined by technology, in contrast to the nomological interpretation in which technology evolves independently, those who believe in technological fixes rather think that, while changing society turns out to be complicated, technological changes can be made easily. In consequence, societal problems should be transferred into the realm of technology, where they can then be solved easily and reliably[15]. Technological solutions thus are put in place to substitute social solutions. The idea behind "technological fixes" is one in which a group of people has realized the existence of certain problems in society and with that knowledge purposefully develops and adapts technology to solve those problems. This ideology (a) assumes that problems of society can indeed be solved solely by technological means, and (b) suggests the existence of an oligarchy, i.e. an elite of people who identify sociological problems and devise technological developments to solve them for society as a whole.

An opposing stance to the passive role human actors have according to technological determinism is proposed by the protagonists of "Social Construction of Technology" (SCOT), which states that technology does not evolve out of itself, but rather is the product of social relations and power structures. Pinch and Bijker (1984) describe that

> *"[in] SCOT the developmental process of a technological artefact is described as an alternation of variation and selection. This results in a 'multidirectional' model. [...] Of course, with historical hindsight, it is possible to collapse the multidirectional model on to a simpler linear model; but this misses the thrust of our argument, that the 'successful' stages in the development are not the only possible ones. [...] If a multidirectional model is adopted, it is possible to ask why some of the variants 'die', whereas others 'survive'".*

In the field of computer history, Mahoney (2005) follows a similar argumentation when describing that technological development in great parts is a product of social relations and thus the result of decisions made in the past for various reasons. As a consequence, assessments like being good or bad become arbitrary or, according to MacKenzie, "explanations of success and failure in terms of the intrinsic superiority or inferiority of technologies are suspect because of the path dependence of the history of technology."

When analysing the world of technology with a technological determinism approach in mind, at least in its nomological flavour, descriptions of technology become quite simple. Everything is supposed to be factual and inevitable, so one just has to explain what can be observed, and what can be observed is precisely how it inevitably has to be. For the same reasons, it makes telling the history of any artefact just as easy. When following the SCOT approach, in contrast, both undertakings become what Bijker *et al.* (2012) calls "thick descriptions" which consist of "a wealth of detailed information about the technical, social, economic, and political aspects of the case under study" (page xliii). Such thick descriptions include describing not only what is, but also why it is, what could be, what has become and also what has been disregarded. They make it necessary to determine and describe the driving forces within society, their interrelations, and their influences on the evolution of technology. A clear dichotomy between technical and social would therefore, according to Bijker *et al.* (2012), "promptly evaporate" and

[15] see also Oelschlaeger (1979).

thus “technical, scientific, economic, political, and social categories would overlap and become soft” (ibid, page 4) or, as MacKenzie and Wajcman (1999) put it, “technology and society are mutually constitutive” (page 23).

4. The Role of Individuals: Interaction

The perspectives presented so far were described without a reference to particular human actors. While it is clear that the relevant discourses do involve actual people and that technology is indeed designed by human beings, no individual human being was in focus. This changes by completing the model with the perspective of **interactions**. The interaction considered here occurs between a person and a digital artefact. In a school context, one of the most interesting individuals who interact with the device would most likely be the learner. The term interaction has many definitions within computing. Sometimes it is used in a very broad sense, referring to mutual influence between an artefact and an individual. In the ARIadne context, we understand interaction more narrowly, referring to a person interacting with an artefact by making use of its features. However, during such an interaction with an artefact, users change as a result of the experiences they have had with it.

When someone uses an instant messenger, their knowledge about the specific messenger, about communication technology as a whole, their attitude towards communication, their own perception of being available for communication and many other things change. With reference to Knobelsdorf (2011)[16], Schulte (2008), Schulte and Budde (2018) and Budde (2021) associate this interaction with a transformation of

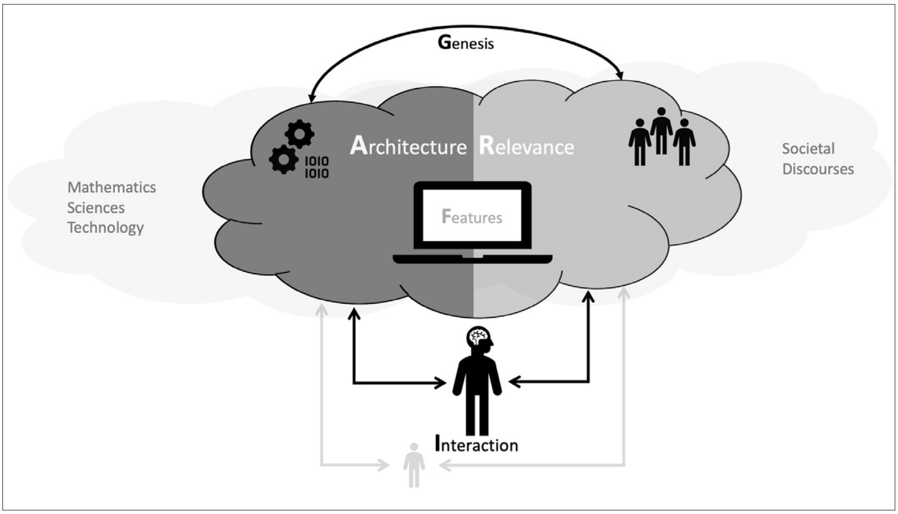

Fig. 2. The ARIadne principle with its perspective of descriptions and their interrelations.

[16]For an English language description of the main concept relevant here, see Schulte and Knobelsdorf (2007).

world-view (the perception and interpretation of people in relation to the context of the world around them), self-view (the perception and interpretation of people in relation to their own role in the context of the world around them), and action patterns (the options for action within the interaction).

Individuals have a distinct relation towards a digital artefact. When interacting, they make use of skills and knowledge regarding this digital artefact, both in terms of its architecture, as well as of its relevance. This enables them to use the artefact with some level of competency. As every person is individual, this relationship must, of course, be understood individually, too. However, both in practice and in science, archetypical and super-individual relations are particularly interesting as they allow for an identification of relevant explanatory contexts which can be used more broadly than what would be possible when focusing solely on individual circumstances. In accordance with Erden *et al.* (2008), we call such generalizable relations an **interaction role**. Which role concrete users of an artefact have is not a stable property, but can change over time or even from situation to situation. Interactions with spreadsheet applications provide a good example for such roles: It has been found that one can identify people who see spreadsheets merely as a tool used for writing things down in an orderly manner. Others see it as an extended kind of calculator, while a third group of users creates complex applications within spreadsheets (see Borghouts *et al.* (2019)). All of these roles require different sets of skills and knowledge. According to Fischer (2002), such roles and the associated self-views, world-views and action schemes are not fixed but change within the process of interaction, allowing the artefacts to be shaped by individual needs and through actions, while at the same time, the interaction with the artefacts itself shapes those interacting with it.

If one takes the analysis of the interaction and the interaction roles of the learners (or generally of those for whom one wants to explain something) as the starting point of the duality analysis, their self-views, world-views and action schemes come into focus, and hence become accessible to an educational reconstruction (see Duit *et al.* (2012)), where the interaction roles of students within different contexts are considered before developing an intervention[17]. Additional potentials arise when not only considering oneself or learners as the individuals being in interaction with the device, but when taking other stakeholders into account, too. One can then assume their roles and try to empathetically understand their needs and goals by relating them to one's own. This way, decisions and opinions are based not only on one's own relation towards an artefact but include social and intersubjective deliberations.

5. Relation to other Approaches

As described above, ARIadne is based on a number of concepts, mainly from the field of philosophy of technology:

- The Duality Programme separates the structures of a digital artefact from its function. (Kroes, 1998; Kroes and Meijers, 2006; De Ridder, 2007)

[17] see, e.g., in Terfloth et al. (2020).

- The ambiguity of the term "Function" led to a perception of features of being both characteristics of technology, as well as of intention. (Vermaas and Dorst, 2007; Vermaas, 2009, 2013)
- While Technological Determinism neglects an interrelation between technology and society (Bimber, 1994; Johnston, 2018),
- The idea of Social Construction Of Technology emphasizes how social reality influences the genesis of technological artefacts. (Pinch and Bijker, 1984; MacKenzie and Wajcman, 1999)
- Interaction Roles highlight how different understandings of one's one relation towards a digital artefact lead to different knowledge prerequisites in respect to architecture, as well as to relevance. (Erden *et al.*, 2008)

Characteristic aspects of ARIadne can also be identified in other areas of computing:

Approaches in the field of Human Computer Interaction (HCI) develop a human-centred perspective on technology. HCI theories like Activity Theory (e.g., Bertelsen and Bødker (2003)), Situated Action Models (e.g., Nardi (1996)) and Distributed Cognition (e.g., Hollan *et al.* (2000)) share a common sense of artefacts being embedded into cognitive processes and contexts of use. Based on these insights, HCI develops directives for the design of digital artefacts which are embedded into their processes of use.

In the German educational discourse regarding "Digitale Bildung", models like the Dagstuhl triangle (Missomelius, 2016)[18] and the Frankfurt triangle (Brinda *et al.*, 2019)[19] emphasize the general need to look at digital artefacts from a number of perspectives which are historically covered by different branches of science, didactics and education. However, despite stating that for "a comprehensive analysis, reflection and design of the digital transformation can only be successful, if all [...] perspectives are taken systematically and repeatedly" (Brinda *et al.*, 2019), the perspectives themselves are only slightly related to each other and are only vaguely based on theoretical models or empiric evidence but rather serve the purpose of an education policy agenda.

With their notion of Machine Behaviour, Rahwan *et al.* (2019) point out that a perspective focusing on a single artefact, which is designed deliberately, and which therefore can be explained quite easily, is not sufficient. When taking a wider perspective, interrelations with other artefacts and with society are becoming more and more complex. Similarly, the artefacts themselves become ever more complex, especially considering artefacts based on data science and artificial intelligence. In consequence, simple explanations become impossible. Rahwan *et al.* (2019) hence suggest that, to explain how digital technology works, it has to be observed in the field, quite like how the behaviour of animals is investigated by watching them in their natural habitat. While introducing and integrating the insights and methods of the respective fields of science this way is an important new perspective on the products of computing, Rahwan *et al.* remain focussed on the artefacts themselves and therefore consider those as-

[18] An English description of the Dagstuhl triangle can be found in Brinda and Diethelm (2017).

[19] An brief English language description of the Frankfurt Triangle can be found in (Borukhovich-Weis *et al.*, 2021).

pects we call relevance only very briefly as factors which merely influence the alleged behaviour of machines. In the ARIadne model, in contrast, these aspects and those of the architecture are of equal importance. Playing them down, argued from ARIadne's perspectives, increases the risk of developing a naive view on technology and may provoke a perception of technological determinism where either technology evolves without any societal influence, or where societal problems can presumably be solved by technological means alone.

All in all, while the general idea of explaining digital artefacts from a number of distinct perspectives is not new by itself, the ARIadne approach is going at least one step further by combining several perspectives into one coherent model which not only acknowledges that different perspectives exist but which systematically interrelates them. The resulting model is not intended to be a work of philosophy, i.e. identifying every aspect of the concepts of digital artefacts in an excruciating level of detail, but is rather intended to be a practical model and guiding principle which helps to analyse a subject to help teachers identify the relevant aspects of knowledge.

6. A Summary and an Example

In this article, we have developed perspectives on digital artefacts. Fig. 2 shows them in relation to each other. Each of the perspectives answers one or more questions in relation to the artefact:

Feature "What is its functionality?" in the sense of "What can one do with it?" On the feature level, these questions are answered by stating genuine capabilities of the artefact rather than on the goals and intentions of using it for a certain purpose.

Relevance "What is it used for?" in the sense of the greater goal of using it; "What does one associate with it?" in the sense of hopes, fears and attitudes towards it; "What influence does it have?" in the sense of effects on society. In consequence, relevance also covers normative and ethical questions like "Which social norms influence its usage?"

Architecture "How does it work?" in the sense of its technical inner workings; "How is it constructed?" in the sense of its building blocks and how they are combined. This structure also includes intangible aspects like algorithms and data structures.

Genesis "How did it come into existence?"; "What was it like before?"; "Why is it the way it is now?" as an interrelation between architecture and relevance over time; This can even go as far as "How might it become in the future?" as a well-founded hypothesis.

Interaction "How does one interact with it?" in the sense of how it is used by an individual; "What role does one have towards it?" in the sense of how one sees oneself in relation to the artefact and what kind of knowledge this involves, "What role do others have towards it?" as a bridge to understand the actions and interests of other stakeholders.

In addition to the short examples used in the explanation of the perspectives that constitute ARIadne, we now illustrate the exploratory potential of the principle by applying it to a real-world example in the context of mobile phone services. While modern mobile phones have numerous features, we here focus on the aspect of location independent mobile availability in mobile phone networks. We chose this example because mobile phone communication is an aspect of everyone's everyday life, and knowledge about what is behind it is therefore likely to be relevant. This is also the reason why the topic has been made the content of several experimental courses developed at Freie Universität Berlin and Paderborn University. It has since been implemented and tested in local schools.

The content analysis based on the ARIadne principle in our example starts with a description of maybe the most basic featur*e* of today's mobile phones: One can call someone else by dialling that person's mobile phone number without having to know the current location of the phone in question. What seems so natural in everyday interaction today is way more complex than one might assume. Taking a first look into the genesi*s* o*f* th*e* architectur*e* of mobile phone systems, it becomes clear that in the classic landline-based telephone network, the problem of having to know where a phone was located did not exist at all. Every phone had its individual pair of cables which connected it to the local telephone exchange. Dialling a phone number made machinery at telephone exchanges select the exact pair of cables the phone was connected to. While within the telephone network, there was a degree of flexibility regarding the routing of a telephone call, the telephone number itself was enough of an instruction to tell the telephone switches how to make the connection. The route from sender to receiver was hence determined by a combination of the number dialled by the caller and the network topology known to the telephone company.

Going one step further in the *genesis* towards early mobile phone systems, one realizes that they initially used to work similarly. However, instead of having a cable connected to the phone which is to be called, a connection is made by means of radio towers using radio waves. In early mobile telephone services, such as the IMTS (Improved Mobile Telephone Service) in the USA, the caller hence had to know where the receiving phone was located and had to communicate this knowledge by telling the operator or later by dialling the respective area code together with the telephone number assigned to the individual phone (*interaction*). Only then a connection could be established. When, during the conversation, the mobile phone moved out of the area covered by the radio tower it was connected to, the conversation was terminated and had to be re-established by dialling again.

This technological reality leads to implications within the perspective of *relevance*, as its shortcomings have implications regarding the usefulness of the artefact for certain purposes. The existing system was perfectly fine in some cases. When, for example, a company wanted to contact a mobile phone located at a construction site, it was feasible to dial an area code first as it was clear where that phone was at a certain time. In many other cases, however, having to know where someone was before being able to call them was cumbersome at best or even impossible at worst, and not being able to maintain a connection when someone was moving out of the coverage zone of a radio tower made the whole system less useful when being used in moving vehicles. Some use cases were hence not feasible using the existing technology. When being mobile was supposed to mean being in unforeseen locations and having to communicate while on the go, both cases being important in business contexts, the connection and its establishment had to become independent of having to explicitly select a radio tower. From an architectural point of view, these requirements were met with the development of the services like the AMPS (Advanced Mobile Phone System) which was in operation in the USA until 2008.

Two of the most important *features* of this new network were that callers now did not have to know the location of the phone they were calling any more, and that calls were automatically handed over from one radio tower to the next in the case someone left the area covered by a specific tower. To achieve this, the audio stream, which in AMPS was still analogue, was complemented by digital data which allowed the network to know the location of the individual phones using it. The relevant basic principles of this technological *architecture* established in the late 1970s (e.g. described by Young (1979) and Fluhr and Porter (1979))[20] still apply in the modern mobile phone networks using GSM, UMTS, LTE or 5G.

In contrast to the landlines and the early mobile networks, the telephone number alone does not provide enough information on how and where to reach a phone. Hence, this information has to come from somewhere else. Indeed, when powered on and not in a dead zone, every mobile phone is near one of more radio towers which are spread across the country. When trying to patch a call through to a certain phone, the network infrastructure must make a connection with the correct radio tower. To accomplish that, the network needs to know which radio tower a phone is closest to at a certain point in time. This information has to come from the phones themselves. Mobile phones connect themselves to the radio tower with the strongest signal and register themselves with them. This registration information is put into a central database at the Mobile Telephone Switching Office (MTSO) which, therefore, at any given time has the information on the rough locations of all phones currently using the service[21]. When a phone is connected to the network, the network always knows which radio tower to use when a call (or a text message for that matter) is to be delivered to a certain phone. As all of this happens without anyone having to explicitly enter the relevant information, no aspect of this architectural process is subject to the *interaction* between the user and the network. It is completely transparent to the user. The additional problem of moving devices leaving the zone of a radio tower is solved in a similarly implicit fashion, as connections are now handed over from one radio tower to the next without any perceivable interruption of the service and without the need or even the possibility for any human intervention.

Knowing about the existence of said database of the location of every mobile phone currently logged into the network, important questions of *relevance* arise, as having access to such a database creates potential for law enforcement but also for commercial

[20] Said literature is somewhat vague on the aspect of a common database of all users currently registered in the mobile phone network. However, this aspect is very prominently laid out in the description of Germany's "C-Netz" in Kedaj et al. (1993)

[21] The architectural description here is somewhat simplified, neglecting, for example, necessary communication between different MTSOs, the existence of different providers, as well as details about the layout of cells.

evaluation, for unwarranted surveillance, or even for criminal misuse. All of these potentials have been exploited or at least considered in some form or the other. They led to intensive discourse regarding whether such data may or may not be used, if and how long it must be saved, and who is allowed to have access to it for what purpose. On the one hand, laws restrict the usage of the data to the maintenance and operation of the network itself. On the other hand, there is a strong urge to use the data for purposes of public safety, so debates at the moment changed from a discussion about the mere fact whether location data obtained this way may be used for law enforcement to network operators seeing themselves in a position where they are required by law to save the data for later access under certain circumstances.

Fig. 3 depicts the ARIadne path taken here. It clearly demonstrates the back and forth between the different perspectives. Paths for other features of other artefacts will

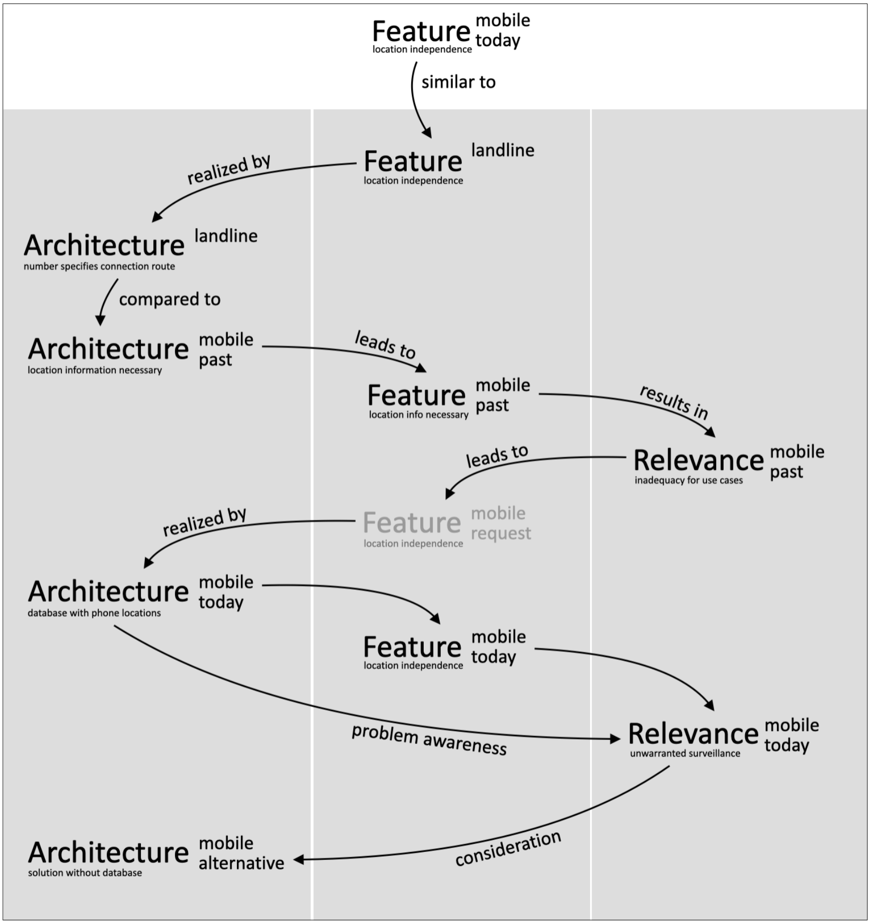

Fig. 3. The ARIadne path of exploring one of the basic features of modern mobile phone communication. For reasons of simplicity, the aspects of interactions are not explicitly mentioned here as they reflect the various states of the feature.

differ in detail and might quite likely be longer, but should all be characterized by these frequent changes of perspectives.

This short journey through the perspectives on this single, yet very basic, feature of mobile phone systems is by no means extensive. If one wanted to create an extensive documentation of this and other basic features of mobile phones, one would not only have to look at certain aspects in more detail but should also question the simplified argumentation given in this section, in which major decisions stiell were portrayed as if they were unavoidable. The Ethernet standard used in local area networks, for example, does work without the need for any centralized location database, despite the fact it also allows devices to connect to each other regardless of where they are within the network topology. Whether a technology similar to Ethernet would be feasible for mobile phone networks goes beyond this article and maybe even beyond what might be a subject of lessons covering mobile communication. Nevertheless, the existence of alternatives should always be actively considered in all perspectives on digital artefacts. Technology never has to be the way it is. In every step of its genesis, there have been alternatives, and hence there always are alternatives to the status quo.

7. Possible Use Cases

Computing education is an area in which one cannot rely on the knowledge and the methods one learned at school or when starting as a teacher still being relevant at a later time. Both technical knowledge and societal relevance change consistently and sometimes rapidly, leading to an ongoing need to familiarise oneself with new content. With our explanations and examples, we have shown that the ARIadne model can be used to explore digital artefacts from a number of important perspectives. It makes a complex mesh of aspects accessible and allows researchers and educators to focus on those aspects they are interested in, while at the same time allowing them to relate their interests and their knowledge to associated perspectives. This, we hope, makes ARIadne a valuable tool when performing a subject analysis, e.g. when creating curricula both on a bigger scale, and as an important initial step when composing a teaching unit.

While ARIadne can provide teachers and curriculum planners with the necessary background, an ARIadne analysis by itself is not necessary a blueprint for lessons and courses as such. The aforementioned courses about mobile phone networks, for instance, do not cover all the aspects mentioned in the analysis, but rather focus on some aspects relevant to their main goal of fostering data awareness. The actual functionality of the mobile phone network is not the main focus, but is only one aspect of the ubiquity of location data and the potentials and dangers associated with it based on the concept of data awareness (see Höper (2021)). Having analysed the subject in a broader fashion, however, puts teachers in a position in which they have a strong foundation to build their lessons on and could hence answer questions which go beyond the main focus, e.g. when pupils ask what something is for or why it is the way it is.

The goal of computing education typically lies in conveying the basic concepts of computer science. However, this knowledge is often quite detached from the everyday world of those who should lean it. An ARIadne analysis could be helpful as it links architectural aspects of existing artefacts to its features and its societal relevance. This also makes it a tool for bridging computing education with other subjects for multidisciplinary courses. These use cases target teachers and curriculum builders. We would, however, argue that ARIadne should indeed itself become the content of lessons, as when students got to know the principle and were able to apply it to artefacts they encounter in their later life, it would put them into a position from which they could identify and explore the necessary knowledge and thus stay up to date with evolving technology beyond what they came in contact with in school.

8. Future Work

When defining a discipline, one needs a concept or main idea which constitutes it and helps to define how it is perceived. Fletcher (1995), for example, describes the Turing-equivalence of all computers as the "founding idea of the discipline" of computing, as it is "abstracting away from the differences in instruction sets, speed and storage capacity of particular machines" and that "without this essential insight we would have no academic discipline, just a miscellany of knowledge about various machines that do various kinds of computation." Similar concepts and main ideas are necessary when targeting a broader educational approach towards understanding the digital world. ARIadne can be a first step in this direction.

ARIadne is targeted at figuring out *what* is to be taught. The question remains *how* these things ought to be taught. Due to its premise of being based on existing artefacts rather than on the systematic construction of substantive knowledge, ARIadne should be compatible with approaches based on educational reconstruction (Duit *et al.*, 2012). Educational reconstruction is based on an analysis of the learners' knowledge, i.e. in terms of architecture, relevance, features and interactions, and a target concept derived from a domain-specific analysis. A comparison of the two then is the basis for suitable interventions[22]. This being said, a systematic alignment of ARIadne with educational methods has not yet been undertaken.

In this article, we have presented how the ARIadne principle can be used to explore and interrelate different perspectives of digital artefacts. It constitutes a generic model (i.e. it is not bound to a certain artefact) for the exploration of digital artefacts. Within its perspectives, ARIadne itself does not provide any guidelines on how an artefact can be scrutinized, what granularity is required when examining it, which concepts help to understand it in relation to the perspectives, and which models help to make sense of it all. As a task for future work, we would therefore argue, that within the perspectives, properties and concepts have to be identified which are interrelatable to the other

[22] see Duality Reconstruction (Schulte, 2008) and Hybrid Interaction Systems (Schulte and Budde, 2018; Budde, 2021)

perspectives of ARIadne. This need for interrelations calls for new concepts within the established perspectives itself, which means that new concepts for describing artefacts have to be developed.

Within the perspective of architecture, for instance, existing concepts like algorithms, models, and data are not likely to be a good starting points as they are almost as complex and multifaceted as the vague concept of architecture itself and, when taught bottom-up, as it is common in computing classes, are disconnected from the features of reality of real-world artefacts and hence not well suited for the purpose indicated here. A new systematic idea or model is needed for a non-arbitrary approach to architectural descriptions. For the architecture perspective, this could, for example, be the identification of properties of digital artefacts which distinguish them from their analogue counterparts[23]. Such an endeavour could be the foundation for an artefact-based approach to computing education or a conceptual technology-aware approach to ICT, making the former more relevant to the vast number of students who do not want to become computer scientists, and transforming the latter from just making use of digital tools (which is frequently criticized, e.g., in Furber (2012)) to exploring the technological and societal foundations of these tools in order to not only make good use of what the digital world has to offer, but also to understand it and hence to be able to make informed decisions about it and to shape it according to one's own needs. Such an approach, believe, could even help tearing down the wall between computing education and ICT which, at present, hampers both subjects as discourse concerning the necessary interrelations is disregarded.

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[23] An example for such a property could be the separation of content and presentation. Whereas in analogue media, what is written down and the way it is written down are inseparable, in digital media, one can change the formatting of a piece of text independently of the contents of the text and vice versa. The architectural background behind this property is the possibility to have two separate objects which can be manipulated independently and which, through responsive evaluations, are instantly combined to a common representation of a single perceived object which can be both rephrased and reformatted.

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