Digital Materials to Support Learning
Success Stories in Teaching Computing Science

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Abstract: ***Technology has a deep impact on everyday life of most people today, and computing science, information and communication technologies, and digital media are finding their way to education, too. The use of technology and digital materials is, however, a matter of ongoing debate, and educators are called upon to decide whether and when to use digital materials or not. At the department of informatics didactics in Klagenfurt, we developed our own teaching approach and do have a rich experience in the use of unplugged and plugged activities in the classroom. This paper gives some background information about our learning approach and shows, through three examples, how digital materials can be introduced successfully at all levels of education, from elementary up to university level. It also shows that digital materials, when used appropriately, allow for broader methodological approach and stimulates more differentiated way of teaching.***

Index Terms: ***Neurodidactics, Computer Supported Learning, Digital Materials, K-12 education***

1. *Introduction*

At the beginning of 2018, the European Union (EU) Commission presented the Digital Education Action Plan [1]. It outlines how the EU intends to support educational institutions and education systems regarding digital transformation. According to the Commission, the development of relevant digital competences is urgently needed in the age of rapid digital change, both professionally and privately. The Action Plan focuses on the use of digital and innovative educational practices and has three priorities: (a) making better use of digital technologies for teaching and learning, (b) developing relevant digital competences and skills for the digital transformation, and (c) improving education through better data analysis and foresight.

The action plan stimulated a lot of projects in Austria and in the EU, but digital readiness in education requires knowhow and involves adaptation and change. Schools, universities and training institutions in Europe are diverse concerning equipment, teacher skills and varying approaches in using technology. It will take some time to close all the gaps, and, even more, to have enough digitally skilled educators. Digital competence is part of the revised European Reference Framework of Key Competences for Lifelong Learning [2], which all citizens should have … but being digitally competent is more than just being able to use technology appropriately [3]. As best-practice examples are not that wide-spread, and as further education of teachers still needs some time, debates on the use of new media and digital devices are continuing [4, 5].

The objective of this paper is to demonstrate that the use of digital materials or digital learning resources, when done appropriately, can be an enrichment for teaching at any school level. Even more, it also shows that by using digital learning resources, classroom interventions can help stimulating the learning brain. For this, we briefly introduce our brain-based teaching approach COOL-Informatics [6] and show using some examples at the primary school level, the secondary school level, and the University level, how the use of digital materials helped us in implementing successful learning strategies. Furthermore, we report on how accompanying school teachers' resistance to the use of digital materials decreased.

This contribution is structured as follows. Section 2 introduces the use of digital materials in an educational setting, and it also explains our brain-based teaching approach called COOL-Informatics in some detail. Section 3 presents three scenarios where teaching is supported using digital materials. Section 4

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reflects on the benefits and points out arguments for an improved learning experience, whereas Section 5 concludes with a summary and the implication on the way we use digital materials in our own classes.

2. Background

2.1 Digital Learning Resources in Education

The terms “digital learning resource” and “digital material” are used mutually in this paper. They refer to materials or digital artefacts included in the context of a course or interventions that support the learner's achievement of the described learning goals and include graphics or photos, audio and video, simulations and animations or even prepared or programmed learning modules. But even though that there are a lot of opportunities, as an educator, we need good arguments for the use of digital materials.

As mentioned above, the impact of digital materials is still rated contradictorily. These contradictions go back to the fact that the effective variables of using digital technologies in the learning process are difficult to identify and the relationship between learners and the medium of learning is very complex. It still is not sure that digital materials have a direct effect on learning processes and outcomes in the sense of a cause-and-effect relationship. Rather, various factors, such as the acceptance of digital media used by learners and teachers or the self-learning competences of learners, might influence the effect of media and materials in the learning process. Kerres [7] postulates that digital materials do not directly affect the learners but are individually processed by them, which can be decisive for the effect of the digital medium.

However, he further assumes that digital materials have an immanent effect due to their media form (e.g. certain technical characteristics). Thus, certain situations can increase the motivation to learn and bring about a more intensive learning behavior (through visualization, simulation, interactivity, etc.). The learning content, learning tempo, and temporal and local planning of learning can usually be organized by the learners themselves. At the same time, digital materials also represent a "raw material" in that they open creative leeway that can be shaped by a media-didactic concept. In this way, digital materials influence their users.

Although no reliable statements are to be found in literature about the direct effect of digital materials in the sense of a cause-and-effect relationship so far, they at least have "immanent effects”. These immanent effects or potentials influence learning on several levels [8, p.29] (translated from German):

1. Digital materials enable a more self-organized learning and educational process in all dimensions by enabling self-organized actions and interactions in the generation of knowledge, in the exchange of knowledge and in learning from existing knowledge sources.
2. Social networks or other applications (e.g. WIKIs, social media video portals, blogs, etc.) in which texts, images or videos are shared with other users, enable community building, networking, and cooperation with other people or organizations with the same thematic background. In this way, experiential learning in professional and nonprofessional contexts can be supported by digital learning resources, too.
3. A reflection of work and learning processes - and therefore learning to learn - can be supported by e-portfolios or blogs in which one's own work and learning progress is documented and reflected.

With these findings, educators should have enough reasons for introducing digital materials into their lectures. But also, children seem to be in favor of new technologies. In 2016, Deloitte published the Digital Education Survey [9] that analyzes 2,800+ responses from demographically-diverse teachers, parents, and students in the US. The study showed that 90 % of all children use digital learning materials at home and 2/3 start by the age of 5. And even more interesting, 73 % of the children say more access to digital material would increase their time spent learning over the summer.

So, motivation and new possibilities are already a strong reason for the use of digital materials. And, with the advent of neuroscience and neurobiology, there are additional reasons for having digital content available to supplement our traditional classes.

	Neurodidactical principles	
	Teaching and learning methods	***Neurodidactical basis***
1. Discovery	• Solution-based learning [10] • Observational learning • Step-by-step instructions and tasks • Video tutorials, Hands-on, Minds-on • Learning with all senses	• Pattern recognition • Mirror neurons • Individual learning rhythm • modality / multimedia effect
2. Cooperation	• Team and group work [11,12] • Peer tutoring and peer teaching, [13,14] • Pair programming [15,16] • Cross-curricular learning • Project-based learning	• "A joy (=knowledge) shared is a joy (=knowledge) doubled." • Recall = re-storage in long-term memory • Integrating individual needs, talents and competences as well as practical relevance
3. Individuality	• Competence-based learning • Questioning, [17,18] • Self-organized learning with compulsory and optional tasks	• Connecting new information to previous knowledge, • Considering individual interests, needs, tasks, methods and learning rhythm
4. Activity	• Hands-on, Minds-on • Learning by doing [17,19] • Learning by animation, simulation and playing [20,21] • Learning by playing and designing games (creative learning)	• Knowledge must be newly created (constructed) by each learner (= constructivism) • Learning is an active process (= progressive education)

Table 1: The four principles of COOL Informatics [6]. Every principle is connected to a neurodidactical

2.2 Brain-Based Teaching

Using imaging techniques (e.g. fMRI) in cognitive neuroscience and neurobiology, new insights into the functioning of the brain were gained, which, to varying degrees, now also find their way into school practice. This new scientific direction is called "Neurodidactics" [22, 23, 24], and already in the 1980s, brain-based education became popular in the Anglo-American region [25].

Brain-based teaching attempts to translate neuroscientific findings into didactically concrete recommendations for the design of teaching. As such, it can be understood as basic, applied, and practice-oriented science. In the practice-oriented field of neurodidactics, for example, practical concepts, interventions, and recommendations for action are derived from models. As there are too many factors contributing to good teaching [26], and as the learning brain is complex, the field of brain-based teaching is also not uncontested. Up to now, neurosciences alone cannot guarantee successful teaching at schools or universities, but the insights provided into the possibilities and restrictions of the learning brain help more and more in explaining why some learning environments support learning and others do not. Caine and Caine [23] summarize a lot of issues that must be considered when teaching according to neurodidactic principles. Overall, students need the opportunity to gain concrete experiences. Learning processes that are integrated into social situations are more effective, as is the consideration of interests and ideas. The connection with previous knowledge is a central component of the learning process and positive emotions lead to more effective learning. Students understand the connection between individual details and the whole, which helps them to remember details better. In addition, the time for reflection improves learning (consolidation). Students learn better by combining information and experience. The recognition and integration of individual differences promotes learning processes. Students learn better through a supportive, challenging environment and the consideration of individual competences is of great importance.

At our department, we developed a teaching approach called "COOL Informatics" [6], which is based on neurodidactical principles. The acronym COOL, of course, has special meanings in the context of “COOL Informatics”, and it can be translated as follows:

1. “Cool” means motivating, interesting, fun and effective.
2. “COoperative Open Learning” is an Austrian teaching model [27] that offers thematic, methodic, and institutional openness as well as cooperation on different levels and between different subjects.
3. “COmputer-supported Open Learning” refers to all forms of technology-supported learning, like CSCL (Computer-supported Collaborative Learning), E-Learning or Mobile Learning as well as eCOOL, the E-Learning variant of the COOL teaching model.

“COOL Informatics” is not simply combining all these fields to one approach, but it goes one step further. On the one hand, it extends the aspect of computer-supported learning to “computer science-supported” by implementing core concepts of informatics in other subjects wherever possible and reasonable (e.g. by comparing algorithms and the description of the way to school). On the other hand, it gets a new framework and a bases for neurodidactical principles. Corresponding to different meanings, the theoretical background of the “COOL Informatics” approach includes numerous teaching concepts and methods as well as a wide range of related work. It includes some corresponding and effective teaching and learning methods as well as related neurodidactical elements.

An overview of the four principles can be found in Table 1. It shows that the principles encompass “Discovery”, “Cooperation”, “Individuality” and “Activity”, and later on in Section 4, the relationship between these principles and the use of digital materials will be discussed in more detail.

The COOL Informatics concept forms the basis for different projects at our department and has its roots in projects like “Experiencing Informatics” [28] (which was also inspired by CS-unplugged [21]). COOL-Informatics now is one cornerstone of our “Informatics-Lab” (“Informatikwerkstatt” in German), a workshop that is open to the public and to schools and that is also used for our University’s teacher training and for the further development of STEM and non-STEM teachers. Since 2015, we had more than 14.000 attendees in our workshops and events and, in addition to scientific support [29], we provide a Creative-Common-based and rich set of materials (including the related didactic concepts) to all users of our workshops and partners [30]. Stemming from the experiences with elementary school children, secondary school pupils, and students, this paper now shows three ways of successfully using digital materials in education and relates them also to their neurodidactic background.

3. *Experiences with Digital Materials in Education*

3.1. Digital Materials at the Elementary and Primary Level

Whereas digital materials are already standard in higher education (mostly in STEM-related fields) at our Universities in Austria, especially elementary and primary school teachers are still confronted with arguments for and against the use of new media in teaching and educational accompaniment. Myths, educational doctrines, but also technological hurdles complete the picture. This situation differs from country to country (not all of them do have curricula focusing on computing science or ICT from the elementary level onwards, (see the work of Pasterk [31] for more details), but in all the cases one has to ask the question, if and when the use of technology does make sense.

In the year 2018, our department launched two projects that aimed at conveying the image of computing science correctly. The first project deals with computational thinking and is called “The Elementary Beaver”. It focusses on children age 4 to 7 and tries to break down typical beaver contest examples, which supports the learning of computational thinking skills, to the elementary level. The second project is called “Informatics in the Park”, and it is part of an international price-winning [32] initiative in collaboration with a science and technology park close to our University. It aims at providing a continuous computing science curriculum from elementary to secondary school level. The design of our interventions and modules not only followed COOL informatics but also stick to the principle of using digital technologies only when necessary or when there is clearly a chance to extend the “methodical treasure chest” of the related pedagogues.

Figure 1: (Left) Children following an interactive guide for training step-by-step instructions. Pictures, sound, and animation are possible (Right) In the front: taken from the beaver contest 2016, an application for experimenting with water pipes and valves to support learning computational and algorithmic thinking. (Both pictures copyright by “Informatikwerkstatt, AAU Klagenfurt”)

In the first step in both projects, the pupils got in contact with digital devices like cameras and tablets. They played around with recording functionality, produced a diary and finally used digital materials to work on problems (see Figure 1, left side). It turned out that both, the creation of digital artefacts and the use of digital artefacts was key to success.

The Bebras contest and, with it, hundreds of Bebras examples are designed for children age 8 and above as they assume reading and writing skills. In the Elementary Beaver project, we managed to break down 80 % of these examples to age level 4 to 7, but partially needed digital materials to do so. Whereas a lot of examples can be implemented in an unplugged manner (as board games, activity games), some would require expensive materials or cannot be realized in a safe manner. The watering system is such an example (see Figure 1, right side). It trains logical thinking and is somehow also an abstract representation of a circuit. The valves are the switches - with the two positions "open" and "closed". According to the input funnels and the switch positions, the information "water flows" and "water does not flow" move through the circuit - down to the flowers. Electronic devices contain electronic circuits through which electricity flows but creating such a system in real life with pipes and valves would have been fun, but not feasible at the elementary level – using digital materials however, this was easy to implement.

Although the teachers involved were initially cautious, they found the use of digital materials in both projects to be a strong enrichment of their classes and they began to make use of them. Even more, as they noticed that digital materials are not replacing but extending their collection of materials, they started asking us for implementing new applications. For the children, on the other hand, the materials were fascinating and, first driven by curiosity, they began to get more involved with the artefacts.

To summarize, in both projects at the elementary and primary school level, we are focusing on observational learning, step-by-step instructions and tasks, short video tutorials, hands-on, and learning with all senses, self-organized learning with compulsory and optional tasks, learning by doing, learning by animation, simulation, and playing. A lot would have been possible in an unplugged manner, but especially the use of digital materials enabled us to reach more children at the same time and to implement examples in an age-appropriate way, following the interests of the children and without requiring reading and writing skills.

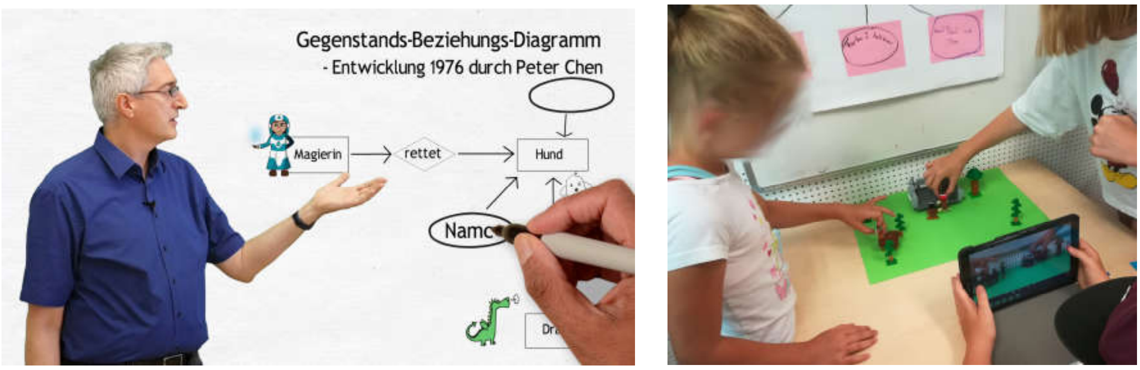

Figure 2: For a lot of topics we do have videos for teachers and/or for pupils. (Left) For teacher training, we are using a video showing how to introduce modelling techniques to children. (Right) The children are using paper/pencil and digital materials to design their stories. After modelling, they utilize stop-motion techniques to tell their stories. (Both pictures copyright by “Informatikwerkstatt, AAU Klagenfurt”)

3.2. Digital Materials at the Primary and Secondary Level

As mentioned above, our department runs a project called “Informatics-Lab”. It is a workshop open to the public and available for school-classes and in-service teachers as well as our teacher training students. The workshop covers a lot of topics from the field of computing science, like coding, hardware, logic, modelling, robotics, and safety and is also the driving factor behind events like the “Childs-Congress” [33], IT-camps and much more. Our plugged and unplugged materials are available from the end of primary school to secondary school level, but a lot of them are designed in an interdisciplinary manner which in turn makes them very successful among our partners. Schools from all over Carinthia are booking units, and students from our teacher training program do have the opportunity to train their skills.

With about 3.000 – 3.500 attendees a year sustainability is very important, and without the use of digital materials this would not have been possible at that size. An increase in skills, self-concept and attitudes is easily measured by an online questionnaire (c.f. project KAUA [29]) but delivering the content to the children aged 8 up to 18 is very demanding. The reason is that the pupils visiting our events and workshops differ in age and thus previous knowledge, their school-type and also their interests. In order to be successful, flexibility in tasks, materials and also in the didactic concepts, is a must. In order to deal with these issues, our teachers do have training materials and templates available online, and a lot of tutorials, step-by-step guides and quizzes are implemented in a digital manner in order to deal with visitors in full-class-size. During the past couple of years quite a lot of materials and guidelines are created. They are checked according to gender issues, their interdisciplinarity, and when they have successfully been implemented in the classroom, they are uploaded to a repository for broader use.

According acceptance among in-service teachers, we soon learned that they needed examples of how to use the materials, and so we started to record successful classroom interventions and now provide them as videos to our partners but also to future teachers (see Figure 2, left side). These videos not only contain background information (also as subtitles and a PDF transcript), but also examples and recordings of real classroom situations. Qualitative feedback shows, that teachers prefer this variant compared to conventional collections of materials or textbooks.

According to our younger visitors, digital materials are “naturally” mixed with all other types of materials. When modelling is a topic, paper and pencils are used as well as clay and/or LEGO bricks and characters. This is continued by either creating small stories using stop-motion (see Figure 2, right side), or by utilizing modelling tools on a laptop or tablet. With that, finally, objects or scenes are printed using a 3D printer. Without digital materials, only part of the creation process would have been covered. With digital materials the pupils experience the possibilities but also the limits of new technologies, but always have the feeling that their use is not artificial and on purpose.

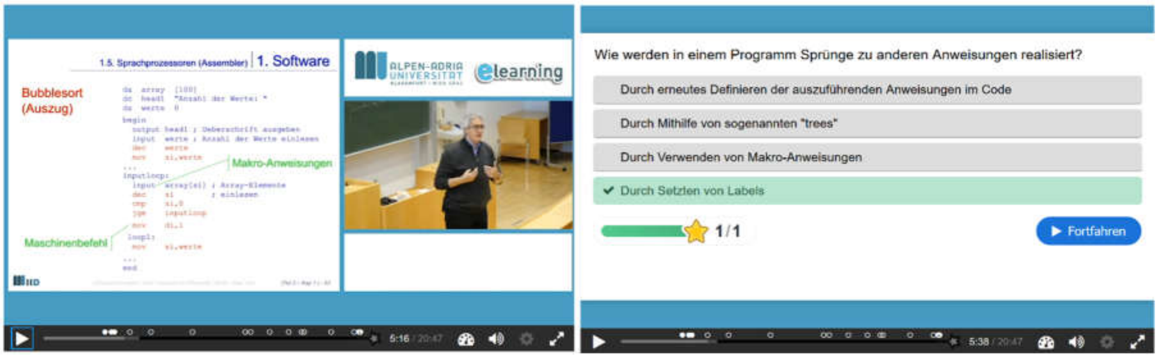

Figure 3: H5P Video explaining and testing for the functionality of an assembler. (Left) The recording is enriched by the slides used in the course. (Right) Sample question (German about how to implement jumping to specific statements in the assembler code) that is raised after listening to some parts of the video.

3.3. *Digital Materials at the University Level*

Since approximately 2005, our university forces and assists lecturers in using new technologies in teaching. What started with some early adopters, was very successful and with 2015 nearly all university teachers now make use of Moodle as an E-Learning platform. Most of them still use it as a repository for their hand-outs only, but quite some apply of all the features that this platform offers.

One lecture, obligatory to several different curricula at the technical faculty of the University of Klagenfurt is called “Introduction to Computing Science”. It is designed for freshmen and takes a closer (and sometimes also deeper) look at the various topics of the field – be it digital numbers, coding, computer architecture, assembler and compiler, networking and so on. The lecture is being constantly optimized, but we found a significant improvement when it came to the examinations (before, dropout was at about 30 % and negative final scores were at about 40 %) after implementing the following changes: (i) we made video tutorials available, (ii) introduced small step-by-step instructions for the most important competencies, and (iii) provided meaningful examples and solutions to the students via the Moodle course. In the accompanying practical labs, we (iv) were supporting the students by introducing group/team work and (v) installed peer tutors. We (vi) provided questionnaires and quizzes and (vii) used animations and simulations to foster their competencies.

It took us a lot of resources to change the lecture, but in the end, it turned out that these efforts were crowned with success. The dropout-rate went back to 10 % and the number of negative scores also went back to 10 %. Even more, the feedback for this class constantly got better. The positive effects on grades was not only due to the use of digital materials, but in terms of feedback, the students appreciated the materials and videos a lot – and thus rate the lecture among the best at our University (it now constantly yields grade 1.0, the median at our Faculty is at 1,70 according to the Austrian grading scheme, where 1 is Very Good and 5 is Not Sufficient).

There was still some room for improvement, and so, in 2018 we decided to make even more use of the digital materials that we have. One challenge in teaching was still the functionality of an assembler (and students lost quite some points at that topic during the examinations). We thus took the video recording of the assembler unit and extended it by making use of H5P, so we added interactivity to the video and added quizzes and explanations to it (see Figure 3). It turned out that the motivation to deal with the content was even higher and the examination results showed that the extra effort again payed off. In the last year (the lecture is read every semester) only one student finished the lecture with a negative grade, and the overall grades also improved. Currently, also a 3D/VR game of a functioning CPU is under development, too, but already now we can say that the use of digital materials payed off. The qualitative feedback that we collected demonstrates that students highly appreciate their use. They mention that they are able to learn whenever and wherever they want, they are motivated to work on the quizzes in teams and, even more, interactivity helped them in preparing for the examinations.

4. *Reflection*

The previous section briefly presented three examples of the use of digital materials in projects of our department. The use of the media resulted from the requirements of the teaching scenarios and clearly supports neurodidactic teaching methods. This section summarizes the tackled principles (Discovery, Cooperation, Individuality, and Activity, see Sec. 2.2) and as such, it serves as a guide for teachers seeking arguments for the use of digital media.

Discovery. This type of learning has its basis in pattern recognition, an individual learning rhythm and the modality and multimedia effect. In the elementary and primary school project, digital materials were perfectly suitable as they supported step-by-step instructions and observational learning in form of video tutorials (without reading skills) to deal with very inhomogeneous age-groups resulting in a quite individual learning progress. At the secondary level, we were able to also cover solution-based learning and learning with all senses (3D printing, following a product-chain approach). This is perceived a necessity as the brain always looks for the "whole", and without the use of digital artefacts, a lot of computing science interventions would lose their connection to reality. Finally, at University level, again digital materials allowed for step-by-step tasks and tutorials for a huge number of students in a course.

Cooperation. This type of learning has its roots in the way how recall and re-storage in long-term memory works, and how information is combined with practical relevance. Digital materials do not seem to be of relevance here, but in the elementary/primary school project they function as glue between the pupils and smaller teams. Recordings are used to communicate and document what happened, and they are shared as a joy to others. Without reading/writing skills this would not have been possible (or only possible with the help of accompanying personnel). At the secondary level, working together on a project in teams or acting as peers is normal. Paper has its limitations (handwriting, changeability, digitalization), and again digital materials act as a catalysator for ideas, they speed up the communication process, allow for quickly modifying design decisions, and finally, allow for sharing ideas (and thus joys) to others immediately. At the university level, digital materials additionally supported team and group work as well as project-based learning, as dislocation of team members could be handled easily.

Individuality. This type of learning has its basis in considering individual interests, needs, tasks, and learning rhythm. It is also influenced by the fact, that new information must be connected to previous knowledge. At age group 4 to 7, digital materials supported self-organized learning to some extent only, as it had to be stimulated by the pedagogues accompanying them. Traditional learning materials can of course also deal with individuality, but the number of physical copies is often limited, they might be occupied by others, and cannot adjust themselves to changing interests. Here, digital materials are helpful insofar, as a lot of recordings/drawings and experiments/task were available for a larger number of pupils at the same time, and the software behind our examples could take care of individual interests. At the secondary and university level questioning and competence-based learning are already supported by common learning management systems, and digital materials in combination with H5P now allow for an even better management of individual interests and a learning rhythm.

Activity. This type of learning is based on the fact that learning is an active process, and that knowledge has to be created by each learner actively. At the elementary and primary level, animations and games helped us to create new stimuli for children and to broaden the set of materials of teachers. At the secondary and University level, a lot of our interventions and units involved creating own digital games (stimulating creative learning) or materials. Especially the holistic approach (design-implement-play) that naturally makes use of digital materials, implies a lot of different activities and thus supports constructionism and constructivism.

The use of digital materials can also be grounded on a neurodidactic basis, or, putting it the other way around: brain-based teaching can be well-supported by digital materials. There are immanent effects (as mentioned in Section 2.1), but there are additional reasons that justify using digital materials in a teaching situation: (i) they allow for dealing with very inhomogeneous learning groups, even without reading/writing skills supporting pattern recognition and an individual learning rhythm, (ii) by following a product-chain model, they can support and stimulate all senses, making use of the modality and multimedia effect, (iii) they extend the possibilities of paper/pencil artefacts by providing the ability to modify and share them instantly and without being on-site, (iv) they are able to "adjust" to the user and thus also can guide the learner through his or her learning experience, (v) they are easy to reproduce and to apply in smaller and larger classroom settings, and finally (vi), they can provide a new and holistic stimuli to the learner, also forcing them to be more active compared to traditional classroom settings.

5. Conclusion

The world's digital transformation will accelerate with the rapid advance of new technologies and this makes investing in digital skills throughout life to be of the utmost importance. Here, digital Materials can be very helpful in this respect as they support the educational process by immanent effects. But, due to missing cause-and-effect relationships the impact of digital learning resources is still rated contradictory.

This paper now takes a closer look at different learning scenarios and projects at the department of informatics didactics at the University of Klagenfurt and relates the use of digital materials to neurodidactic and teaching principles (like discovery-, cooperation-, individuality-, and activity-bases learning). It then shows that there are more than immanent effects contributing to the success and usefulness of digital learning resources, and the presented examples and arguments should help all of us in giving more thought on the use of digital media in our own teaching units in the future.

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