Center of Excellence for
Technology Education

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Future Prospects of Technology Education

WAXMANN

Center of Excellence for
Technology Education (CETE)

Vol. 4

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Preface

Future prospects of Technology Education (CETE Vol. IV)

In 2016 the publication series of *CETE* started with the first volume titled *Technology Education Today*, with the intention of taking stock of what is still a disparate discipline. It was followed by the second volume in 2018, a more research-oriented volume *Research in Technology Education – International Approaches,* and finally in 2020 with the third volume titled *The impact of Technology Education – International Insights*, also aimed at presenting an overview of the research landscape. In retrospect, these publications prove that t*echnology education* has now established itself as an independent and clearly defined scientific discipline, albeit with nationally different foci and research priorities. Secondly, the publications document the enormous spectrum and the wide range of relevant topics, the narrower research context of which comes from a wide variety of disciplines, and thirdly, this now seems obvious, the volumes published so far show very impressively that what is known in Germany as *technology education* presents itself as a decidedly internationally oriented research discourse.

This was the exact original approach that led to the founding of the international network CETE with the help of project funds from the *DAAD*.

CETE (Center of Excellence for Technology Education) was conceived from the outset as a network of leading university research institutions in the field of technical education. The goals associated with the founding of CETE as an international network were defined by joint research projects, study and research stays and the realisation of international workshops and summer schools. The core of these activities was to advance research in technical educational processes and, as a major side effect, at the same time to promote young scientists for the technical disciplines.

Without the funding that has been made available by the German Academic Exchange Service (DAAD) from the *Federal Ministry of Education and Research* (BMBF) in the *Thematic Networks* programme line, since the beginning of 2015, this overall extraordinarily successful work by CETE would not have been possible.

An essential part of science consists in the publication of current research results to advance the disciplinary discourse through national and international experiences, but also critical approaches and contributions. Evidence of

CETE's decidedly international orientation can be seen in the thorough list of responsible editors of the CETE publications, now grown to four volumes, who are at the same time CETE members. CETE members are not exclusively from the founding core at the University of Duisburg Essen in Germany but also from Switzerland, Luxembourg, the United Kingdom, the Netherlands, and the United States of America; each conducting their research in the context of top-ranked universities.

Of course, what applies to the editorship also applies to the authors of all previously published CETE volumes, whose national origins now significantly exceed and extend the national origins of the original founding members.

The fourth volume, which is finally available seven years after the publication of the first volume of the CETE series and provisionally concludes this series, deals, how could it be otherwise, with the *Future Prospects of Technology Education*.

Volume IV of the CETE publication series, similar to the first three volumes, covers an overly broad range of themes and scientific topics through an international authorship again. In seven different chapters, the framework topic technology education is presented with current research work from the disciplinary areas *Digitization* (1), *Methodology and Design Technology* (2), *Gender* (3), *Diversity* (4), *Language* (5), *Curriculum Development* (6) and, finally, *International Communication in Technology Education – Developments* (7).

This volume starts with an article on the role of digitization in technology education: Gabriele Graube (Technical University of Braunschweig, Department of Educational Science) examines *The nature of digitalisation and challenges for education systems and technology education* and sees this phenomenon *in the mirror of industrial revolutions*.

The second chapter, which deals with the subject of *Methodology Design Technology* in the broadest sense, consists of a contribution by Stefan Fletcher (University Duisburg Essen, Department of Didactics of Technology) about *3D printing in design technology* and also includes another extremely interesting contribution by Phoebe Perlwitz and Jennifer Stemmann (both: Education teacher training college Freiburg, Department of Didactics of Technology) on the question of *Serious games in technology education*.

In a series on the issue of *Future Prospects of Technological Education*, the consideration of the gender and diversity problem was of course particularly important to the editors; on the one hand, because these two topics undoubtedly have the longest research tradition and, secondly, because these topics have received such broad attention like hardly any other in the spectrum of technology education in the national and international research landscape. That is why Veronika Becker (University of Duisburg-Essen, Department of School Research) Gabriele Graube (Technical University Braunschweig, Department for Educational Science), and Ingelore Mammes (University Duisburg Essen, Department of School Research) are asking with special consideration about the gender aspect *On the connection between socialisation, stereotypes and gender. Are career and study paths part of technical education?!* And in the closely related topic area of diversity, the US researchers Hao He (University of Missouri, School of Information Science and Learning Technologies), Johannes Strobel (SRI Education, STEM & CS Education program), and Alexander Koch (Haute Ecole Pédagogique Fribourg,) have a specific look in their *Exploratory study on teachers' perception in relation to stem* the special *troublemakers* onto the subject.

In the fifth chapter, which is dedicated to the issue of *Language*, there is a contribution by Julia Pötzl, Verena Rasp and Alfred Riedl (all: TU Munich, Department of Educational Sciences) on the subject *Learning opportunities to promote language skills for industrial-technical occupations. Challenges in dual vocational education and training in Germany*.

There are four contributions on the question of *Curriculum Development*, in chapter six: firstly, by Ibrahim Delen (Usak University), Kadir Demir (İzmir Demokrasi University), Dury Bayram (Eindhoven University of Technology), Elise Quandt (Eindhoven University of Technology), and Ruurd Taconis (Eindhoven University of Technology) on the topic *Using technology to support pedagogy of design-based pedagogy in teacher education*, secondly by Esther Booth, Ingelore Mammes, and Dieter Münk (all: University Duisburg Essen, Faculty of Educational Science) on the demand, which has so far received little research at least in Germany: *Career choices of women and men in STEM*. Thirdly, the contribution by Martin Lang (University Duisburg Essen, Department Didactics of Technology) and Wulf Bödeker (Ministry of School and Further Education, NRW) on the question of *Education for sustainable development as a guiding principle of modern technology teaching,* and fourth and lastly, the article by Charles Max (Université du Luxembourg, Faculté des Sciences Humaines, des Sciences de l'Éducation et des Sciences Sociales), which deals with the question of *Investigating learning and teaching practices in elementary science and technology education. An integrated activity-theoretical framework*.

Chapter seven concludes what is currently the last volume in the CETE series, in keeping with the network intentions pursued by CETE, the pioneering and prospective considerations of Marc de Vries (Delft University of Technology, Faculty of Applied Sciences) on precisely this aspect of international networking and network building, the central question of *International communication in technology education developments*.

At the end of a project, which has sought to build networks in the field of technology education – and that is as demanding as it is labour-intensive and successful –, the project staff at the University of Duisburg-Essen, together with their international project and network partners in the USA, Switzerland, the UK, Luxembourg, and the Netherlands (and, of course, also together with the researchers who have documented their work in this series) hope to have made a substantial contribution in a young discipline that is still largely characterized by desiderata, at least in Germany, and in this way to the urgently needed further international networking in the field of technology education.

It is therefore a very special concern of the editors at this point to sincerely thank all those involved (as well as the participants) – especially in the context of the network meetings –, e.g. the summer schools for the promotion of young scientists as well as the specialist conferences that are organized, for their cooperation and, of course, also for the working time expended: After all, it is obvious that a comprehensive scientific anthology like this one could not come about without the participation of a large number of dedicated researchers. Ultimately, our thanks also go to the funding policy of the DAAD because without this financial support over the relatively long period of four years, the labour-intensive and therefore, unfortunately, also cost-intensive network work in the scientific context would not have been possible.

Prof. Dr. Dieter Münk

References

de Vries, M.J., Fletcher, S., Kruse, S., Labudde, P., Lang, M., Mammes, I., Max, C., Münk, D., Nicholl, B., Strobel, J. & Winterbottom, M. (Hrsg.) (2020): The Impact of Technology Education. International Insights. Münster: Waxmann.

de Vries, M.J. & Fletcher, S. & Kruse, S. & Labudde, P. & Lang, M. & Mammes, I. & Max, C. & Münk, D. & Nicholl, B. & Strobel, J. & Winterbottom, M. (Hrsg.) (2018): Research in Technology Education. International Approachs. Münster: Waxmann.

de Vries, M.J. & Fletcher, S. & Kruse, S. & Labudde, P. & Lang, M. & Mammes, I. & Max, C. & Münk, D. & Nicholl, B. & Strobel, J. & Winterbottom, M. (Hrsg.) (2016): Technology Education Today. Münster: Waxmann.

Gabriele Graube

The nature of digitalisation and challenges for education systems and technology education

Digitalisation in the mirror of industrial revolutions

Introduction

Terms such as digital education and digitalisation, which are to be found primarily in discourses on education policy, are fuzzy and mask the complexity of the issue and the challenges facing educational institutions. The following article intends to contribute to illuminating the topic; firstly, by showing the history of digitalisation, with its connection with inventors, developers, technical systems, users and social change. The development lines of digitalisation and its basic principles will be illustrated. Based on this, conclusions will be drawn for education, education systems and technology education.

Historical overview – from calculating aids to computers

Today, a computer has countless functions for the most diverse areas of application, ranging from text and photo editing to graphic and web design, digital dentistry and digital twins. In these applications, the basic function of computing is increasingly in the background or disappears into a black box. Therefore, we will first begin by outlining the technical design of this original computing function.

In the beginning, fingers (lat: digitus), stones, sticks, shells, and later notched pieces of wood helped us to count and do arithmetic. The use of the fingers brought in the decimal system, which uses the number 10 as its basis. The oldest technical aid was a slide rule (abacus), followed by number and slide rules, before the first mechanical calculating machines were developed, which were, initially, only able to add. They already possessed systems for input, processing and output of values and this basic principle EVA (IPO) is still the basic scheme of any data processing system today.

The Z1 was an electromechanical calculating machine built around the middle of the last century by Konrad Zuse using relay and tube technology. The Z1 was based on the dual or binary system, in which numbers are represented only by the digits zero and one (0, 1). This system is easier to use for technical applications, since it is only necessary to realise two physically distinguishable states (current is flowing, current is not flowing).

Electromechanical computers consisted of: An input/output unit, a programmable arithmetic unit, a memory unit and a punched tape as a programme unit (Rojas 1998). They were an enormous size and were prone to failure due to their mechanics. With the development of semiconductor technology and microelectronic components in the mid-1950s, the miniaturisation of switching processes began. To emphasise the importance of electronics, in German-speaking countries computers were referred to as 'Elektronische DatenVerarbeitungsAnlagen' (Data processing equipment – EDVA).

The TRADIC (TRansistorized Airborne Digital Computer) is considered to be one of the first computers in a smaller size which was less susceptible to interference and possessed greater processing speeds. Logic circuits could execute the algorithms used (for basic arithmetic) simply and efficiently. The first microcomputer arrived on the market at the beginning of the seventies. This marked the beginning of the miniaturisation of the computer and the dissemination and proliferation of computer technology, thus heralding the start of the third industrial revolution. Today, computers are networked worldwide, their components are embedded in other physical systems and data is the "raw material" from which business models are now created.

Information-transforming systems in the mirror of industrial revolutions

Technical systems can basically be regarded as transformation systems. They have the function of converting, transporting or storing material (M), energy (E) or information (I). In order to be able to distinguish the main function of the transformation from secondary functions, we use labelling with the following letters: for the main flow (M, E, I) and the secondary flows (m, e, i). Technical systems have a defined structure of components which, when the elements interact, enables the system to function. The required input variables (inputs) are converted into output variables (outputs) through interaction of the elements. This process is also referred to as a technical process. In terms of the environment, technical systems can be separated by an expediently defined

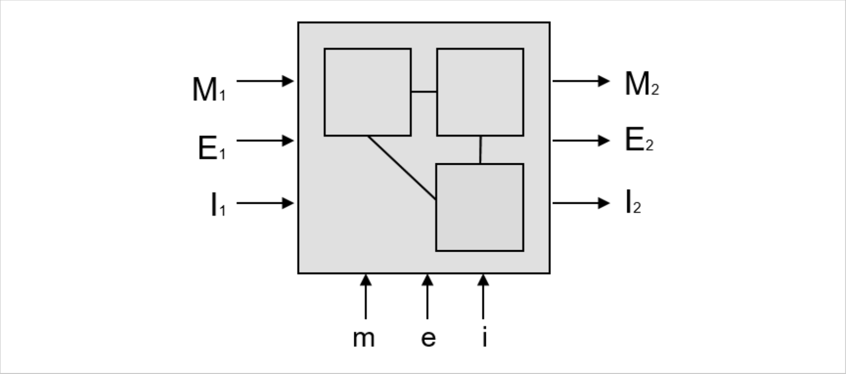

Figure 1: Basic scheme of technical systems

system boundary. In the technical sciences, we have distinguished three types of technical systems for many years (cf. Wolffgramm 1994, Czichos 2019):

- Material-transforming technical systems that extract, process, transport, etc. substances/material (M). (Examples: production plant, transport system).
- Energy-transforming technical systems that convert, distribute, use – among other things – energy (E). (Examples: generator, drive system).
- Information-transforming technical systems that generate, transmit, and display information (I). (Examples: DVD player, smartphone).

Socio-technical systems form a unity of technical systems, people and society and their elements interact with each other and have an effect on each other. Finally, ecosystems form units of nature, humans, technology and society – a way of looking at things that makes the problems and solutions of climate change particularly recognisable. In the following section, we will be examining the characteristics of industrial revolutions in order to then identify basic principles of digitalisation, fine-tune the term digitalisation and discuss the position of humans in this scenario.

First and second industrial revolution

From the 2nd half of the 18th century, the first industrial revolution began, and the hand tool (for transforming material M) was integrated into technical systems (machine tool). Thus, the hand loom was integrated into the mechanical loom. At the same time, energy (E) came to the fore with the invention of the

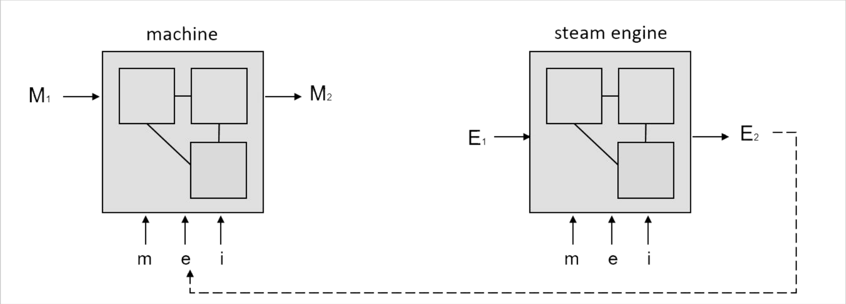

Figure 2: Technical systems in the first industrial revolution

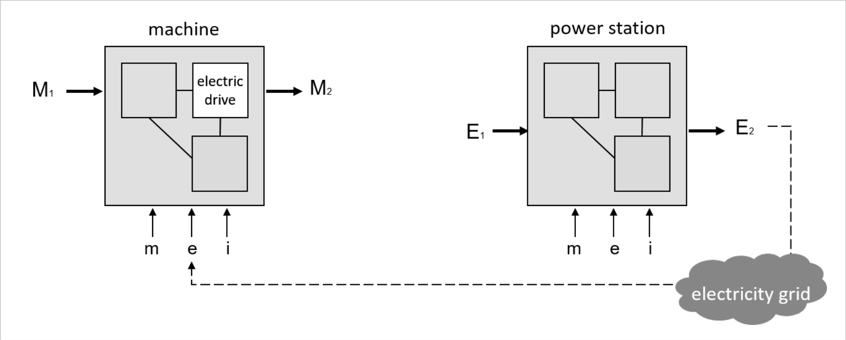

Figure 3: Technical systems in the second industrial revolution

steam engine. Steam engines convert chemical energy of fossil fuels (E1) by combustion, first into thermal energy and then into mechanical energy (E2); in this way, a perfect driving machine was created. It could be coupled with machine tools (with weaving machines, for example) and supplied the necessary drive energy (e).

Incidentally, at the beginning of the 19th century, punched cards were the first machine elements to mechanically provide information (i) for the control of Jacquard looms: the punched cards with their hole patterns provided information for raising or lowering the warp threads. Each individual warp thread could thus be controlled separately, and patterns could be changed by exchanging the punched cards. This invention can be understood as an early precursor of the binary system.

While the first industrial revolution was about mechanisation, the second industrial revolution focused on electrification. From 1870 onwards, electrical energy determined further developments. With the invention of electric drives and their embedding in machine tools, the individual drive of machines became possible. Assembly lines were moved into the factories and all these developments led to the division of labour and mass production. At the same time, power stations and electricity grids were built. Following this, electric drives also found their way into non-industrial areas (e.g. trams) and households. Cams were used as mechanical information carriers (i) to generate non-uniform movements in machine tools and textile machines.

Third industrial revolution

From the middle of the 20^{th} century, the focus was on information and, as a logical progression, the *automation* of production. As it is based on the invention of the computer, it is also called the electronic or digital revolution. The integration of computer components into technical systems represents another milestone in digitalisation. With the internet, a computer network for data exchange was also created.

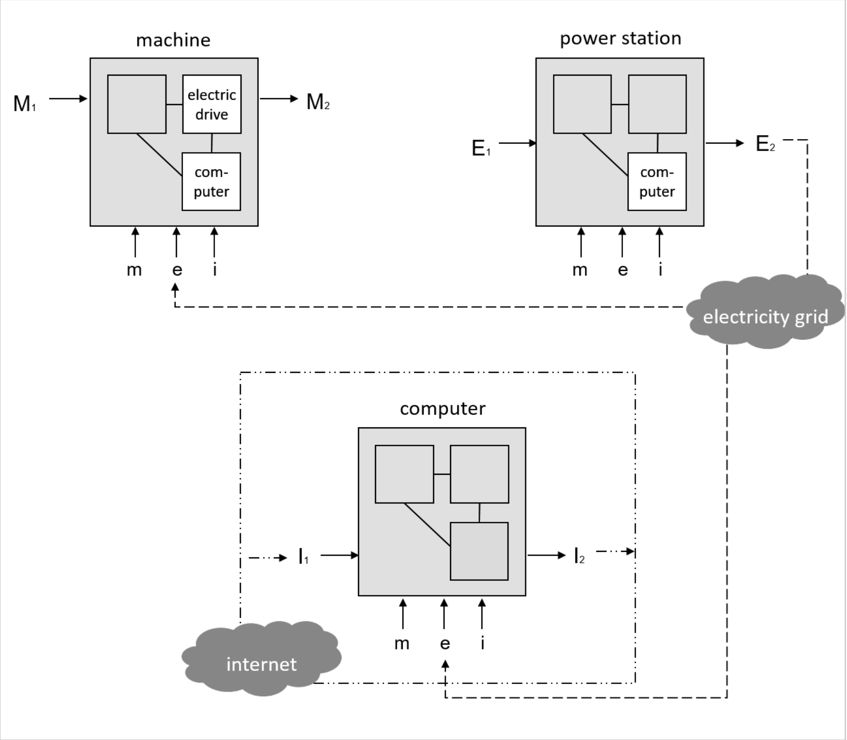

Figure 4: Technical systems in the third industrial revolution

The EVA-principle/IPO-principle of the computer

With its different elements, the computer forms a technical system for the transformation of information (I1 into I2) and is the central element of the digital. On the process side, the initial state is also referred to as input and the final state as output. This is how the term EVA/IPO came into being. The following hardware and software components realise the EVA principle:

Input: Input includes the operations and devices used to enter data into the system. Input devices include the keyboard, the computer mouse, the touchpad, the graphics tablet, the scanner, the microphone, the webcam or the digital camera.

Processing: The entered data is processed in the CPU (central processing unit). The main elements of the CPU are the arithmetic logic unit, the control unit, the memory unit for storing programmes and data, and bus systems for connecting the individual components and transmitting data. The arithmetic logic unit performs arithmetic operations and logical operations. The control unit interprets the instructions (commands/instructions) that a programme specifies and regulates the sequence of commands. Depending on the programming language, the quantity and formal structure/syntax of the instructions differ. The programmes work at different levels:

- At the lowest level we find the machine code, which determines which instructions are executed directly by the processor (e.g. comparison of a value). Today, the machine code is no longer programmed directly, but is, with the help of interpreters, translated from a higher programming language into the machine code. All systems that have a processor need a machine code. This includes not only computers themselves, but also embedded systems such as smartphones, washing machines, airbags, etc. With computers, for example, the machine code can be recognised by the exe files.
- Above this we have the level of the operating system. Here are all the programmes that manage memory, hard disks, input and output devices and other hardware resources. The operating system (OS) forms the interface to application programmes. At the operating system level, users can communicate with the system to make specific configurations (e.g. to manage internal storage space for applications, to set up and to manage access rights and privacy regulations). This work requires special IT skills. With the machine programme and operating system, the user has a ready-to-use system at his disposal.

- At the top level we have the application programmes. These are the programmes with which users usually come into contact. These programmes support human activities (e.g. word processing, image editing) and change work processes.

Output: The processed data is passed on to the user via man-machine interfaces. Output devices are monitors, printers, speakers or projectors. Some peripherals also combine input and output functions (e.g. touch screen, printer with a scanning function). From a systems theory point of view, input and output systems occupy a special place because they connect the computer with the environment and enable communication. These interfaces can also be configured as machine-to-machine interfaces, which form the basis of network technologies.

The internet – social communication through computer networking

From a technical point of view, the internet is a network of originally autonomous computers that transmit data via a network protocol. The Internet Protocol (IP) is widely used. Every device that is to be connected to the internet needs an IP address. With it, the sender and receiver of data can be clearly identified.

The internet originated in the military sector in the 1970s. It was not until about 20 years later that it was made available to the public and quickly developed into a network offering internet services for data exchange and communication:

- Via *e-mail,* persons can create, send, receive and manage text messages or also send attached documents. The prerequisite for this is the addressing of sender and recipient via mail addresses.
- The *World Wide Web* (www) transmits web pages to the recipient with the help of a special programme (browser). Web pages contain text, images, video and audio elements, animations and hyperlinks to other web pages. Web pages are generated with the help of special languages (HTML) or application programmes. Every website needs an identification in the form of a URL address (Uniform Resource Locator). Dynamic web pages only build up actively when a call is made, such as with a weather forecast or information on traffic jams.

- In a *Cloud*, IT resources (e.g. data storage, computing capacity, programmes) are available and managed by service providers via the internet (cf. Geisberger and Broy 2012, p. 243).

Today, these services are called "Internet of Services" (iOS). They allow, among other things, one-to-one communication (e.g. mail, remote maintenance of a computer), one-to-many communication (e.g. website, blog, podcast, updates of workplace computers via server computers) and many-to-many communication (e.g. wiki, video conferences, chat rooms).

Today, security issues and protective measures are becoming increasingly important, as the internet also allows the distribution of viruses and malware.

Mechatronics – embedding information-transforming systems

Information-processing systems such as minicomputers, microprocessors or microcontrollers can be integrated into technical systems and take over monitoring, control and regulation tasks, for example.

The range of applications for mechatronic systems extends from automotive electronics to aircraft and even to toy robots in children's playrooms.

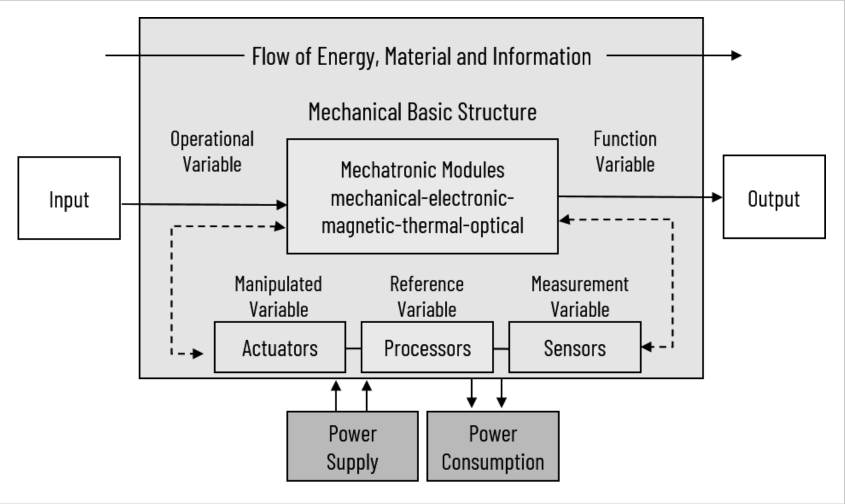

Figure 5: Basic principle of mechatronic systems (in the original Czichos 2019, p. 37, translated by Graube)

They have mechanical, electronic, magnetic, thermal and optical components as well as actuators, sensors and processors. Sensors determine function-relevant measured variables and by feeding them, convert them into electrical reference variables, and then to processors. Together with actuators, the processors generate manipulated variables for closed-loop or open-loop control to optimise the functionality of the system. (cf. Czichos 2019, p. 36)

In terms of systems theory, sensors can be seen to be technical subsystems with which the technical system can perceive information from the environment itself. This information is then processed by information technology in order to be able to control and regulate technical processes via actuators.

Sensors, actuators and processors, as new machine elements, thus contribute to an increase in the autonomy and self-activity of the technical systems as a whole. This gave a boost to automation, which is about "equipping a device so that it works as intended, either completely or partially, without the assistance of a human being" (DIN V 19233).

Fourth industrial revolution

With the fourth industrial revolution, the topic of information will continue on the basis of cyber-physical systems. Phase 1 of Industry 4.0 is understood

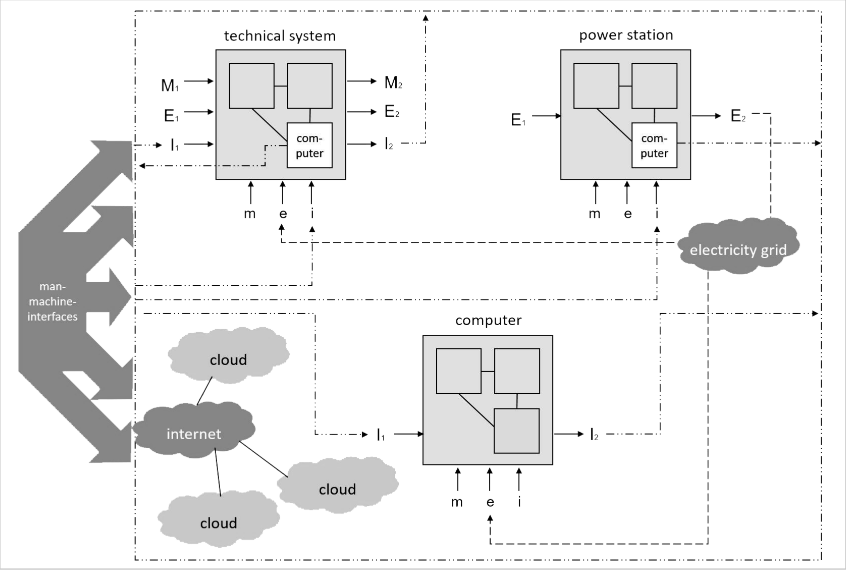

Figure 6: Systems in the fourth industrial revolution

as the mass distribution and use of mechatronic systems and computers (cf. Siepmann 2016). Ubiquitous computing now extends into non-industrial and private areas.

At the centre of this revolution is the networking of intelligent systems into super-systems. In these systems, material, energy and information transformations (M, E, I, m, e, i) are created in physical space using the internet and clouds. At the same time, human-machine interfaces are gaining in importance.

Cyber-physical systems – outsourcing of information-transforming systems and symbolisation

In the further development of mechatronics, a cyber-physical system embodies the unity of reality and digital images. The symbiotic system approach is based on all components being networked by information technology (cf. Drossel et al. 2018, p. 199). Data is transmitted from sensors to clouds via the internet. Here, they are merged with other data, processed and transferred back to the mechatronic system in order to influence physical processes by means of actuators. The information and communications technology infrastructure of CPS

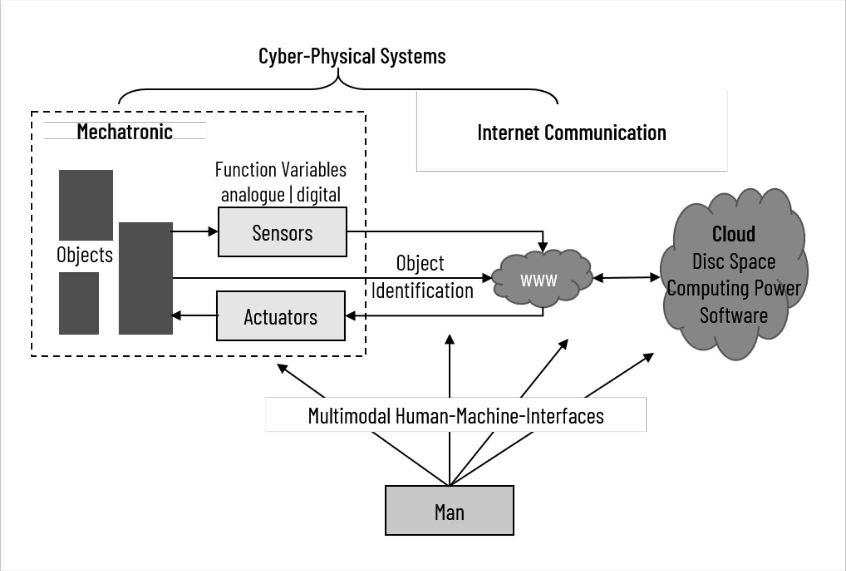

Figure 7: Basic principle of CPS (original figure from Czichos 2019, p. 334, translated by Graube)

no longer needs to be installed on local computers; it resides in Cloud. Storage space, computing power and application software in the cloud become part of the services provided (Cloud computing) (cf. Czichos 2019). CPS can therefore be regarded as mechatronic systems with internet communication.

Principles of CPS

In CPS, sensory, actuator, and cognitive functions are integrated into technical components, enabling them to achieve functionalities only previously fulfilled by biological systems (cf. Drossel et al. 2018, p. 199). CPS represent much more than networked mechatronic structures; in fact, they are rather like robots in the past, like a new class of technical systems. Compared to traditional automation, with its embedded systems and controlled behaviour, cyber-physical systems show increasing complexity, i. e. they are now beyond the stage of being simple machines. They are considered non-closed, i. e. open sociotechnical systems, i. e. the functional interaction of human(s) with technology and technologies goes beyond the design of multimodal human-machine interfaces. CPS possess fundamentally new characteristics (cf. VDI 2013, p. 2; Gruhn 2016; Drossel et al. 2018, pp. 199–200):

- *Autonomous systems:* The systems independently solve complex tasks. To do this, they act with a set purpose without remote control or further human assistance. Thanks to automatic adaptation mechanisms/adaptation systems based on model descriptions of their environment and tasks, there is little or no need for intervention by the developer or user.
- *Dynamically networked systems:* Open architectures work by combining independent, interchangeable and scalable components and services. The technical systems can therefore be interconnected whenever necessary, and their connections can be changed, terminated and reestablished during the period of operation. Conventional system, organization and domain boundaries can be crossed; this means that their composition and structure change dynamically during the period of operation. Networking gives rise to new systems whose functionality and performance exceed the sum of the individual systems. The system boundaries, the interfaces and the roles of the individual systems vary.
- *Interactive socio-technical systems:* Interaction between humans and machines is becoming increasingly multimodal (e.g. speech or gestures) and is based on a wide variety of technologies (e.g. augmented reality or holograms). The technical systems adapt flexibly to the needs of the users and

support them in the contextual sense. They explain themselves and offer the user possibilities for action. To do this, they also use physical sensors (e.g. temperature, pressure) and virtual sensors (e.g. price of goods, importance of customers). On this basis, algorithms are used to analyse data and make decisions about adaptation strategies. The result is a socio-technical overall system.

- *Product-service-systems:* Product-service systems are based on a close interlinking of these products and services. They provide needs based and data-driven services geared to the customer; as a result of this, innovative business models emerge.

Geisberger & Broy (2012) characterise powerful cyber-physical systems in a similar way[1]. This means that CPS increasingly possess properties of complex systems. As with simple systems, the input changes the state of the system. However, CPSs respond differently to the same input at different times, depending on their own state. The output thus depends on the current input, but also on the previous system's state and the stored algorithms.

Enabling technology

CPS were recognized early on as enabling technology for innovative applications. In the meantime, CPS have become a central plank in product development, and no longer focus solely on industry but permeate all areas of people's lives. Meanwhile, internet-enabled vending machines and robots have moved into households (washing, baking, cooking, cleaning machines) and mobile phones have become multifunctional systems in the hands of every individual. Data from different sensors, evaluation and inventory data can be linked and evaluated using defined models when predicting medical outcomes and requesting services from other providers (e.g. pharmacies, ambulance service) (cf. Geisberger and Broy 2012). The digital and interaction with digital systems has become the new "nature" of man.

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[1] "They can directly grasp their distributed application and environmental situation, interactively influence it together with the users and specifically control their behaviour with regard to the respective situation. In this way, the systems provide their services largely independent of location, but context-specific ('Context Aware'), adapted to the requirements of the application situation, partially autonomous, partially automated, multifunctional as well as networked and distributed for the respective users and stakeholders." Geisberger and Broy 2012, p. 22.

Area	**Examples**
Smart Home	Intelligent electricity meters, intelligent room ventilation systems
Smart Grids	Control in the distribution network, control of generation and consumption, recording of consumption readings
Smart Factories	Automation, self-orientating logistics systems, preventive maintenance, automatic ordering of spare parts
Traffic and Automotive	Driver assistance, safety, navigation, parking systems, autonomous vehicles for agriculture and construction work
Trading	Container monitoring, consignment tracking
Health	Emergency call systems, tracking and monitoring of medical devices, technology and products, Active Assisted Living
Sport	Real-time training analysis, fitness analysis, goal-line decision support
Safety	Tsunami, earthquake warning systems
Military	Drones, air defence systems

Socio-technical discussion

Summing up, the beginning of technical and industrial revolutions was marked by the development of technical systems for the transformation of substances/materials. The second great leap was in the development of technical systems for energy transformation to enable mass transformations of materials. With the third category – information – technical systems are now also able to process and transform data. The peculiarity here is that information, unlike matter and energy, can be duplicated. Countless digital twins with and without analogue counterparts or countless digital variants of each of these objects are possible. In this way, a digital world is created alongside the real world, which

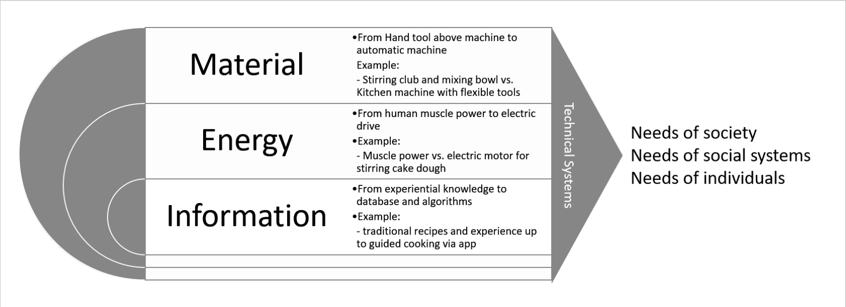

Figure 8: Substance, energy and information as basic categories of technical development

is nevertheless bound to the real world: the computing power of computer systems requires large amounts of energy on the one hand, and on the other hand, computers always have a physical building structure despite all its virtuality.

At the same time, the real world is linked by the symbiosis and fusion of technical systems for the transformation of material, energy and information and the human being is part of this as an element of the system to satisfy individual and societal needs and demands.

If we focus on digitisation, we can identify four essential design phases or digitisation stages that build on each other and are interdependent:

1. *Computers as individual systems:* A computer is based on the basic operation of calculating with binary numbers, which is technically made possible by the help of electronic systems. A computer needs an input of data, a processing unit and an output of data. Instructions (programmes) are required to process the data.
2. *Internet as a computer interconnection system:* Computers are connected by the internet and can communicate in the technical sense. Social communication is also digitalised via man-machine interfaces and internet services.
3. *Mechatronic systems as individual systems:* Individual systems are also digitalised. Computers are embedded in the systems for this purpose. Sensors provide data that are processed by processors and they forward data to actuators.
4. *Cyber-physical systems (CPS):* In this digitisation stage, digitised systems are connected to the internet and the IT infrastructure of the individual systems is, in most cases, outsourced to clouds. Computer systems are used to control technical systems, for social communication and to develop new services. People use services, generate data and thus become part of the overall system via human-machine interfaces.

In a *narrow conceptual version*, digitisation therefore means using computers to implement all processes for inputting, processing, outputting, storing and transmitting data (at the technical systems level). In a *broader understanding of the term*, digitalisation is a goal-oriented project to develop and use technical systems and super-systems that are equipped with specific IT components, sensors, actuators, internet communication, cloud access and human-machine interfaces depending on the requirements (at the socio-technical systems level). The aim is to use a technical infrastructure to automatically collect, process and use available data, collected locally and globally, in order to optimise existing internal processes, expand existing business models and develop completely new products and services.

Digitisation leads to data being permanently generated, used and processed in socio-technical systems with increasingly autonomous technical systems. According to Marx's concept of capital, one could meanwhile also speak of "data-hacking systems" or, in relation to the "perpetuum mobile", also of "perpetuum informatio". This means that in addition to material resources (raw materials) and energetic resources (energy sources), Big Data is a resource that is generated and not exhausted by the mere existence and use of IT systems.

With the penetration and networking of CPS in a multitude of social and personal areas, the original tool character of technology is increasingly receding into the background and being replaced by the system character. The striving of social systems for communication, social exchange and social interaction has been described by Luhmann as the glue of social systems (cf. Luhmann 2011). If we transfer this metaphor to sociotechnical systems, the intelligent networking of everything with everything becomes the new glue of sociotechnical systems. CPS, as agile tentacles, form permanent and situational space grids of never-ending information. Sociotechnology 4.0 is thus becoming synonymous with a dense network of human and machine actors in which not only technology is developed and used, but also data is generated and can also be industrially obtained and used for completely new purposes. Data is thus becoming the "new raw material" (Big Data), enabling data collection, processing and use to an unprecedented extent in all areas of society.

The ultimate question arising from the socio-technical changes is the role of the human being in the digital and digitalised world. The developer role is a crucial one because it determines the functionality of the IT systems and their purpose in the social fabric. In the CPS, man and machine are linked through shared action and the role of the user is defined via the CPS architecture and algorithms. Human-machine interfaces enable inputs (e.g. touch screen, keyboard, gestures, speech) and provide feedback. CPS developers need specific knowledge and expertise. There are questions from mechanical engineering, electronics, sensor and actuator technology, software, production, communication and information technology, and we must take this into account when designing the system. This requires interdisciplinary and cooperative collaboration in the following:

- Development, production and exploitation
- Operation and maintenance
- Services, consulting, adaptation and further development,