The Role of Computer Science Education for Understanding and Shaping the Digital Society

Ralf Romeike(✉)

Freie Universität Berlin, Königin-Luise-Street 24-26, 14195 Berlin, Germany
ralf.romeike@fu-berlin.de

Abstract. In the omnipresent discussion on the role of ICT in education, the contribution of computer science education is often mentioned, but not always understood. This paper discusses the relation between ICT education and computer science education and the benefits of understanding the fundamental concepts and ideas of Computer Science (CS). Computer science is a dynamic and highly innovative science, whose products make a significant contribution to the development of the so-called "Digital Society." How should computer science teaching be adapted to the continuous technical further developments? Based on the outcomes of several research projects, this paper will outline how innovations in computer science can be taken up in order to improve the teaching of computer science. i.e., the topic of "databases" will in future offer a broader perspective on how to deal with data in the sense of "data management". Agile methods, which are known from professional software development, can support learners and teachers, despite difficult school conditions, to better achieve the objectives in project based teaching. Programmable microcontrollers extend the view of computers as standing on a desktop towards ubiquitous embedded or also cyber-physical systems, which enable new and motivating approaches for the design of computer science lessons in the context of physical computing. As a target perspective, pupils should be able to understand the phenomena of the "digital society", but also to be involved in the design of them in accordance to their needs.

Keywords: Computer science education · Digitalization

1 Introduction

It was the year of 2016 in which the term "digitalization" had arrived in the education debate and dominated the debates under the keyword "digital education". In Germany, the discussion was fueled not least by the fact that the Standing Conference of the Ministers of Education and Cultural Affairs (KMK) made the digitalization of society a focal topic and presented a strategy for "Education in the Digital World" [11]. Although more and more people are now interested in digital media and want to use it in educational processes, the question of what "digitalization" actually is still leads to uncertainty among many teachers. Although the results of digitalization are obvious - digital media are omnipresent and influence all conceivable everyday processes - their

Published by Springer Nature Switzerland AG 2019
A. Tatnall and N. Mavengere (Eds.): SUZA 2019, IFIP AICT 564, pp. 167–176, 2019.
https://doi.org/10.1007/978-3-030-28764-1_19

causes, fundamentals and further application and design possibilities are still a mystery for many people. Although word has got around that digital “something has to do with 0 and 1”, in fact this description can neither explain digitalization nor estimate its effects and possibilities.

In his book “More than 0 and 1”, Honegger [4] puts it in a nutshell: digitalization in the narrower sense refers to the transformation of analogue (i.e. infinitely variable continuous) data into digital form, i.e. form that can be reproduced on digits and thus processed by computers. As a result, data from all areas of life that can be digitilized can now be automatically recorded, stored, processed, transmitted and disseminated at low cost. The associated enormous increase in the availability of information results in far-reaching opportunities and challenges for society. The basis and driving force of digitalization is computer science. An understanding of its fundamentals, ideas and principles is therefore necessary if one wants to understand and help shape the function, opportunities and development of digital media. The aim of this article is to use the discussion on digital education to show what contribution computer science education can make to understanding the digital world and thus also to offer starting points for ICT education.

2 Digitalization

The extent of the “digital revolution” will be illustrated by a simple example (cf. [15]): Imagine sitting in the top row of Berlin’s Olympic Stadium at 12 noon and from a magical cloud “dripping” into the (waterproof) stadium - just one drop per minute, but the volume of the drop doubles every time. The stadium’s gonna be full up sometime. But how long can we take and watch the play? After 1 min 2 drops fall, then 4 drops, then 8 drops, then 16 drops and so on. After 45 min the Olympic stadium is still 93% empty, but we don’t have time for a nap anymore - only 4 min later the stadium will be full. We also find such exponential growth in the information technology development of the last 50 years. Computers, for example, double their performance every two years, and the volume of data on the Internet grows just as rapidly. We also seem to get used to the developments very quickly: smartphones, navigation systems, the Internet and portable computers have already changed everyday habits massively, even though just about 10 years ago the iPhone was the first smartphone to be sold on a massive scale. Today, it’s hard to imagine that Facebook recently had no significance and that the mobile Internet was only just starting out. If one considers the further development of Internet services such as MySpace, StudiVZ or Second Life[1], it becomes clear that it is hardly foreseeable which concrete technologies will be relevant in the coming years. Analogous to our introductory example, it is now perhaps 12:45 pm. We seem to be facing enormous, hardly foreseeable changes due to digitalization, but the development will not be over at 12:49 pm. Just a few years ago, ICT education researchers also discussed how Second Life, for example, could be opened up for ICT education. Flashing back, it can be described as regrettable how much energy, lifetime and money

[1] These Internet services had millions of users at times, but are largely irrelevant today.

has been invested in the processing of extremely short-term trends and how little the education system has ultimately profited from them.

In the field of school informatics, experiences with less sustainable approaches have also been made. The worldwide failure of information technology related education since the 1980s has repeatedly shown that if the technical and social developments driven by computer science are reduced to the use and application of tools and the discussion of their effects, success can only be achieved in the short term (cf. [1]). Such knowledge and acquired skills were often simply obsolete when pupils left school. Computer science education addresses the problem of short-living skills by orienting itself towards fundamental ideas and principles of the reference discipline of computer science.

3 Fundamental Ideas and Principles of Computer Science

Why is a school subject "computer" or "digital media" not a good idea? For the same reason that there is no subject "pocket calculator" in school: Educational processes that focus primarily on the application and discussion of current media and tools lead to directly applicable and useful skills, but these are quickly obsolete. For this reason, school refers to the underlying scientific disciplines, so that pupils first acquire basic competences and, building on this, application skills. For example, in the subjects of physics, chemistry and mathematics, the principles, fundamental ideas, methods and working methods of the respective science are to be conveyed, so that an understanding of the specialist tools, problems and solution strategies develops from this. Computer science education is also based on fundamental ideas (cf. [14]), concepts and principles of computer science. This will be illustrated in the following using the example of word processing.

For example, let's take the present text and try to double the line spacing between the two lines below this line. People who are mainly proficient in using word processing systems typically try to achieve the goal by marking the two lines and setting the "Line spacing" option to "double line" in the menu bar. The result of this action, however, turns out differently than expected: Not only are the two marked lines separated from each other, but further lines above and below are also displayed as double lines. In computer science education, pupils at lower secondary level learn the concepts that explain this phenomenon: In word processing systems, different types (classes) of text elements must be distinguished, such as characters and paragraphs, each of which has its own properties (attributes); "line spacing" is an attribute of the Paragraph class. If a line of the paragraph affected by the selection is assigned the attribute value "double line", this applies inevitably to all lines of the paragraph. This concept can be applied to various word processing systems (e.g. MS Word, Open Office, Latex). The consideration of the underlying classes and attributes also helps in the efficient handling and understanding of other software applications. Empirical studies have shown that the teaching of such conceptual basics leads to more sustainable competences than functional-application-oriented teaching ("user training"), which focuses solely on user skills [18].

But what are the ideas and principles behind digitalization? Let us first consider the human senses of seeing and hearing. With a transmission rate comparable to about 1 Mbit/s, the eyes offer the fastest connection of the outside world to the brain. But how can visual information be digitized and processed in the computer? Typical topics in the subject area deal with image processing products such as Photoshop, image formats such as JPEG or the storage space requirement of an image in the memory of the digital camera in megabytes. These are also terms which can be assigned to the application skills and which can change quickly. One principle that comes to bear here is the way in which visual information is represented and thus digitally captured. There are two main procedures to be distinguished here: The acquisition of visual information pixel by pixel in the form of a pixel graphic is known from digital cameras. Associated with this are, for example, phenomena of increasing blur and staircase effects when enlarging the image as well as high memory requirements when displaying in high quality. These phenomena typically do not occur when enlarging letters and logos in poster printing. This is due to the fact that in these cases the visual information is efficiently represented as vector graphics. The overall picture is described by the underlying geometric objects (e.g. lines, ellipses, fill patterns), so that the overall object can be "drawn" in any size, similar to "painting by numbers". The principles behind these two processes are not limited to the digitization of visual information. Music, for example, is represented with comparable methods. Analog audio signals are digitized by sampling and storing a sample (according to the sampling rate). As with pixel graphics, information is lost and the larger the sample size, the greater the memory requirements - and thus the higher the quality. Comparable to vector graphics is the MIDI format, in which especially instrument type, pitch, duration and volume (comparable to notes) are described, so that music can be generated from them. We do not only find these processes underlying digitalization in information technology. Sampling is used in all possible application contexts, e.g. in opinion polls or any other surveys; the representation of facts by modelling key factors is a typical scientific approach. These examples clearly show that the core and contribution of computer science, and thus also of computer science education, is not limited to the creation and application of computers and computer software, but above all focuses on the development of creative solution strategies. These strategies always precede the implementation of automated processes using computers (see also Sect. 6).

Strategies for processing large amounts of data have recently become known as Big Data. How these can be used and which competences pupils can acquire to understand Big Data, to deal with data and to use them will be examined in the following.

4 Big Data - Understanding, Managing, Benefiting

Without an understanding of how data and information are obtained, an understanding of Big Data is hardly possible. An understanding of how large amounts of data are stored and processed seems equally important. In the "digital society", for example, the relevance of conscious and reflected handling of data for each individual has greatly increased. Through the ubiquitous networked digital systems, we generate and use data multiple times a day and make decisions about our data. In social media, data is exposed or protected, phone book contacts and other data on the smartphone are synchronized with servers and across devices, personal and business data on computers and in the cloud must be protected from loss and unauthorized access. Quasi incidentally, we permanently leave behind metadata (e.g., the GPS location or radio cell of the smartphone, origin, browser type and – settings for Internet surfing or Tweet location and language, but also the background color used on Twitter are stored and evaluated by the relevant service providers), mostly without being aware of it. As the volume of data grows rapidly, so does the speed at which data is generated and transferred (velocity) and the bandwidth of data types and sources (variety). These three properties are the core characteristics of Big Data.

Big Data is also highly relevant for ICT education. Interfaces to information technology also become clear. For example, Tulodziecki [16, 17] refers to a teaching example developed by our Research Group, in which the pupils use and further develop an IT system for the analysis and evaluation of data streams and get to know the basics of data management and big data. Tulodziecki [17] makes it clear that central questions of ICT education can and should also be dealt with on the basis of these computer science related questions. In the teaching example, pupils learn to evaluate and visualize data from the Twitter data stream and to gain new insights ([8], see Fig. 1). They encounter potential dangers of Big Data, but will also get to know the opportunities and possibilities when using and evaluating public data sources. To this end, they acquire skills in data analysis (classification, clustering and association), metadata analysis, real-time analysis of data on the Internet and monitoring.

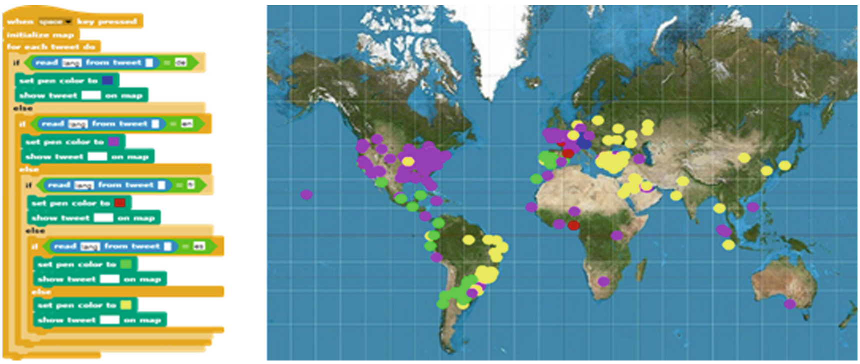

Fig. 1. Visualization of Twitter metadata using the block-based programming language Snap*!*.

5 Perspectives on Phenomena of a "Digital World"

Since 2016, the cooperation between the fields of ICT education and computer science education has intensified and led to a common perspective which constructively underpinned the discourse on digital media in Germany. In February 2016, the seminar "Informatics and School" took place at Schloss Dagstuhl. It dealt with the relationship between computer science education and "digital education" and continued a constructive interdisciplinary discourse between representatives of computer science, computer science didactics, media pedagogy, ICT education, politics, schools and business. As a result of the seminar, the joint “Dagstuhl Declaration: Education in the Digital Networked World” [7] was published, which provides a promising approach for further discourse. Digital education should therefore look at the phenomena, artefacts, systems and situations of the “digital world” encountered by pupils from an application, socio-cultural and technological perspective. In the following expert discussion, the “Dagstuhl Triangle” presented in the declaration was expanded into a “house of digital education”, which intermeshes the perspectives mentioned with the roles that digital media can play in educational processes (cf. [2]). Thus, basic competences with regard to digital media as a teaching subject, the use of digital media as a design tool and object, and the use of digital media as a teaching and organizational tool are taken into account.

Computer science education deals in particular with the basic concepts, principles and ideas of the digital world as a subject of instruction. The aim is to understand phenomena, to question them and to be able to assess corresponding decisions and effects. The use of digital media as a means or object of design aims at creative and productive acting and designing and experiences its application especially in the individual disciplines, but requires an understanding of the underlying computer science concepts. These also make it possible not only to use passive digital media (e.g. static websites, posters, blogs), but also to design active digital media themselves, e.g. by programming apps or simulations.

6 Computational Thinking and Creativity

In addition to developing a sound understanding of the phenomena of the digital world, computer science education aims to develop a special way of thinking, which has been called “computational thinking” for some years now [19] and which is an important basis for the introduction of computer science education as a school subject in more and more countries (e.g. in Great Britain from the 1st class onwards). Computational Thinking (cf. [3]) emphasizes the importance of thinking and analyzing problems and problem-solving strategies that precede their subsequent implementation with a computer. This includes the application of various concepts central to computer science such as logic (analysis and prediction), abstraction (omitting the unimportant), decomposition (splitting complexity into partial problems) and algorithmization (automating and reproducing processes) as well as working methods promoted in computer science and in the use and design of digital media. This includes creativity (designing and implementing ideas), debugging (finding and correcting mistakes), perseverance (learning to master problems) and collaboration (working together). In the following, I will show how computer science education can help to promote computational thinking and creativity, using agile project teaching and creative design with programmable microcontrollers as examples.

6.1 Project-Based Teaching and Learning with Agile Methods

One of the most important teaching goals is that pupils learn to set goals independently, to develop and implement solution strategies cooperatively and to overcome problems together. Against the background of the increasing automation of routine intellectual activity, it is to be expected that the significance of such competencies will increase even more. A recognized form of teaching to promote these competences is project teaching. The core objective here is for the pupils to develop a product, acquire competences in self-organization and learn in social interaction to assume joint responsibility. Teaching projects often follow the classical project method according to Frey/Schäfer [5], according to which the project implementation is first planned in detail and then realized in a long phase. However, the school conditions for such an approach are rather project-unfriendly. The teaching time spread over a few hours per week, surprises in everyday school life (e.g. illness, holidays), changes in the objectives of the project as well as the difficulty of maintaining motivation over a longer period of time make project teaching a challenge and often lead to failure.

In the context of computer science, project-like working methods are central in practice and also well researched scientifically. Similar to the problems outlined in the project lessons, there are also some challenges to be overcome on the software practice side. Approximately 15 years ago, so-called agile methods were developed as a solution, which help to structure the process better with the help of concrete practices and at the same time enable more flexibility. With the aim of supporting pupils in project organization and better achieving the objectives of project teaching, we have adapted agile methods for teaching and have been testing their use in computer science teaching at various schools since 2013 (cf. [6, 10]) (Fig. 2).

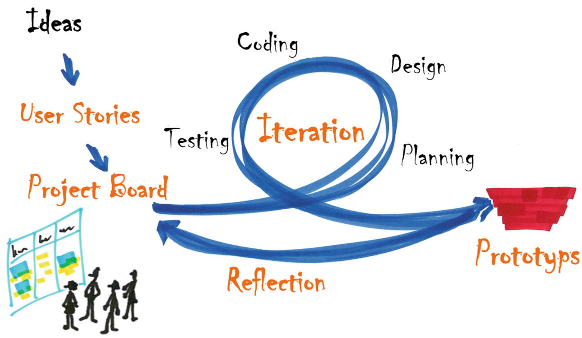

Fig. 2. Agile framework for school projects [13]

The process is divided into different iterations, each of which leads to an intermediate product that can be presented as a prototype. On the basis of a project board, the pupils organize the division of the work themselves, communication processes are supported by regular meetings, reflection phases and working in pairs (cf. [13]). An evaluation shows that the above mentioned goals of project teaching can be better achieved with agile methods, especially the promotion of self-organization and social competence of the pupils. It was also easier for the teachers to plan, supervise and evaluate the projects. In addition, it was found that the pupils were able to apply the competences acquired in the agile projects to other subjects as well.

6.2 Understanding and Designing Embedded Systems with Physical Computing

The discussion about digital media has been and still is mainly related to software that is used on universal hardware (e.g. PCs, tablets, smartphones); the hardware itself is generally assumed to be given. With the increasing miniaturization and spread of microcontrollers, which are used as embedded systems in the most diverse objects of everyday life, the typical image of "computers" is also changing. These can also be found today in cars (modern cars have over 100 networked microcontrollers) and watches as well as in interactive toys. Microcontrollers are also becoming increasingly important in educational contexts. The Calliope project (cf. [9]) plans to make a programmable microcontroller available to primary school children throughout Germany from spring 2017 in the form of the Calliope mini, with the aim of turning children from passive users into active designers of digital media. Other hardware platforms such as Arduino and Raspberry Pi have also become widespread and enable the creative design of interactive objects, known as physical computing, with hardware and software. Such interactive objects consist of various sensors that collect data (e.g. volume, temperature, brightness) and actuators (e.g. LEDs, motors, speakers) that can respond based on the data collected by the sensors (Fig. 3).

Fig. 3. Student results of physical computing: interactive objects with embedded systems.

Physical Computing thus offers a (tangible) context for CS phenomena of the digitalized world and enables pupils to experience typical information design experiences: In their projects, they learn that initial problems are usually imprecise and that modelling decisions have to be made. You will experience surprises in the course of the project, which are associated with occasional frustration, but above all also success.

Due to the interactive character of Physical Computing, they receive immediate feedback and learn to persevere when problems occur. In class, it is evident that pupils are motivated by this approach. They acquire key competences for understanding digitalization, e.g. with regard to the differences between analogue and digital, and learn to understand the penetration of the living world with embedded digital systems in an action-oriented and creative way (cf. [12]).

7 Summary

The increasing digitalization of all areas of life means that schools can no longer afford to use digital media only as a teaching and organizational tool, but must instead consider clarifying the phenomenon of the digital world, i.e. the world shaped by information technology. In more and more countries, for example, binding teaching offers for all pupils are being set up on an international level. The concepts and principles of computer science provide the technical basis for such offers. Not only do they make it possible to use digital media effectively and efficiently in the classroom, but they also create the technical prerequisites for being able to assess the effects of digitalization and make a sound assessment of them. By enabling pupils to learn to creatively deal with digital media in computer science lessons and to acquire computational thinking skills, e.g. with regard to self-organized learning, computer science lessons can lay an important foundation for all subjects. The ultimate goal of "digital education" should be to ensure that digital media are used naturally and creatively in all subjects and beyond school. Students should therefore not only be able to understand the digital society, but should also be able to actively shape it. In the sense of a solidarity between ICT education and computer science, it seems desirable that the individual reference disciplines emphasize their concrete contribution to digital education even more clearly. The discussion initiated in 2016 gives cause for optimism that the discourse between ICT education and computer science education will continue to develop constructively.

References

1. Breier, N.: Stand und Perspektive der informatischen Bildung (State and Perspective of Informatics Education). In: Lecture at the 1st Symposium of the GI Section Hamburg Computer Science Teachers (2004). https://www.ew.uni-hamburg.de/ueber-die-fakultaet/personen/breier/files/vortrag291004.pdf. Accessed 15 Jan 2017
2. Brinda, T.: Statement of the Gesellschaft für Informatik on the KMK strategy paper "Education in the digital world" (2016). https://fb-iad.gi.de/fileadmin/stellungnahmen/gi-fbiad-stellungnahme-kmk-strategie-digitale-bildung.pdf. Accessed 15 Jan 2017
3. CAS Barefoot: computational thinking (2014). http://barefootcas.org.uk/barefoot-primary-computing-resources/concepts/computational-thinking/. Accessed 15 Jan 2017
4. Frey, K., Schäfer, U.: Die Projektmethode (The Project Method). Beltz, Weinheim (1982)
5. Gallenbacher, J.: INFOS 2015: Informatik allgemeinbildend begreifen (16. GI-Fachtagung Informatik und Schule, Darmstadt). Köllen, Bonn (2015)

6. GI (Gesellschaft für Informatik e.V.): Dagstuhl-Erklärung: Bildung in der digital vernetzten Welt (Dagstuhl declaration: education in the digitally networked world) (2016). https://www.gi.de/fileadmin/redaktion/Themen/dagstuhl-erklaerung-bildung-in-der-digitalen-welt-2016.pdf. Accessed 15 Jan 2017
7. Grillenberger, A., Romeike, R.: Big-Data-Analyse im Informatikunterricht mit Datenstromsystemen: Ein Unterrichtsbeispiel (Big data analysis in computer science education with data stream systems: a lesson example). In: INFOS 2015: Informatik allgemeinbildend begreifen (16. GI-Fachtagung Informatik und Schule, Darmstadt), pp. 135–144. Köllen, Bonn (2015)
8. Honegger, B.D.: Mehr als 0 und 1: Schule in einer digitalisierten Welt (More than 0 and 1: School in a Digitalized World). hep Verlag, Bern (2016)
9. Humbert, L., Hilbig, A.: Calliope – Informatiksystem für Schülerhände – Digitale Kompetenzen mit informatischer Grundlage entwickeln (Calliope - Informatics system for pupil hands - Developing digital competences with an informatics basis) (2017). https://calliope.cc/content/7-lehrer-informationen/calliope4iea_humbert_hilbig.pdf. 15 Jan 2017
10. Kastl, P., Romeike, R.: Entwicklung eines agilen Frameworks für Projektunterricht mit Design-Based Research (Development of an agile framework for project teaching with design-based research). In: Gallenbacher, J. (ed.): INFOS 2015: Informatik allgemeinbildend verstehen (16th GI Symposium on Computer Science and School, Darmstadt), p. 201. Köllen, Bonn (2015)
11. KMK (Kultusministerkonferenz) (2016): Bildung in der digitalen Welt. Strategie der Kultusministerkonferenz (Education in the digital world. Strategy of the Standing Conference of the Ministers of Education and Cultural Affairs of the States in the Federal Republic of Germany). https://www.kmk.org/fileadmin/Dateien/pdf/PresseUndAktuelles/2016/Bildung_digital_world_web_version.pdf. 15 Jan 2017
12. Przybylla, M., Romeike, R.: Physical Computing im Informatikunterricht (Physical computing in computer science lessons). In: Breier, N., Stechert, P., Wilke, T. (eds.) INFOS 2013: Informatik erweitert Horizonte (15th GI Symposium on Computer Science and School, Kiel), pp. 137–146. Köllen, Bonn (2013)
13. Romeike, R., Göttel, T.: Agile projects in high school computing education - emphasizing a learners perspective. In: Knobelsdorf, M., Romeike, R. (Hrsg.) Grand Challenges in Primary and Secondary Computing Education (The 7th Workshop in Primary and Secondary Computing Education WiPSCE 2012, Hamburg), pp. 48–57. ACM, New York (2013)
14. Schwill, A.: Fundamentale Ideen der Informatik (Fundamental Ideas in Computer Science). Zentralblatt für Didaktik der Mathematik **25**(1), 20–31 (1993)
15. Stanzl, J.: Exponentielles Wachstum: Ertrinken in 4 Minuten (Exponential growth: drowning in 4 minutes) (2010). https://www.godmode-trader.de/artikel/exponentielles-wachstum-ertrinken-in-4-minuten,2286650. 15 Jan 2017
16. Tulodziecki: Big Data als Herausforderung für die Medienpädagogik - Aktuelle Debatten beim GMK-Forum 2015 im “Rückspiegel” (Big data as a challenge for ICT education). In: Brüggemann/Thomas Knaus/Dorothee M. Meister (ed.) Kommunikationskulturen in digitalen Welten Konzepte und Strategien der Medienpädagogik und Medienbildung zum GMK-Forum 2015 in Köln. kopaed, Munich (2016a)
17. Tulodziecki, G.: Konkurrenz oder Kooperation? Zur Entwicklung des Verhältnisses von Medienbildung und informatischer Bildung (Competition or cooperation? On the development of the relationship between ICT education and computer education). MedienPädagogik: J. Theory Pract. ICT Educ. **25**, 7–25 (2016b)
18. Voss, S.: Modellierung von Standardsoftwaresystemen aus didaktischer Sicht (Modelling of standard software systems from a didactic point of view). Dissertation, TU Munich, Munich (2006)
19. Wing, J.M.: Computational thinking. Commun. ACM **49**(3), 33–35 (2006)