



# How Might We Raise Interest in Robotics, Coding, Artificial Intelligence, STEAM and Sustainable Development in University and On-the-Job Teacher Training?

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Schools are searching for strategies to foster 4C competencies (Creativity, Cooperation, Communication and Critical Thinking) in children. Scientific Reasoning, Critical Thinking, and the ability to debunk myths are already important competencies that can be fostered with science education. How can we approach the majority of seventh grade students in a given school to create innovative approaches for the future, and leverage their skills in science, art and (digital) technology along the path? And are the teachers ready to guide them on this path? This article focuses on the questions: how did the teachers adopt both the STEAM approach, and the use of digital tools while being supervised by researchers and student teachers and how did this change their beliefs about technology in education. As a pathway, we aimed to connect Robotics, Coding, Artificial Intelligence (AI) with the Sustainable Development Goals (SDGs) of the United Nations. To end poverty, protect the environment, and ensure that all people enjoy peace and prosperity by 2030, the SDGs are incorporated into national policies and school curricula. With this, citizens, teachers, and governments alike struggle with strategies on how these goals can be reached by 2030, facing the growing challenges in an ever increasingly complex and insecure world. It is clear that technology will take a dominant role in this development. Based on the STEAM paradigm and the 5E approach of the Biological Sciences Curriculum Study (BSCS), we have developed a pedagogical concept that encompasses both the technological aspects, AI and the SDGs. We tested this concept as part of an on-the-job teacher training project with 60 education science student teachers and 8 teachers in their classrooms, together with their 116 7th grade

students and found out that STEAM-based projects with a sixth phase in addition to the 5E approach can be carried out promisingly with the help of digital creativity tools. We found that the 5E model with an additional sixth phase is well suited for bringing STEAM into the classroom.

**Keywords:** STEAM, robotics, computational thinking (CT), Sustainable Development Goals (SDGs), teacher–education, Piaget, Vygotski

## INTRODUCTION

Scientific reasoning, critical thinking, and the ability to debunk myths are important competencies that can be fostered with science education. But how can a majority of students in a given school leverage their skills in science, art and technology to create innovative paths that will lead them to a positive future, and how can teachers guide them on their journey?

The 5E model, which dates to the 1980s (Bybee et al., 2006), serves as the basis for this study. Since then, many digital innovations have found their way into the lives of students. Likewise, their everyday living has changed. Due to becoming an internal part of the modern school system, it became necessary to investigate whether sustainability and digitalization are compatible with a 40 year old teaching model. Furthermore, modern, and digital education is lacking in the German school system.

In a large STEAM (Science, Technology, Engineering, Arts, and Mathematics)-based project we aimed to connect Robotics, Coding, Artificial Intelligence (AI) with the Sustainable Development Goals (SDGs) of the United Nations. These Goals are implemented worldwide into curricula “as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity” (United Nations Development Programme, 2021). This means that governments and education must strive to develop and implement strategies on how these goals can be communicated within their classrooms and how it is even possible to reach them before 2030. Can advancing the “smart” use of technology be a possible solution to achieve these goals?

In the following, the theoretical framework of the research will first be outlined. This includes the presentation of developmental psychological aspects, the 5E model, based on the works of Bybee et al. (2006) and Bybee (2009), the explanation of what digital creativity tools is as well as the connection between STEAM education and the SDGs. We then describe the research questions, our approach, and the materials and methods we used. Finally, we present and discuss the results, draw a conclusion and give a brief outlook on possible future research.

## THEORETICAL FRAMEWORK

When we look at digital creativity tools, at the first glance they remind us of the toys that students are playing games with. This is our motivation to start by briefly examining the developmental psychological perspective on the process of playing as a concept of learning. Next, the 5E-model, on

which the field study is based, the aspect of STEAM digital creativity tools and STEAM education will be presented. Lastly, a brief description of the school where the test was conducted is given.

### Developmental Psychological Aspects of Playing as a Concept of Learning

Playing can mean several different things that children can engage in. According to psychologist Lev Vygotski, *playing*, be it with toys or a game, is triggered by situations that might be relevant for children’s lives and engages them to transform these certain situations into a game. For example: when a child observes a stagecoach driving by, it might react by playing “stagecoach driver.” Within this game-situation, the child prepares himself to engage in a situation where it might become, eventually, an actual stagecoach driver.

Further on, according to psychologist Jean Piaget, playing—as a concept of how Vygotski described it—can be divided into two different developmental stages that describe how, and to what extent, a child benefits from playing. The first of these stages is practice. Here, the physical development with respect to play takes place by imitating known basic principles and understanding the uses of objects, thus satisfying the intrinsic urge to explore (Leong and Bodrova, 1996), which can be applied to this study by letting the children explore the given tools and partaking in construction games. The next stage, according to Piaget, is symbolic play, in which mental models are created, where every object can be a placeholder for something else, which are then applied in play (Leong and Bodrova, 1996). The advantage of play is that it gives the learners a sense of self-control, which serves as a base to take on new challenges more self-efficiently (Leong and Bodrova, 1996). Both Lev Vygotski and Jean Piaget assume an interiorization process in their theories, in which learners develop their conceptions, ideas and models with the help of concrete actions (Aebli, 1985). This means that, through playful situations, complex interrelationships can be modeled in an understandable way (Kircher et al., 2014). One of the big ideas of STEAM Education and the Maker Movement is linking basic knowledge in physics with everyday technology using construction games. Within these games, students can explore complex socio-technical issues in a playful situation. This enables learners to be creative during the construction process and thus to realize many ideas (Kircher et al., 2014).

### The 5E-Model

To facilitate the learning of physical concepts, learners must be engaged in appropriate learning activities. These activities

should be designed in three parts to be as effective as possible. In the first part, goals should be identified. Following this, the current learning status should be discussed. The last part should determine the means by which the learners can reach the identified goal from their current position (Etkina et al., 2006). This tripartition can be expanded into more parts to allow learners to delve deeper into the given subject matter. The 5E-model was developed based on constructivist learning theory and cognition psychology as well as proven methods in science education (Duran and Duran, 2004) to create lessons in a student instead of teacher centered way (Turan, 2021). The model can be used within single or few hours as well as for longer units. Teachers that participated in studies in which the 5E-Model was applied, said to have more confidence and are more comfortable in teaching sciences (Duran and Duran, 2004). Nevertheless, studies also showed that it is hard for teachers to find suitable activities and materials for different phases of the 5E-Model (Namdar and Kucuk, 2018). Furthermore, several studies have shown different barriers, like classroom management and time issues, that hinder teachers from implementing the 5E into their own lesson planning (Turan, 2021).

The 5E-Model consists of the following five phases: Engagement, Exploration, Explanation, Elaboration, and Evaluation. In the first phase, learners are confronted with the learning content, which activates their existing knowledge and their curiosity (Bybee et al., 2006). It is also possible to determine what students might already know about the topic or what (mis)conceptions they have (Duran and Duran, 2004). Accordingly, the learners are confronted with a problem to solve. The phase is successful when the pupils are engaged in the problem and are intrinsically motivated to solve it (Bybee, 2009). In Vygotski's approach, the motivation and the need for action are to be located here.

In the Exploration phase, learners are given the opportunity to freely explore and become familiar with the essential skills and concepts that are made necessary by the problem posed in the engagement phase (Duran and Duran, 2004). This phase should be designed so that all learners have the same experience to build knowledge and skills. The role of the teacher in this phase can be seen as merely accompanying to allow students to explore as freely as possible (Bybee, 2009) and explicitly not giving away any kind of explanation, which is reserved for the following phase (Duran and Duran, 2004).

The Explanation phase allows learners to demonstrate their understanding of the concepts by explaining certain aspects or the entire concept itself (Bybee et al., 2006). In this way, the Explanation phase helps to ensure that learners develop a consistent vocabulary related to the problem, and present the concepts, information, and skills they have grasped in an understandable way (Bybee, 2009). Furthermore, a teacher should only fill in with explanations, if the Student's way of explaining is not sufficient or contains misconceptions (Duran and Duran, 2004; Namdar and Kucuk, 2018).

In the Elaboration phase, learners can consolidate their abilities and understanding regarding the topic, thereby leading them to a deeper understanding and adapted skills (Bybee et al., 2006). In this phase, learners can build on the concepts and

skills they have already understood by, for example, applying them to new concepts within the problem. For this purpose, the interaction between learners in groups can be seen as a major factor for the success of the phase. The group discussions and collaborations provide opportunities to receive feedback from other learners on the one hand and to enter an exchange about their knowledge on the other hand. The goal of the elaboration phase is the transfer of knowledge from previous phases to new problems (Bybee, 2009). Here, as in the Exploration phase, the playful approach emphasized by Vygotsky is followed.

In the Evaluation phase, the learners are given the opportunity to reflect on their learning journey (Bybee et al., 2006). In this final phase they also receive feedback on their learning progress, skills, and insights (Bybee, 2009). This should give the teachers proof of the Student's learning success and can be conducted in a formal or informal way (Duran and Duran, 2004).

In the Exchange phase, a sixth phase we added to the 5E in the last week of the field study, we provided an opportunity for all participants to reflect and exchange on what and how they learned. This phase was added to emphasize the exchange between learners as well as between learners and teachers. We found this to be a very profitable addition to the 5E-Model, to get insight into the students as well as the teachers' experience of the whole project to enrich the Evaluation phase. Accordingly, this phase focuses more on meta-cognitive skills than the other phases. In Vygotskian thinking, the Engage phase would stimulate the children to open their Zone of Proximal Development, while the Explore and Elaborate phase provide the necessary playground for the learners to simulate the situation they engage in, test and improve their competencies, and simulate possible outcomes. The Explain and Exchange phase with their focus on inter-group communication provide the students with the necessary opportunity to negotiate the rules of their game in Vygotskian theory. From a social-constructivist perspective, these phases provide the opportunity to exchange insights, models and world-views and assess the relevance for life in the view of their peers. While the "Explore" phase is generally open and playful, the "Elaborate" Phase targets the development of a testable prototype that might be evaluated in the subsequent "Evaluate" Phase. This connects to the learning theory of Piaget, where children test their hypotheses by play.

## STEAM Education

The core idea behind STEM (Science, Technology, Engineering and Math) Education is to connect the sciences, rather than teaching them in isolation (Krakower, 2018). But even though the relationship between different disciplines was recognized, the creative aspects of them were missing. Due to becoming more influential and significant in this digital and global world, such aspects were incorporated into the STEM framework (Yakman, 2008), resulting in the existence of the STEAM approach. The natural science disciplines are not only complemented by the arts, but also by methods to encourage creativity and innovation. These methods, like visual thinking, were derived from artistic fields (Thomas and Huffman, 2020). If Art would be used in a narrow sense, e.g., just in the form of painting, learners would not see where this is connected to and relevant for STEAM problems.

Art can only be integrated into the learning process if it is used in a broader sense. Here learners progress by integrating the arts in the area of problem solving (Quigley et al., 2020). By integrating the Arts aspect, more individuals can be reached, who have little interest in traditional STEM contexts (Thomas and Huffman, 2020). In the context of STEAM education, collaboration, and mutual feedback among learners worked very well, as has been observed by Cassie Quigley from the University of Pittsburgh. This was due in part to the use of technology and assignments that encourage collaborative work. Each learner in a group was assigned a task according to their abilities to solve a problem cooperatively as a group (Quigley et al., 2020). This cooperative and problem-solving approach of learning is at the forefront of STEAM education (Jackson et al., 2020).

### Sustainable Development Goals

The United Nations formulated 17 goals to improve human life on earth in the near future. They are known as the Sustainable Development Goals or SDGs. Each of these goals aims for different aspects of life and contains different targets and possible actions to reach it. Some of the SDGs are already covered by the STEAM education definition. For example, SDG 09 promotes to “Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation” (United Nations Department of Economic and Social Affairs, 2021). SDG 07 is to “Ensure access to affordable, reliable, sustainable, and modern energy for all” (United Nations Department of Economic and Social Affairs, 2021). The Art aspect includes considerations of societal developments, and the aspect of Engineering relates to the SDGs via the creative as well as logical use of technical tools to solve global problems (Yakman, 2008).

### STEAM Digital Creativity Tools

STEAM tools aim to support the training of creative thinking as well as the competence of problem solving and critical thinking (Makeblock, 2019). The intrinsic drive for discovery postulated by Piaget can also be nurtured with the help of STEAM tools by encouraging learners to find creative solutions to specific problems. In this regard, digital creativity tools, such as those used in the field study we conducted, are suitable for this purpose, as they are child-friendly and contain many technical resources which are relevant for the teaching of physics. Digital creativity tools refer to various devices that, among other things, can be used to stimulate the learners’ creativity in order to find solutions to problems. A digital creativity tool can be used to integrate STEAM education in schools and develop problem solving skills, creativity, and boost the students motivation (Kalogiannakis et al., 2021). A study commissioned by LEGO Education, conducted in 2019 by Harris Insights and Analytics, examined Students’ confidence in the context of STEAM education and digital creativity tools. In this study, only 14% of German students reported being very confident in learning STEAM content (Harris Insights and Analytics, 2019). Furthermore, a study on the physical area of light and optics showed a significant increase in both learning success and creativity among students who learnt these topics using STEAM methods (Wandari et al., 2018). Accordingly, compared to traditional instruction, there is a

significant positive difference in the use of digital technologies in STEAM-based instruction (Tamim, 2011). A study that examined the use of another digital creativity tool (BBC micro: bit) found teachers being more open about using such a tool if this has a connection to the everyday life of a student and is generally useful (Kalogiannakis et al., 2021). They also show to be more positive about using digital tools if they have multiple uses in school contexts and allows students and teachers to learn from it (Papadakis, 2022).

Recent past works like the ones from Kalogiannakis et al. (2021) and Papadakis (2022) mainly focused on the usage of digital tools like apps and programming languages in a school context and lacked physical tools. Therefore we wanted to gain more insight on several educational tools presented in the following.

In our study, the results of which are presented in this paper, we used four different tools (Makeblock mTiny, Makeblock Cody Rocky, Makeblock Neuron, and DJI Tello Edu Drone) each of which has different characteristics.

The Makeblock mTiny was chosen for the project because it offers screen-free programming and thus reduces screen time, on the other hand it enables inexperienced students to experience and understand complex programming in a playful and uncomplicated way, while at the same time teaches the basics of computational thinking. A meta study regarding ScratchJr which is similar to the way the mTiny is programmed, shows it to be useful in introducing young students to STEAM education (Papadakis, 2022).

The Makeblock Codey Rocky was selected because this tool is a further development of the mTiny. It contains many sensors with which learners can program various commands and then see if Codey Rocky reacts to them. It can also be controlled directly using an app or be programmed using a block-based programming language. It was chosen as an addition to the mTiny, because this robot cannot be controlled via Joystick and has to be programmed or controlled with the help of a tablet device.

The Makeblock Neuron set was chosen for the project because its properties allow it to be easily used as a versatile construction kit. This is based on a number of sensors that allow various measurements and, on the other hand, a large number of actuators that can be attached and controlled, even remotely to simulate an Internet of Things (IoT) environment. In addition, it is possible to connect the Neuron set with the Codey Rocky and thus exploit a potential for mobile or robotics applications. The set can be programmed without a screen by connecting individual blocks in a certain order to build simple measuring devices. In addition, it can be programmed via app in a block-based coding environment, which, according to Kalogiannakis et al. (2021) seems to help students understand the general concept of a programming language.

We selected to use a DJI Tello Edu drone for the project because drones can enable students to study and control an object that can freely move in a 3-dimensional, Cartesian space. In mathematics and physics education, this option was only accessible in simulations or thought experiments before the introduction of drones. In addition, drones are becoming

increasingly present in today's world and students should therefore learn how to handle them in a safe manner that obeys rules of privacy. We chose the Tello Edu drone as its small size and weight allows it to be used in the classroom, making it very suitable for this project. An app makes it possible to program this drone using a block-based language. For classroom use, it is important that students can test their code within the app in a simulated flight environment before they are provided with the actual drone. This enhances safety, reduces the need to load batteries and reduces the overall cost for the school.

## MATERIALS AND METHODS

Digital STEAM Creativity Tools were used for teaching and learning Robotics, Sensors, Artificial Intelligence and Computational Thinking together with a Vygotskian teaching approach in a large scale, school-spanning field study. For our research, a mixed method design was conducted with different focus areas.

The field study project was structured using a modified 5E model (Bybee et al., 2006; see **Figure 1**), which was used in the context of the university with the English terms but translated for the students with appropriate German terms. The individual phases and activities are briefly described below. Across all the phases of the project, each unit was transparently accompanied by appropriate presentations by the staff. At the beginning of each lesson, the learners were thus offered a classification of the respective day in the overall project as well as an overview of the daily schedule.

The *Engagement* phase took place in the first week of the project. The thematic introduction was done by means of two videos on different SDGs, of which each learning landscape watched one video. The first video focused on SDGs 2 *Zero Hunger* and 6 *Clean Water and Sanitation* (see **Supplementary Figure 1**), whereas the second video focused on SDGs 3 *Good Health and Wellbeing* and 11 *Sustainable Cities and Communities* (see **Supplementary Figure 2**).

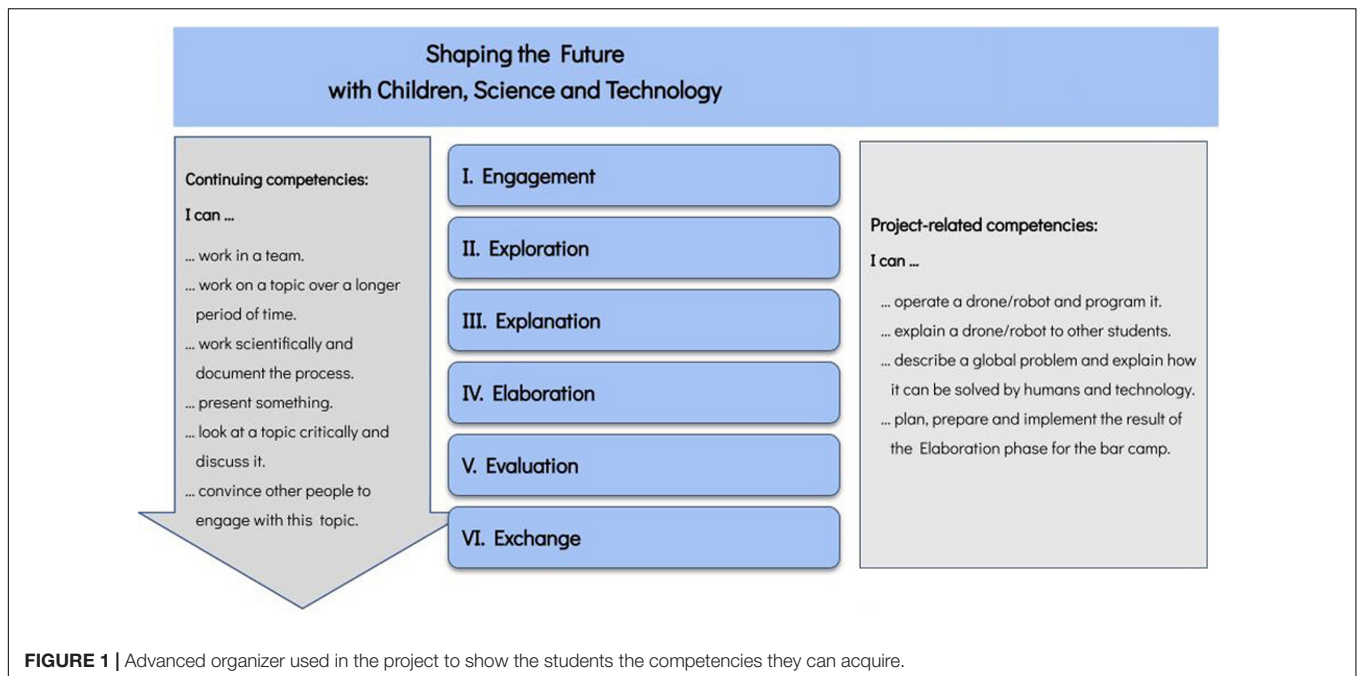
Following these videos, the students reflected on what they had seen with the help of in-depth questions on a padlet and conducted their own research on the SDGs. In this phase, the staff of the University of Cologne continued to explain the entire project process to the 7th grade students in detail. In the following second project week, the *Exploration* phase, the students, guided by university students, got to know the digital creativity tools. The teachers only played a minor role in supporting the 7th graders as well as the university students in terms of classroom management. Again, a distinction was made between the learning landscapes, so that in learning landscape A the devices mTiny, Codey Rocky and Neuron were used, and in learning landscape B the Codey Rocky, Neuron and the Tello (Edu) drone were used to test how the provided tools influence the designed solutions. During the *Explanation* phase, which was carried out in the third week, learners had to explain the possibilities of one of the devices they tested on a digital worksheet in Google Classroom. This was then evaluated as part of the study. In this way, the positive and negative characteristics,

and programming possibilities of the digital creativity tools in the perspective of the student could be studied. In addition, core groups had to display and explain the STEAM tools they had researched to other core groups so that an exchange could take place about all the devices and each student saw a short presentation about each tool. The *Elaboration* phase was extended to the fourth to sixth week. The phase started with the learners working in small groups to choose a topic related to the SDGs and one of the creativity tools, and then working on either their own or pre-determined research questions. Their aim was to find a solution to a problem that could be modeled using the tools.

This led to the fifth phase, the *Evaluation* phase. In this phase the students mainly prepared the presentation of their projects to a public audience. Since the learners were free to work on their project, prepare a presentation or do both at the same time, this phase blurs with the preceding *Elaboration* until the day of presentation: The Barcamp. This event was designed to resemble a design pitch to raise venture capital, or to raise public awareness for a project. The learners presented their solutions to the public in the form of a video conference. Access to the video conference was possible for everyone after prior registration. After each presentation, the audience had the opportunity to ask the presenters questions and give feedback on their prototypes. In the *Exchange* phase, the sixth phase we added to the 5E, in the last week of the field study, there was an opportunity for both learners and teachers to share and reflect on the project. An intervention on Artificial Intelligence was also conducted during this week to give the students a perspective on what modern technology could enable their own projects to do. Furthermore, the students filled out various surveys regarding final university student theses. Because of the burden of the surveys on the students we chose not to collect measurable data.

Due to the COVID-19 pandemic, the project had to be launched exclusively digitally. Accordingly, the students took part in a video conference led by University of Cologne staff. In the following week, due to the pandemic situation, it was possible to switch to a hybrid state that lasted for another 2 weeks. In this state, the groups were separated into subgroups, which alternated in daily visits to the school. While one group was able to go to school, the second group was connected to the lessons with the help of tablet PCs. From the fourth week of the project onward, the restrictions were eased, and the core groups were then present until the end of the project. Students who were not employed at the University of Cologne and who conducted some parts of the project were connected via tablet PC video conferencing during the project in order to minimize the risk of contagion for all involved.

The project was carried out at the Helios School—Inclusive University School of the City of Cologne. This school is designed by University of Cologne education scientist Kersten Reich in the tradition of John Dewey's laboratory school at Chicago University, but under today's conditions (Reich, 2018). Dewey anticipated already 100 years ago the needs of education that we consider crucial today, namely the multiperspectivity and broad access to learning. His vision of a school included the participation of students in social processes where they would



build on their skills in communication as well as problem solving. One of the schools main foundations is, according to Deweys as well as Reichs research, the principle of learning and teaching through *learning by doing* (Reich, 2018). The Helios School was founded under a constructivist perspective toward education but had to face two major problems. The first being the heavy focus of the German educational system on the attainment of a degree rather than social equity. The second problem lies in the German teacher training system, which is split into theoretical and practical units (Reich, 2018).

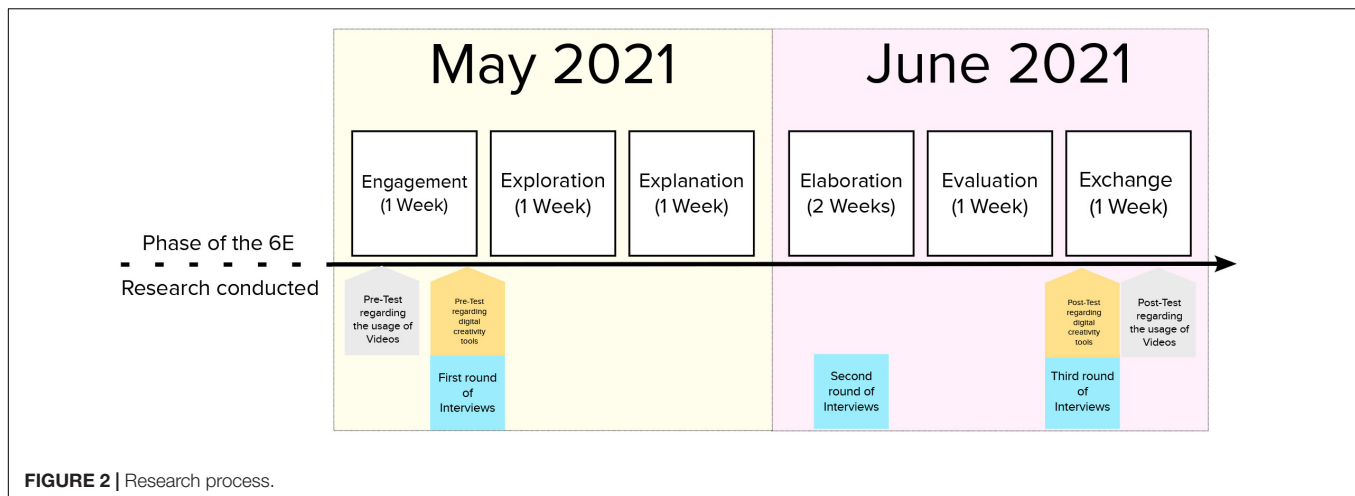
The participants comprised about 116 7th grade students of the Helios Inclusive University School of Cologne, Germany together with their 14 teachers. The age range of the teachers was between 28 and 46 years. The teachers had been in teaching for between less than one and more than 16 years at the time of the study. The teachers' subjects ranged from social studies over languages to STEM and physical education, also one of the teachers was a special education teacher who did not specify further subjects. Furthermore over 200 students of the Bachelor and Master programs of University of Cologne's STEM Teacher Training Department took part in this study, of which 40 were actively involved in the implementation of this field study, while the rest supported them with templates and feedback. All 40 actively involved university students and 116 7th graders took part in a 7 week on-the-job training program that was part of the regular 7th grader classes. The pupils were divided into the two learning landscapes A and B with each three different Stem Groups, which is the equivalent to a school class at the IUS.

To conclude the evaluation of the specific tools used, we used a pre-post-test on the partaking teachers, as well as a pre-post-test on the 7th grade students to evaluate the usage of videos. Furthermore, university students and teachers were

interviewed regarding their view on the whole project at different times of the field study (see **Figure 2**).

The pre-post-tests regarding the evaluation of the digital creativity tools were formulated according to the rules for formulating questions for qualitative surveys (Döring et al., 2016). The questionnaires of the pre- and post-test differ in a few questions, which are only useful in each case in the pre- or post-test, for example, when first thoughts about a respective tool or experiences from the field study are asked. For each of the devices it was asked what thoughts the teachers had in each case when they saw the device for the first time. Teachers were also asked what they liked and disliked about each tool. This was intended to identify certain advantages or criticisms of the tools. Regarding possible points of criticism, the teachers could also suggest possible improvements. Also, a possible place of use away from the field study in combination with the willingness to use a digital creativity tool in the classroom was asked. This question gives first indications whether the field study has changed the willingness of the teachers to use digital creativity tools in the classroom. General desires for a digital creativity tool were also considered. This should highlight certain characteristics that digital creativity tools should have in order to be considered by teachers for use in the classroom. Teachers' responses were anonymized but coded so that pre-tests and post-tests could be matched without revealing teachers' identities.

The pre-post-tests regarding the use of videos were modeled after the *IPN Interessensstudie* (Measuring Students' interest in physics) from Häussler (1987). The original test assumed that student interest is not one-dimensional and not constant, but a complex situative variable that must be modeled along the three dimensions *topic*, *context* and *activity*. Sample item questions were "Do you want to learn more (*activity*) about how colors occur (*topic*) in the sky (*context*)" or "Do you want to



discuss and evaluate (*activity*) the positive and negative effect of micro-electronics (*topic*) on our lives (*context*)” (Häussler, 1987). To introduce students into the subject and to compensate for different prior knowledge of the participants, a short one-page introductory text was provided for each topic. After reading these texts, participants should indicate their interest to follow the topic in different contexts and with different activities. Interest was indicated using a five-point scale ranging from “My interest in this (item) is very high” to “My interest in this (item) is very low” (Häussler, 1987).

A test of the mathematical model conducted by Häussler on 4,034 students between 11 and 16 years revealed that the 3 dimensions are largely independent of each other, with interaction terms between the dimensions explaining only 2% of the variance (Häussler, 1987). Hence, it is reasonable to assure that the topics and contexts can be modified or exchanged independently of each other. We chose contexts that were derived from the SDGs for the pre-post-testing in this study. The one-page introductory texts of the original study were replaced by the introductory videos in the engagement phase. The proposed activities (to learn more, to construct, to discuss) of the 6E process were similar to the original study, and students could indicate on a 5-point scale if they are interested to take part in it. In addition, there were open-ended questions in which the students could independently write down activities they would take part in. These answers were clustered into *suggested* activities that are connected to the topic and context of the video, and *independent* activities that might still be connected to the context of the video (e.g., climate change) but did not have any connection to the lessons and the topic of the video (e.g., using public transportation to reduce CO<sub>2</sub> emission).

The questionnaire was tested with students to ensure that their understanding of the questions was comparable to the original study. Pre-testing took place immediately after the videos were shown. 91 Students took part in the pre-test (83%). The post-test that was conducted about 6 weeks later, after all activities took place. 83 students took part in the post-test (75%). The anonymous surveys ensured the privacy of the students. Since no code was generated and no socio-demographic

data was collected, no conclusions can be drawn about individual students.

For the interviews, five participating teachers from the cooperating school were interviewed in three rounds each at the beginning, between the exploration and explanatory phase, in the elaboration phase, and after the end of the field study. The teachers were two women and three men. In the interviews, many open-ended questions were asked, which encouraged the persons to tell their stories freely and to follow up where, for example, dissatisfaction could be suspected. Of interest in the interviews were negative as well as positive personal experiences and aspects, learning situations, attitudes toward technology and cooperation with the school. The aim was to capture as many views as possible and to record the learning process of the individuals.

After the transcription, the qualitative data were analyzed according to Kuckartz (2018) using MAXQDA. Example main categories are praise, positive experiences, growth, learning process, attitude toward technology, criticism, negative experiences, wishes. Subcategories were then inductively derived from the data.

Since the research was conducted in German, the data is also mainly in German. Furthermore, conclusions about individuals could be drawn from the interviews despite greatest efforts to anonymize them. Therefore, the appendix of the interviews (**Appendix A**) is not distributed publicly but can be viewed on request.

## RESULTS

### How Can STEAM Education Based on the 5E Model Be Introduced in Schools?

One of two different videos was shown in the Engagement Phase in each of the different learning groups A or B. As a result of the survey regarding the effectiveness of the used videos, 23.8% of the students in learning group A and 26.1% in learning group B formulated ideas after watching the video on how to improve the life of people around the world. Another 21.4% of learning landscape A and 8.7% of the learning landscape B

described ideas suggested by the respective video. Only 4.8% (A) and 10.9% (B) said they would have no ideas. In each case 50% (A) and 54.3% (B) made no statement (**Appendix B**, Chapter 4, Diagram 1). Through the video analysis survey, it was found that there was a tendency for increased interest in physics among the learners at the Inclusive University School prior to the project implementation. Even though the initial interest was measured immediately after watching the respective video, the results indicated a decrease in the interest (**Appendix B**, Chapter 6, Diagram 21 and 27).

Overall, through the pre-post survey regarding the use of video, it was found that engaging videos were instrumental in generating students interest in the subject matter. A video 4–5 min in length was sufficient for the interviewed students (**Appendix B**, Chapter 8, Item 15) if all essential problems and solution ideas were presented.

Due to pandemic teaching modes, the Exploration phase could not be conducted with all students at the same time. The participating teachers did not feel that the involvement of students via distance learning was adequate, causing frustration. Students found it difficult to participate in class via video conferencing (**Appendix A**, L4, Interview 2, pos. 5). As an alternative, for example, a more targeted use of university students in online teaching could be identified by having them help develop programs, with those who are not in school, that could then be tested on site (**Appendix A**, L1, Interview 1, pos. 21).

Many of those involved in the project commented positively in connection with the playful and practical opportunities offered by the devices. It was emphasized several times that not only the students had fun with the tools, but also the adult members of the project (**Appendix A**, L4, Interview 1, pos. 25). Several teachers as well as students wished for an extension of the Exploration Phase (**Appendix A**, L1, L3, L4, B1).

From the Students' presentations and completed worksheets, it can already be concluded that through the Explore phase, they learned about many of the positive and negative features of each device and understood how to achieve possible goals with these devices (**Appendix B**, Chapter 12, Summarized Evaluation). This highlighted the simplicity and intuitiveness of the devices, as the learners only had 90 min to get to know each one, but most importantly, it reinforced the success of the previous exploration phase.

Concluding this phase, the playful introduction of the devices aroused the interest of the learners encouraging them to expand the capabilities with the device. This has been shown that they were able to recognize the advantages and disadvantages as well as potential, with help, in the short time available. Furthermore, it seems to make sense to extend this phase to give all students the opportunity to get to know each device intensively, instead of only being able to try out three of the four devices for about 90 min each, as was the case in this project.

Sharing learning outcomes across learning landscapes in the Explanation phase was seen by teachers as critical for students because learning landscapes had little contact and additional connectivity issues would have limited already

difficult communication. However, the fact that the students had to explain the devices to each other was seen positively (**Appendix A**, L2, Interview 2, pos. 7–9).

It can be concluded that while mutual exchange is important, it should be limited to the known peer group and, ideally under non-pandemic conditions, should take place in person. This means, for example, that there is no inhibition of communication that could arise from speaking in front of other children. This is an aspect that could be investigated in further studies in the future.

Regarding the Elaboration phase, a teacher reported that the students did not understand why, despite being fully present in class again, they should still interact with university students in videoconferences (**Appendix A**, L2, Interview 2, pos. 13). Therefore, the help that the university students were supposed to represent was not accepted by the pupils. Which is why, from the moment when all pupils were back in class, the university students perceived the negative reaction to support via videoconferencing (**Appendix A**, B1, Interview 3, pos. 7, 26).

This phase was described as particularly stressful by both teachers and members of the university team. They were forced to deliver the intervention, manage the classroom, and provide technical support to multiple groups simultaneously (**Appendix A**, L2, Interview 2, pos. 21; M3, Interview 1, pos. 21–41). The projects the students worked on were deepened and revised by them to solve a selected problem connected to the SDGs. They organized themselves into groups and worked on their projects without further instruction from the teachers or university students. No further motivation was needed than handing out the digital creativity tools and giving them a short overview of the schedule.

Extending this phase was mentioned afterward as a possible improvement (**Appendix A**, L1, Interview 3, pos. 9), since the students only had about 12 h over a 2 week period to work on their projects.

Summing up this phase, it can be said that the students had a good opportunity to work on their own projects. In order to create a more relaxed environment for all involved, including the teachers and in our case students of the university, this phase could be extended to allow more time on the one hand and on the other hand to give the teachers more possibilities to interact.

In the Evaluation phase the presentation of the Students' projects to a public audience took place. Since the learners were free to work on their project, prepare a presentation or do both at the same time, this phase blurs with the preceding Elaboration until the day of presentation.

The participation of the learners in the oral feedback in the Exchange phase was excellent and helped us to understand their perception of the project as well as providing insight on what could be improved going forward.

As mentioned with the Evaluate Phase, this phase has been added to the 5E model to allow for sharing of the learning journey. This exchange should only refer to the learning process and explicitly not to the learning outcome, so that the students can give unevaluated feedback, whereupon the learning process can be better adapted for them in the future.



The Post-Survey regarding the usage of videos in the learning landscapes A and B showed that 38.6% (A) and 35.9% (B) of the 7th grade students had their own ideas on how they could improve the life of people, which is an increase of + 14.8% (A) and + 9.8% (B) in contrast to the pre-Survey. Further 22.7% (A) and 23.1% (B) gave ideas suggested by the respective Videos they had watched. Nevertheless 27.3 (A) and 25.6% (B) of the students said they would have no ideas, which is a drastic increase of + 22.5% (A) and + 14.7% (B). Additionally, 11.4% (A) and 15.4% (B) did not answer this question in the Post-test (**Appendix B**, Chapter 5, Diagram 14). A possible Explanation for the increase of students saying to have no ideas is the decrease in students not answering this question. They might have just answered with no intention of giving an idea but unwilling to not-answer to this question.

The results show that interest in physics decreased after the 7-week project period, which could be associated with a kind of routine and saturation that occurred among the students (**Appendix B**, Chapter 6, Diagram 21, Diagram 27).

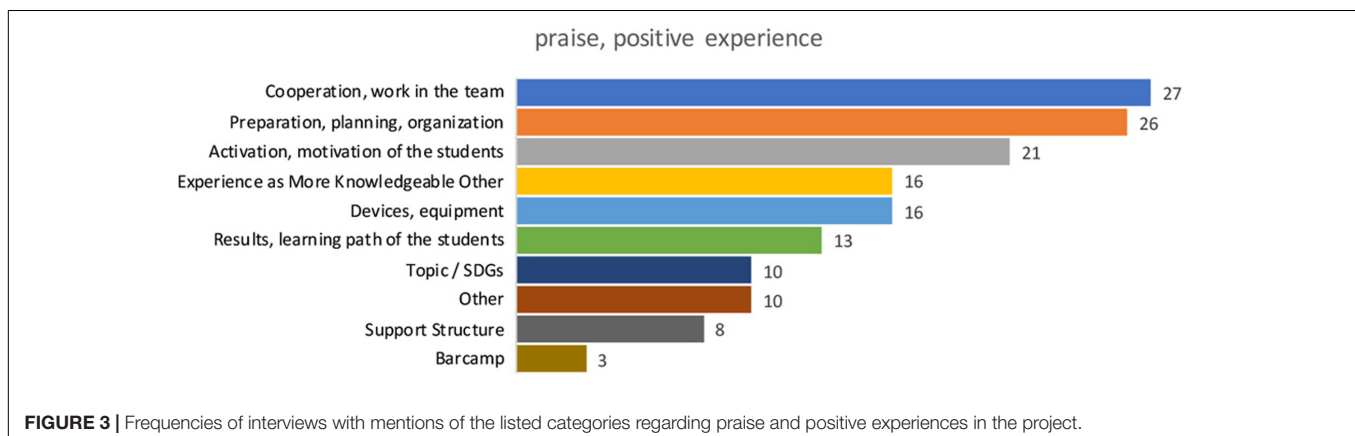
The project was well received by the teachers involved, especially regarding the cooperation between the university and the school, the motivation that the pupils experienced through the project, the equipment used as well as the learning paths taken by the learners (see **Figure 3**). In terms of the learning process, communication with students, the use of technology in the classroom, and programming were emphasized, and the interdisciplinary teaching was, among other things, also praised (see **Figure 4**). The main points of criticism relate to the usage of video conferences and didactic decisions and content. Also, the wish to strengthen teamwork was often mentioned, as well as more transparency in terms of organization (see **Figure 5**). Due to the COVID-19 pandemic, some phases of the project had to be designed either through distance learning or hybrid learning. This is also the biggest point of criticism from those involved. Because this will (hopefully) no longer be a problem in the future, this point of criticism should not be overestimated. The individual phases of the project also suffered from distance learning and hybrid learning, especially around the Explore and Elaborate phases. In a renewed implementation or consistent further development of the project, more time for these important practical parts should be considered. Furthermore,

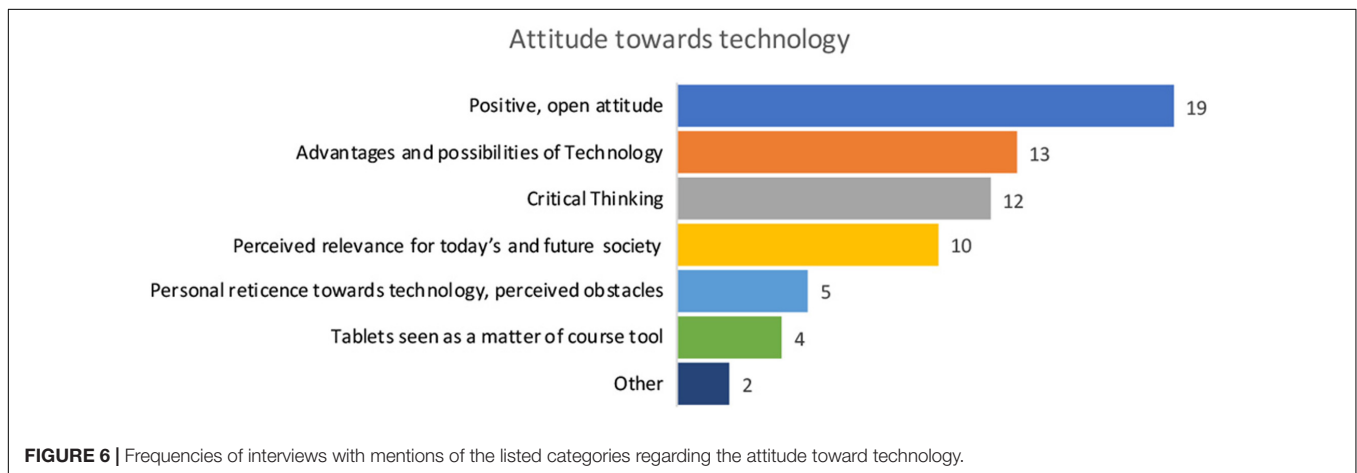
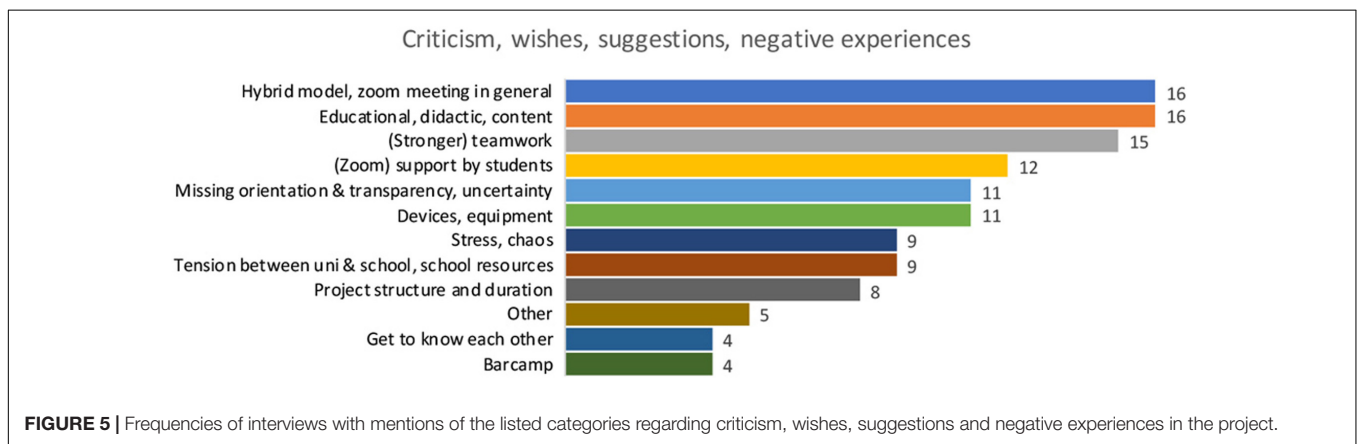
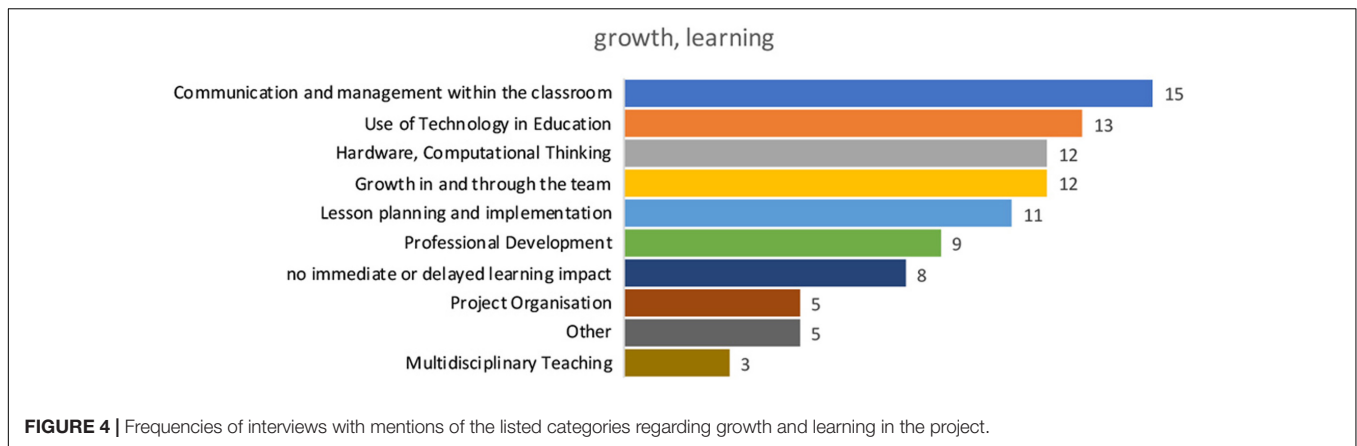
in a renewed implementation special incentives and insights could be created through possible links with experts on the respective topic.

### What Is the Attitude of Teachers Toward the Adoption of STEAM Tools in the Context of STEAM Teaching and How Does It Change in the Course of a 7-Week, On-the-Job Training Program?

In the pre-post-test, the teachers expressed confidence in their Students' ability to work with the devices prior to the project, since they had great trust in their Students' abilities (**Appendix B**, Chapter 11, pos. 6, K10). Their belief that the students had already grown up with technology and thus had a high affinity for technology served as an important factor, which is why intuitive handling was to be expected (**Appendix B**, Chapter 11, pos. 6, K101). The teachers also reported little fear of contact on the part of the students and a high degree of curiosity. (**Appendix B**, Chapter 11, pos. 6, K102). All teachers at the project school indicated in a survey that they had not previously used any of the devices used in this project, nor had they used similar devices, in the classroom (**Appendix B**, Chapter 11, pos. 5, G50). Most of the persons interviewed showed a positive attitude toward technology in school lessons and emphasized on the advantages of it; but not without mentioning the importance of critical thinking while using technology (see **Figure 6**).

When asked in the post-test whether they would use other devices in the future, other than the ones used in the project, two teachers indicated *yes*, whereas one indicated *no* (**Appendix B**, Chapter 11, pos. 5, G50). Due to the wording of the question, it remains unclear at this point whether teachers would use the devices used in the project for teaching in the future. The teachers who stated *yes* to the above question named other projects and workshops as possible reasons along with other devices (**Appendix B**, Chapter 11, pos. 5, G51). When asked why the teachers have not yet used any digital creativity tools in their lessons, a lack of experience or the lack of the necessary equipment were the main reasons (**Appendix B**, Chapter 11, pos. 5, G50). Nevertheless, in many





interviews it was made clear that all participants were open toward using technology in their lessons and highlighted the advantages of it.

The digital creativity tools used in the project were generally well received by the teachers and students involved in the project. Nevertheless, from the point of view of the study participants, there are also possibilities for improving the tools, which draw attention to the disadvantages of the devices.

The easiest accessible device, the mTiny, was also rated the least popular by the participating teachers of all the devices. This can be explained with the target group (age 3 and older) that is usually addressed by this device. The mTiny can therefore only be recommended to a very limited extent for use in the seventh grade or higher, as it offers too few options for this age group, which is why students who already have experience with digital products quickly reach the limits of the device (**Appendix B**, Chapter 11, pos. 1, G10.4). It would therefore be an option to improve the

mTiny by creating the possibility of programming using a tablet PC. This would enable more complex tasks for higher grades as well as technical enhancements.

The Codey Rocky, on the other hand, is much more suitable for the project's target group according to the data available. This can be concluded from the fact that the complexity is appropriate and variable, i.e., it is very easy to get started with the tool, but at the same time very complex problems can be processed. The given robustness against falls is also a factor that can play a central role in everyday school life (**Appendix B**, Chapter 11, pos. 2, G20.4).

Some teachers suspect that it looks too childish for seventh-grade students, which could create a barrier to learning. In contrast, however, the appearance was also viewed positively by other teachers as well as students. However, it was also suggested that a neutral version be developed for adolescent learners (**Appendix B**, Chapter 11, pos. 2, G20.1). Of the teachers involved in the project, four out of five stated in the pre-test that they would not use Codey Rocky in their lessons outside of the project. The main reasons for this were uncertainty in dealing with digital creativity tools and a lack of ideas for integrating the tool in a project in a meaningful way. One teacher stated that she would use the device in grades four to seven to reduce fear of contact with technical devices. In the post-test, on the other hand, one of the teachers who could not yet imagine using the Codey Rocky in the classroom in the pre-test, stated that she would want to use this device in the sixth or seventh grade in the context of programming. Another teacher, who stated in the pre-test that she had no ideas for the usage of it, answered in the post-test that she still had no ideas, but that she would build on the Students' results from the project to see how they could be transferred into reality or what possibilities already existed. In total, four teachers responded in the post-test that they could imagine using it in school (**Appendix B**, Chapter 11, pos. 2, G20.4).

The Neuron set is perceived as very positive both individually and as an extension of the Codey Rocky. The color scheme of the individual building blocks signaling the purpose of the blocks was also positively emphasized. According to the teachers, this reinforces the inclusive character of the set and thus makes it easier to work with. The variable complexity, as with the Codey Rocky, also ensures a wide range of applications (**Appendix B**, Chapter 11, pos. 4, G40.2).

Overall, this digital creativity tool was also well received by the subjects of this study, as already in the pre-test three of the four teachers who answered this question stated that they would use the device in their own lessons outside of the project as a toy on the one hand and as an experimental kit for learners on the other. In addition, the set is intuitive and can be used from grade six in creative contexts without prescribing concrete tasks, since the urge to discover can be acted out here. One of the teachers also stated that she did not want to limit the use of the set to one grade level but wanted to use it in all grades. She confirmed this in the post-test and added that the complexity showed great variability. In the post-test, four of the five respondents said they would use the device outside of the project. It should be added here that one person would use it in grades five to seven, and another

person noted that the Neuron Set was useful in science projects on the one hand, and as a pastime during breaks on the other. One teacher seemed to be particularly enthusiastic about the Neuron Set, stating that she would choose the Neuron Set if she were allowed to choose only one device for school, as it could be used in a variety of ways in science, arts, and social studies subjects. However, this teacher emphasized that she would never buy such a set because she was convinced that technology is always developing and therefore such a set could quickly become obsolete. Only one teacher stated in the pre- or post-test that they did not know whether they would use the Neuron set. However, these are two different teachers who did not fill out the corresponding test, so that no change can be determined here. The variability of the Neuron Set was described by many teachers as a positive aspect. It was also frequently mentioned that the set promotes the urge to discover and to be creative. The possibility of combining the set with the Codey Rocky was also emphasized by the teachers as a positive aspect. The haptics of the individual blocks, complexity and yet simplicity and highlighting the individual functions of the building blocks were also mentioned. Also, the Neuron Set promotes inclusive learning opportunities and ties into learners' interests (**Appendix B**, Chapter 11, pos. 4, G40.2).

The DJI Tello drone is suitable as a means of addressing several aspects of math and science education in the classroom. However, the math and science aspects should be central to reach this purpose, as it could otherwise distract too much from the actual subject matter. (**Appendix A**, Interview Transcription: René Foellmer, pos. 30).

One example was the discussion of possible flight paths for a load of water after being dropped from the drone on a plant. This discussion resembled an item of the Force Concept Inventory (FCI) which is regularly used in physics education. Nevertheless, this discussion was observed in the *elaborate* phase of a group concerned with the SDG 2: *promote sustainable agriculture* and was initiated by the problem solving process, without intervention by teachers. The possibility to program the drone, instead of controlling it, is positively emphasized by teachers (**Appendix B**, Chapter 11, pos. 3, G30.2).

Of the teachers involved in the project, two stated in the pre-test that they would also use the drones presented outside of the project, for example to take aerial photos. The teachers considered the drones equally suitable for higher grades, since responsible handling of the drones is important, and many questions can be raised. The other person who would use the drones outside of the project would use them in a foreign language and humanities class in grades seven and eight. Another teacher stated in the pre-test that she would not use the drone in her classes outside of the project because she did not have the confidence to develop a didactic concept and also did not have the subject expertise. This opinion changed in the post-test, with this teacher now being confident enough to use the drone in her own lessons after the project. Overall, of the five teachers who answered this question in the post-test, three said they would use the drone outside of the project. One person would continue to use it in projects and only one person answered that they did not know what they would use the drone for. Again, for the

drone, grades seven and eight were indicated as possible settings (**Appendix B**, Chapter 11, pos. 3, G30.4).

## CONCLUSION

This research gives a brief answer to the first research question *How can STEAM education based on the 5E model be introduced in schools?*

The 5E-Model with an additional sixth phase has proven to be a good foundation on how to implement STEAM into school lessons with the help of digital creativity tools. Adding the Exchange phase as a sixth phase to the already established 5E Model seems to be a profitable expansion. On the one hand, it allows exchange between students and students, and students and teachers. On the other hand, it allows both teachers and educational researchers to collect more insights into the Students' way of learning by examining Student's presentations and prototypes. Finally, teachers get to know their students better and can prepare their future teaching in a more adjusted way. The effectiveness of this must be proven in further studies but this and another study conducted by the university of cologne emphasizing on six instead of five phases indicates the possible impact of this addition.

The use of videos to introduce the 7th grade students into the topic proved to be extremely beneficial and it became clear through the interviews and student results that a differentiated examination of the videos can be sufficient to motivate the learners. The devices used were quickly and persistently understood by the students through the introductions designed by university students. This is supported by the observation made within the Exchange phase, seeing the students having designed intelligent examples to explain how the devices work. The fact that most of the supporting students were not on site in the hybrid situation and the pupils therefore had to learn how to use the tools on their own supports the idea that STEAM tools are easy and intuitive to handle (at least compared to typical equipment in a traditional science lab). It also supports promising ideas of STEAM tools as tools to foster creativity, and reduce the workload on teachers, since all activities were guided only by work instructions. The potential of the devices is visible in various projects the students developed. After asking the teachers what a digital creativity tool suitable for STEAM should be able to do, it became clear that the previously mentioned aspect of intuition was the most important. Also, further features like sturdiness just as a prerequisite to promote creativity were mentioned by teachers as something that should be characteristic for a digital creativity tool. Those features can all be found in the tools used in this project as well as many other tools on the market. As we have furthermore seen, the project itself as well as the used digital tools were able to expand and deepen the 4C competencies (Creativity, Cooperation, Communication, and Critical Thinking) and further competencies according to the teachers' assessments.

The research question *What is the attitude of teachers toward the adoption of STEAM tools in the context of STEM Teaching and*

*how does it change in the course of a 7-Week, on-the-Job training program?* is difficult to answer due to the data situation.

The teachers participating in the project mentioned many different features a digital creativity tool should offer. What seems to be important to many of them is that the tool should be intuitive to use. In other words, it should be obvious at first glance how the device can be used, so that with the help of such tools, basic computer literacy can be taught in a playful manner at an early age. In contrast, it was also mentioned that a digital creativity tool should have a certain complexity so that students remain motivated not only to learn on the device but also to explore its different facets. Other frequently mentioned characteristics are that such a tool should, above all, promote creativity and explorative learning. Furthermore, it should be versatile and combinable so that it is able to implement most of the ideas and conceptions of the students. Features that are important for everyday school life, such as robustness and safety, were also mentioned by the teachers.

What furthermore seems to be important, is the possibility to individualize the devices so that the students can build up a personal relationship with them. From a special education perspective, it was also important to the school's teachers that a digital creativity tool could be used by all students in one way, that being ideally for those unable to read or write.

Overall, only a small change is observable, since only a few teachers who completed the pre-test also completed the post-test. However, a tendency toward more readiness can be observed when the tools are considered individually. In the post-test, more people indicated that they wanted to use these or similar tools in the classroom. The research question cannot be answered in general terms, but at least the described tendency can be derived from the available data, since in the pre-test, none of the teachers stated that they had previously used a digital creativity tool in the classroom, whereas in the post-test several teachers stated that they would consider doing so in the future.

In order to answer the title question *How might we raise interest in Robotics, Coding, AI, STEAM and Sustainable Development in university and on-the-job teacher training?* conclusively it requires more research in the future and could be focusing on different areas of the basis laid with this paper. One example could be more in-depth research regarding individual tools or certain activities for the respective phases of the expanded 5E-Model. It is also possible to adapt the field study for other schools and try to get more teachers to answer the research forms, to gain more insight on this concept and also avoid having to use video conferences and involve the university students in a better way.

## DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: <https://uni-koeln.sciebo.de/s/aWF3sU4PomZVQk4>.

## ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants or their legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

AB, CS, and JH contributed to the conception and design of the study, and wrote sections of the manuscript. AB led the design of the pedagogical concept. JH led the design of the problem based learning scenarios for computational thinking and selected the appropriate technological platforms, performed the analysis of the interview with domain experts, and wrote the first draft of the manuscript, acted as the main author and revised the manuscript. JH and CS organized the cooperation with the school and conducted jointly the interviews. CS performed the analysis of the interview with teachers. SM developed and evaluated questionnaires to assess the influence of the videos in the engage phase on the students. All authors approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2022.872637/full#supplementary-material>

**Supplementary Figure 1** | Screenshot from the video regarding SDGs 2 zero hunger and 6 clean water and sanitation.

**Supplementary Figure 2** | Screenshot from the video regarding SDGs 3 good health and wellbeing and 11 sustainable cities and communities.

**Supplementary Figure 3** | 7th grade students use the modular neuron-set to build their own prototype of a remote-controlled robot that carries a water pump. In later versions they included a water tank as well as a measuring device for soil moisture to determine when the pump should be activated to water certain spots.

**Supplementary Figure 4** | Students elaborate on how to apply significant payload to a small drone while maintaining stable flight.

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## APPENDIX

**Appendix A** | Interview data with teachers (L) and students (B/M) participating in the project and manufacturer Yu Hu as well as special education teacher René Foellmer.

**Appendix B** | Data regarding video analysis and survey data from participating teachers regarding digital creativity tools.