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**Teaching technology in Early Education as a pathway to future Mechanical Engineers**

Hannes Tegelbeckers, Philipp Schüßler, Linda Vieback, Dr.Stefan Brämer

Hannes Tegelbeckers, Otto-von-Guericke University, Germany, hannes.tegelbeckers@ovgu.de

Philipp Schüßler, Otto-von-Guericke University, Germany, philipp.schuessler@ovgu.de

Linda Vieback, Otto-von-Guericke University, Germany, linda.vieback@ovgu.de

Dr. Stefan Brämer, Otto-von-Guericke University, Germany, Stefan.braemer@ovgu.de

**Abstract :** Early STEM (Science, Technology, Engineering and Mathematics) education is one of the main pillars in getting young adults involved and interested in STEM subjects. If basic concepts about programming, controlling and robotics are picked up early in education then interest and self-efficacy can be increased and lead to an increased willingness in young adults to consider a STEM orientated career. Using A situated learning approach and by utilizing the for these purpose specifically developed on Single Board Computer (SBC) Raspberry Pi, we were able to use existing toolboxes which enables the educator and the learner to engage collectively with technology on a software and hardware level. Most importantly, by using open educational Ressources (OER) and free and open source software (OSS), experimenting in class can be achieved by pooling class and online resources and being able to see the Raspberry Pi as a learning object itself to be discovered and experimented with. So far the setup has been used as an intervention tool in German and Guatemalan secondary schools to change perceptions towards STEM subject. The goal is to show that the setup can be used throughout secondary and higher education, specifically STEM subjects such as Mechanical Engineering, to enable continuous learning on one extremely flexible platform. The Raspberry Pi is now used by logistic companies, smaller and bigger tech companies and other branches as an affordable, easy to manipulate tool for basic programming, data management or mechanical controlling.

**Keywords**: Early STEM Education, Raspberry Pi, Open Educational Resources, Situated Teaching- Learning Environments, ICT in Schools

# 1. Introduction

The shortage of skilled workers in Germany in industries linked to STEM (Science, Technology, Engineering and Mathematics) subjects has become a bleak reality in the public and academic discourse regarding our future workforce and their training and education. According to estimates by the German Chamber of Commerce in 2018, 150,000 vacancies exist in this occupational group alone (c.f. Himmelwarth 2018). Based on this shortage of skilled workers, numerous research and development initiatives are addressing the question of sustainable career orientation, especially in the technical and engineering sciences. Studies suggest that a basic interest in mathematics or technology develops as early as fifth grade and has a significant effect on the subject and career choice in further education (c.f. Caspi et al. 1998; Cook et al. 1996).

Hence, there is a need for early support to raise awareness of technical occupations and engineering courses, to inspire STEM subjects and to maintain interest in them. One way to raise awareness and promote access is through teaching applied computer science and form a basic understanding of computational thinking and the functionality of digital technology. Studies show that sound computer knowledge corresponds to the desire to pursue a technical profession and reduces barriers t develop an interest into STEM subjects (c.f. Ziefle und Jakobs 2009, p. 53). Based on these findings, there is an urgent need to use computer-based, action-oriented and interdisciplinary teaching-learning arrangements in education.

An additional challenge is the often missing standardized implementation of career orientation concepts. Starting at grade 5 has a significant impact on the further development of subject and career choice (see Caspi et al 1998, Cook et al., 1996). Due to the late start of vocational orientation measures, the young people are often left on their own and overwhelmed with the large selection of possible vocational training options or study programs. The aim is to counteract with innovative teaching concepts and teaching-learning arrangements, targeted investments for the development of technical infrastructure and adapted training for teachers and in the field of STEM education.

# 2. Digitalization of education

## 2.1 Chances of Digitalization

The potential of the Internet and the promise of Information and Communication Technologies (ICT) in education are lacking behind the expectations and promises made at the turn of the millennium. Extensive problems have been identified in recent years, such as missing or inadequate infrastructure and frequent hardware malfunctioning or compatibility and update issues of outdate software and operation systems as well as lack of training and staffing (Weinreich & Schulz-Zander, 2000, p. 587 ff.).

Various studies have shown that even the so-called "digital natives" (designation of the generation that grew up with digital media) do not have a better understanding just through the use of digital media and the familiarity in handling associated hardware components (see OECD 2015, World Bank 2016). In addition manufacturers are increasingly focusing on the use of graphic surfaces and embedding the devices in an ecosystem specially created by the manufacturer, which increases the user-friendliness but limits the freedom in dealing with the used soft- and hardware. Nevertheless, access to information, programs and online communities is an undeniable benefit for users, if handled consciously and responsibly.

In the context of educational science, development of programming languages such as logo (Papert 1973) and experiments such as Mitra's Whole in the Wall (c.a. Mitra, 2010) initiative or the breakthrough of the videobased online tutorials of the Khan Academy lead over decades to new approaches to ICT within and outside the classroom. Having access to the Internet alone already provides opportunities for individuals and groups to exchange and network solely through the production and co-editing of teaching and learning materials. In order to be able to optimally use the above mentioned new opportunities, be it socially or personally, Jenkins has created a catalog of competences that describes a media-oriented "participation society". Competencies such as play, simulation, distributed cognition or collective intelligence are desirable in order to promote optimal personal and social development with the available technical aids (Jenkins 2009, p.35 ff).

## 2.2 An ICT approach with Open Source

How detailed technical knowledge and applied computer science as well as mathematical basics are to be included into a modern curriculum is subject to debate and depends on the use and definition of terms such as Digital Competency, IT literacy, ICT Competency and so on. The example of Norway shows an integrated approach where "Digital Competence" is introduced as the new fifth basic competence after reading, writing, arithmetic and oral presentation (see Krumsvik 2012, p. 459). Krumsvik shows for Norway what the OECD studies and ICILS testify: The everyday use of technology does not automatically increase the knowledge of dealing with the same. This requires separate learning settings that focus on this topic (c.f. Brandtzaeg 2016, p.157).

The introduction of programming plays a key role in the understanding of basic applied computer science and furthermore STEM subjects and is thus a core goal of a computer-oriented teaching orientation (see Herper 2004, p.6). The choice of programming languages and environments as well as the software tools used play an important role. In the sense of the above-mentioned orientation in the participatory society, the use of Open Source Software (OSS) and Open Educational Resources (OER) is the most plausible (c.f. Hepburn and Buley 2006). OSS is not only favored because of its significant economic advantages over licensed products, but also because of its potential for community development and the associated step towards a participatory society (see Wieland 2004, pp. 112 ff.). Through their sequential and complementary structure, open-source approaches enable joint project design based on existing source code and expert knowledge, which subsequently can be shared with other members of the community (see Osterloh et al., 2004, p.130).

## 2.3 ICT competences in education

Seymour Papert's Programming Language Logo (1973) provided one of the first computer-centered approach to instructor education using ICT (c.f. Papert 1993). In Germany, information technology fundamentals have been integrated into everyday school life since the 1990s by ITG (Informationstechnische Grundbildung - basic information technology education), especially in the mathematical and computer-aided subject areas. In the meantime, however, following high promises and a first wave of research, it has become clear that ICT and e-learning can not keep its promises made by enthusiasts and representatives of the field (c.f. Kellner 2006, p. 241 ff.). The conversion to ICT integration into the learning environment requires for example a more comprehensive evaluation and training for teachers in order to implement existing and future concepts.

There are several approaches to media and ICT competence models that can be used as a guide for teachers and trainers. UNESCO has published an "ICT Competence Framework for Teachers", which includes, among other things, the various areas of knowledge regarding knowledge and skills in hardware and software applications, the necessary pedagogical basics and the ability to work with ICT in everyday school life (see UNESCO 2011, p 16).

For the development of the necessary applied computer science competencies, the concept of computational thinking can provide the substantive foundation. Computational Thinking is a collective term for certain applied computer sciences core concepts and is defined as "[...] the thought processes involved in formulating problems and their solutions. CAS 2015, p. 6). It highlights five areas of logical thinking which build the core for understanding digital systems: (1) Algorithmically, (2) in terms of decomposition, (3) in generalizations (patterns), (4) in abstractions, (5) in terms of evaluation (see ibid.). Overall Teachers will have to grasp a basic understanding of these core concepts to be able to develop a broader understanding for students in the classroom.  
Another competence framework for teachers was developed by Mishra and Koehler in 2009 (see Graham et al., 2009). He combines basic curricular and educational with technical competences. Especially with these competency models it becomes clear what teachers have to unite in contrast to learners. While learners focus more on application-related content and linking content, teachers not only have to understand and include curricular content but ideally also combine interdisciplinary subject content (see Meriläinen and Piispanen 2014, pp. 69 ff.). This is no longer feasible within a teacher-centered approach but requires new team strategies for the teachers as well as new approaches to the design of the lessons themselves. Here, various approaches have developed. For example, the Computer Supported Collaborative Learning (CSCL) approach represents a way to use ICT for new forms of collaborative learning (Haake et al., 2012, pp. 2 ff.). In this theoretic construct are Dewey and Piaget reform educational approaches, which put the focus of the learning setting on the learner and its individual needs and abilities to contribute to the different contexts. The teacher as well as the learner are on equal terms and learn together, but the tasks of the respective actors differ only in certain areas (c.f. Witt and Grune 2012, p. 55). Teachers have the opportunity to integrate the knowledge and experience of the learners into the lessons. However, this teaching and learning approach requires a rethinking and a restructuring in the respective schools (c.f. LaForce et. al, 2016, p. 7ff). The need for a new learning environment that adapts to the needs of a 21st century society needs to be discussed here. On the one hand, competences are to be considered which relate specifically to the handling of information and its contextualization (see Meriläinenn and Piispanen 2015, p. 237 ff.). On the other hand, the use of computers appear too change thinking patterns entirely, using them as "intellectual prosthesis", more precisely: "[...] cognitive processes are concretely off-loaded to digital objects when we are using computers and this child is learning everywhere in today's digital society" (Krumsvik 2012, p. 467). This makes it especially clear that the integration of ICT is a rethinking in the truest sense of the word.

# 3. Situated Teaching-Learning Arrangements as an experimental approach

Digitalization has widespread implications, which need to be tackled from multiple angles while at the same time trying to keep up with a further, constant changing environments affecting personal and professional areas at the same time.

To address the issue from the perspective of an educational institution, one solution is the conception of situated teaching and learning arrangements with the background of vocational orientation. The goal of these arrangements is among others to stimulate, promote, expand and deepen learners' interest in technology. It puts an emerging possible interest into STEM subjects and possible relevant occupations and/or fields of study in the focus of the students learning process. It blurs the line between education and occupation in the same way the usage of educational material such as the raspberry pi found their way into production facilities and vocational training settings of logistics firms, using the technology to change or improve factory processes within a professional experimental learning and working setting (Zhao et.al. 2015, p.27f).

## 3.2 Implementing situated Teaching – Learning Arrangements

The design of these concepts is based on 4 central pillars:

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| Pillar I | **Early use of appropriate arrangements** Start at the latest from grade 5 Implementation as an integral part of the timetable (at least 45 minutes per week) |
| Pillar II | **Focus on computer-based implementation of the teaching and learning content** Construction of computer knowledge Deepening and transfer of knowledge through interdisciplinary application |
| Pillar III | **Focus on action orientation** Playful learning as a method of problem solving Consciously creating and allowing room for error |
| Pillar IV | **Development of interdisciplinary teaching and learning arrangements** Arrangements for learners Arrangements for teachers (further education) |

Figure 1: 4-pillars - conception of the teaching-learning arrangements

At the Chair of Technical Education and its Didactics of the Otto-von-Guericke-University Magdeburg, a platform for the implementation of situated teaching-learning arrangements is currently being developed, which enables a nationwide use in schools as well as in teacher training (c.f. Bünning et al. 2018). The arrangements are developed and carried out according to the principle of situated learning with a focus in problem based learning (PBL, c.f. La Force, Noble & Blackwell, 2017, p.3f).  
As a theoretical foundation the concept of computational thinking (Wing 2006, pp. 33ff) was used and adapted to the given educational circumstances (e.g. subject specific curriculums, examination regulations etc.) and put into practice in an interdisciplinary context. Hence the focus was direct the following questions:

* How should an interdisciplinary teaching-learning arrangement for a general education school be designed to enable computational thinking?
* What role does digitization play?
* To what extent can real world technical settings be integrated, adapted and made transparent for in- classroom- use?
* What basics do teachers need for using digital teaching and learning tools in the classroom?
* Which framework conditions need to change to enable the successful use of Open Educational Resources (OER) or Open Source Software (OSS)?

Dealing with these questions gives a climbs into the complexity of the topic. If an attempt is made to design state of the art teaching with the appropriate digital teaching and learning tools, a one-off answer to the above questions is not possible. Instead, the answers that have been developed within the classroom must be constantly reflected and optimized while parallel continuing to adapt to the ever changing digital media landscape.  
First, a system is sought for the implementation of the teaching-learning arrangements, which satisfies the most diverse requirements in use as a teaching and learning aid in the context of a timely and meaningful digitization. The following are the key features that a system of digital teaching and learning tools should demonstrate:

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| * Coordinated and maintained hardware and software * Easy to clean (low maintenance) and robust * Mobile application in the classroom / in different rooms. * Use in different grade levels * Adaptation to known systems from everyday life of teachers and students * innovative character of future significance * "low" financial burden on school budget through acquisition and support * Existing concepts, proven teaching-learning arrangements * Interdisciplinary use in different subjects. |

From the point of view of students, who often make their first experiences with the use of digital teaching and learning materials in grade 5, the aspects of intuitive operation, everyday relevance and robustness are relevant. Especially in the introductory phase, the everyday reference becomes a decisive criterion for the success of the assignment because a system is known in its structure or operation from the everyday environment of the learner (in this case, systems such as SMART-TV or the smartphone should be mentioned) the inhibition threshold is lowered which increases the likelihood of interaction. The robustness of such a system also plays a major role because the students are supposed to solve their own tasks by intuitive guided interaction with the system and to have room for trial and error. With the example of Jenkins' play competence, students should be able to playfully understand the system and gain the ability to open it for their own fields of interest and experimentation ideas (for example, to install their own app for everyday use on Smart TV and mobile phone). Accordingly, the hardware and software components must be designed and constructed in a robust, secure and at the same time open and changeable (without causing license violations, for example) way.

## 3.2 The Raspberry Pi in the class room

For such a system, the Raspberry Pi (model: 3B +) is tested and used. The most relevant technical features of this model for technical education are:

* 1.4 GHz processor (4 cores)
* 2 core graphics unit (1024 MB RAM)
* 4x USB 2.0 ports, Ethernet (100 Mbps)
* foil connector (for camera and display)
* WLAN chip (2.4 GHz antenna)
* 40-pin pin strip with 26 digital inputs and outputs.

The Raspberry Pi, with its design adapted for use in educational settings, is an ideal tool for working on and understanding technical and applied computational science relationships. In addition there is an already widespread existing community network that offers examples, ideas and solutions to problems.  
For the first trial of various teaching-learning arrangements, a class set Raspberry Pi was purchased for a class 5 study group. The setups for 2 students consisted of:

* Raspberry Pi + housing
* 5 volt power connection
* Screen with HDMI connection
* Keyboard and mouse.

For the implementation of all Raspberry Pi the operating system Raspbian was installed. At the beginning of each lesson the learners set up and commissioned their own workplaces. This has the advantage that the connectors can be checked by the teacher before all work stations are supplied with power.  
In terms of content, the first half of the year focused on the practical application so that the students could get to know the system of hardware and software in a team of two. It covered basic questions such as "What is the task of an operating system?" Or "How does a computer calculate?" At the same time, the learners were also able to gain initial experience in reading basic Python code and manipulating code in some basic games.  
It has proven to be a great advantage that all students use the same systems and programs. This helped with adressing problems or mistakes including through the aid of high-performance classmates. As the lessons progressed learners became more self-sufficient in working on given tasks and used every chance to alter the setting individually by setting themselves new tasks and problems. At this point, it is necessary to point out that there are students in each learning group who are not keen in grasping a specific, given task or who are not enthusiastic about a certain topic. However, experience here has also shown that often, for the pupil in question, it appeared to be specific hurdles which needed to be overcome to continue with the learning process.  
After the first lessons, the students were able to keep a digital learning diary and used the Raspberry Pi to document learning outcomes and experimental results. That meant they had to create corresponding, individual folder structures and gained experience in the design of documents and presentations.  
In the next step, the Raspberry Pi is not only used as a stand-alone computer, but is used for technical experiments (c.f. Hart-Davis, 2017; Wirth & McGuiag 2014). For this purpose, the class set up has been extended with corresponding electro- technical components (such as LED, sensors, actuators and cables). Thus, for example, a weather station can be built in a playful way, which can be controlled and evaluated with the Raspberry Pi through either programs like Scratch or directly via Python Scripts. In this example Students as early as grade five are enabled to control a LED via an easy accessible and understandable text script which creates the first link between software usage, informatics and technical education

Highlighting the interdisciplinary approach, the example of a waetherstation project shall be given: The step-by-step processing of various survey parameters such as air pressure, precipitation or temperature outlines the various aspects of how weather can be perceived and the extent to which technical devices allow us to easily visualize and document the various types of weather data points. In doing so, local weather data can be collected, and in addition, basic scientific principles of data collection and evaluation as well as larger contexts such as the difference between weather and climate can be brought up. Discussions in the school context may then result in data protection, access to public data, scientific evidence based on the data, climate change and societal decision-making. In mathematics statistical models can be discussed on the basis of the data and their evaluation and in foreign languages ​​similar school projects and their findings can be selected and integrated while ethics plays a role when discussing to which extent the decision-making based on computer-aided model calculations can represent a social progress (Dörner, cf. 1989, p.107ff). It emphasizes that computational thinking is needed as a core element for these viewing and discussion processes, and dealing with the Raspberry Pi is the most cost effective and efficient platform to do it.

## 3.3 Methodological Backgrouond

The teaching-learning arrangements are developed according to the primacy of situated learning. With regard to the executed approaches, this is suitable as a theoretical basis since a central aspect of this approach lies in the examination of (abstract) learning contents. By applying the acquired knowledge in practical situations, the emergence of "sluggish", that is unusable, knowledge should be prevented (see Arnold 2005, p. 5). As a constructivist approach, the interpretation and construction of reality as guiding principle is also a dominant aspect within the situational learning theory (c.f. Tulodziecki, Herzig 2004, p.142). Here the social context in which a learning object is embedded is of particular importance since knowledge is actively constructed on the basis of prior knowledge.

Previous knowledge of students in terms of computational thinking is within a class often unevenly distributed. To support the individual process of constructing knowledge, the educational setting has to reflect the learners own environment and reality. This approach "emphasizes the inseparability of learning with situations and social contexts that lead to content and social experiences" (Bünning et al., 2018, p. 10).  
Accordingly, situated learning clearly supports the concepts outlined in Chapter 3 in which action orientation in real contexts and the construction of knowledge in the form of exploration and concomitant error handling are central (c.f. Wirth & McCuiag, 2014, p.1ff). In addition, a closer look at the approach of situated learning also highlights the importance of the social component of learning. It must be reflected in the design of appropriate teaching / learning arrangements. Finally, to illustrate these considerations, some teaching practice considerations follow.

# 4. Experience from the Classroom

The aim of the first lessons with the Raspberry Pi was to teach the students of the grade 5 the handling of the hardware and software components, so that the pupil can explore and familiarize him or herself with the operative system. Due to the specific orientation of the Raspberry Pis for use in learning settings, many proposed competencies of participatory culture and computational thinking can be directly integrated in this process.  
These include, among others, the milestones:

* Get to know and start up the workplace (basic structure of a PC, getting to know the operating system, installation)
* Cabling Raspberry Pi with the screen, keyboard, mouse, connection to the power supply socket (get to know connector types, get connected to the network)
* Manage data and files, create a folder structure (navigating in an operating system, get to know user rights)
* Create, save, delete and restore documents
* Personal data, security, school server
* Text formatting (HTML), manipulation of data (Calc)
* Manipulation of files via the terminal (command line)

In communicating these subjects of knowledge, the pupils are creating their own guideline to deal with the system which will over time be extended to grasp more and more detailed insight into the system and its capabilities. In the future, the guideline will serve as an aid to other students, so that a corresponding scenario will be constructed, the result of which will be an individual, age-appropriate instruction manual. The product of this first examination of digital teaching and learning materials serves as a template for other learning groups, but it can and should give the students an understanding of how a learning diary works, so that later learning outcomes can be documented in this way.

The students use the Raspberry Pi as a complete replacement of a computer. In the further course, the Raspberry Pi itself becomes the subject of learning. Namely, when experiments are performed with a simple circuit for controlling and programming an LED via the pins of the board. As an example, a simplified traffic light circuit could be simulated within a small project. In this way the learners deal with the structure and functioning of a traffic light. For the first time, they come into contact with a programming language (Python) to control the LEDs and can read and change code as they try to set up the traffic lights. Thus, the "professional" systems surrounding us in everyday life, which often resemble a black box, are made visible (or transparent) for the learners and shown using the open source approach that they can be manipulated or changed. The design of the experimental set-up, with the involvement of online platforms under the supervision of a teacher, can be designed so that learners merge their previous knowledge, try out their own ideas and then jointly choose a strategy to solve the problem. In a direct implementation effort, the learners work in partnership on a PC and document their results in written and pictorial form, e.g. using the camera of a smartphone. They can then upload their images to the Raspberry Pi and create a learning journal with the observations and results of the experiments.

As a computer and simultaneous subject of the learning process, the Raspberry Pi can be used as a cost effective and interdisciplinary learning aid in the classroom. Depending on the level of knowledge, it allows and supports the manipulation of data or data streams on all levels of computer science, enables the use of programming languages and, via the terminal access, offers the opportunity to get to know your own operating system more intensively. It can also be used as a multifunctional, digital exercise book for interdisciplinary projects.  
The application examples briefly presented at the beginning of the sequence with the Raspberry Pi allow for further scope for a deepening of the topics potentially to be dealt with. It can already be said that the construction and application of computer knowledge with the Raspberry Pi as a teaching and learning aid in technical education can succeed.

# 5. Conclusion

The Raspberry Pi was pretested as an interdisciplinary, cost-effective and intuitive system for developing relevant technical and computer literacy skills in public junior high and high schools to boost STEM understanding and interest. The first focus is on the simple commissioning of the computer workstation by the students and the development of simple technical circuits, which are documented by the student with the help of appropriate word processing software. This is seen as the entry point in the implementation of the basic creation of computational thinking while using the Raspberry Pis advantage of adressing hard and software experiences within the same open source learning environment. Further, the acceptance of the system on the part of teachers and parenting should be increased, so that the Raspberry Pi can be used as a teaching aid in everyday school life and is regarded as an all-around option which is easy to use once one got accustomed to handling it.

The people involved (parents, teachers and school administrators) were quickly recruited for the project so that in-house training could be implemented shortly after the project started.

However, the first use in the classroom has shown that students should not be left alone with the technology. In particular, the first lessons, in which they were given simple tasks and freedom to work on different aspects of their choosing presented some learners with challenges they could not tackle on their own. The application of the hardware and software with their diverse offers has led to excessive demands. This counterproductive development was counteracted by starting out with clearly explaining the basic function of the hardware and software to the young learners while successively increasing their level of freedom when approaching problem solving tasks.

At this point the concept and the use of the Rasperry Pi in the classroom should be critically questioned to optimize the developed teaching-learning arrangements.  
The freedom for trial and error must continue to be granted to the students in order to reduce potential contact fears and inhibitions. The initial experience described has shown that it can only be used meaningfully if the relevant teaching team is staffed accordingly, because in the proverbial "worst-case" all learners, in the sense of the Trial & Error approach, force the Raspberry Pi to error messages. From a group size of 20 learners, two to three teachers are recommended here (based on the introduction phase of the Raspberry Pi and depending on the students' previous knowledge and existing skills and abilities in the use of digital teaching and learning tools).  
The general and in depth usage of the Raspberry Pi will continue to be tested, to be able to generalize assumptions about the use of the system for more complex technical tasks in the classroom.

To what extent German schools can build on existing material and the activities of the large Raspberry Pi community needs to be further explored. Further points of reference, based on the Raspberry Pi's hardware base, are the transfer into training formats and suggestions for training supplements, teacher training, as well as possible adaptations to everyday teaching / learning arrangements in the field of technical education.  
For teacher training, teaching-learning arrangements are currently being developed in the area of ​​Technical Education for Sustainable Development, which will be implemented with the Raspberry Pi. These include arrangements in the field of electrical engineering and renewable energies. The content is concerned with the examination of the corresponding technical basics and the context of sustainability (e.g. sustainable use of resources and critical reflection of the technology used).  
An attempt is being made to exploit the potential of the Raspberry Pi both for the challenges described at the outset due to the shortage of skilled workers in STEM professions and for the changing tasks of a contemporary vocational orientation for pupils as well as for the innovative design of teacher training.

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