HOW to Consider Informatics in Primary Education?

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Right now, Informatics education is stretching downwards to reach primary education. This article surveys some approaches to convey basic informatics competences at primary level. Presenting an approach that gives aspects of informatics proper prominence over digital literacy, the article advocates to connect to traditional topics and to build on common learning patterns when introducing aspects of informatics into primary education.

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1 Public Perception of Informatics and Creativity

There still seem to be some misconceptions within the public perception of informatics, suggested by the following quotes:

- "I can not figure out why my son has got bad marks in informatics. At home he is at the computer most of the time!"
- "Why isn't there any button that has to be pressed so that the program is being written automatically?"
- "Why do we have to read this book? Watching the video makes it much easier to imagine the characters and the surroundings!"

The first quote comes from a discussion between parents and a teacher at higher secondary level and indicates a still common point of view that identifies any kind of using a computer with doing or thinking informatics. In turn, informatics implicitly is being reduced to simply mastering application programs.

The second statement was uttered by a pupil in a programming course at higher secondary level and confirms and deepens the foregoing misconception: In common thinking "doing informatics" is supposed to take place within a virtual world designed by others where the user's freedom of choice is restricted to selecting a menu item or pressing some button appropriate for achieving a desired goal. If the goal is out of reach, most probably a different kind of software is needed. Quite commonly, the possibility to become creative at a basic level and to modify the structure of the virtual working environment to increase the number of provided options is out of the professional user's sight, except, maybe, for virtual gaming worlds.

However, all of that is surpassed by the deeper meaning of the last statement which can be heard within all age groups at secondary level of education and indicates a common attitude not to invest too much of ones own creative imagination but rather to accept and consume interpretations of the thinkable provided by others and represented within pre-configured media worlds. An attitude like this has to set the alarm bells ringing for a modern society and its welfare which relies on the brain power of its members.

Becoming visible at secondary level, this attitude most likely originates in the way children experience the (real and the virtual) world at an earlier age. Results of a current Austrian study on internet use and digital competency at preschool age show that 41 percent of Austrian children between three and six years of age use the internet at least once a week, mainly playing online games, being concerned with photos and videos or listening to music [IFES 13]. Consequently an even higher percentage of children at this age group uses digital devices of one kind or another, supposedly focusing on the same scope of activities. It is beyond the scope of this article to rate early use of digital media as good or bad. But the reported situation demands for action as soon as primary education to shape the attitude towards hard- and software of any kind, whether they are perceived as mere communication aids, as ready-to-use tools to perform tasks required by everyday life, as creative tools to express ones ideas beyond the boundaries of an off-the-shelf software system, or as a balanced mixture of all of these.

2 Roles of Informatics Education at Primary Level

2.1 From Europe to Austria: A Reference Model for Digital Competences

Recognition of the necessity of informatics education (in the broadest sense) is not new. In 2006 the European Parliament defined eight key competences that should be acquired by learners at the end of their compulsory education [EUPC06]. These key competences include competence regarding communication in the mother tongue, learning to learn, the sense of initiative and entrepreneurship, and digital competence. The latter is defined as the critical use of Information Society Technology (IST) aiming at a "[…] critical and reflective attitude towards available information and a responsible use of the interactive media", underpinned by basic skills in Information and Communication Technology (ICT) including "[…] the ability to search, collect and process information and use it in a critical and systematic way".

Accordingly, a decree on "Digital Competence in Austrian Schools" issued in 2010 by the Austrian Ministry of Education, Art and Culture recommends to include principles of reflective use of media in education at school, emphasizing ICT skills like information retrieval with digital media or self-responsibilty within digital networks including ethical and legal issues [BMU10]. A corresponding reference model for digital competences at the age of 10, respectively 14, was presented at the end of 2012, comprising four competence areas at primary level, namely:

1. Information Technology, Man and Society,
2. Informatics Systems: Using Digital Devices and Networks
3. Applications: Digital Tools in Everyday Life
4. Concepts of Informatics: First Insights into Informatics.

Comparing the number of items within each of these competence areas indicates that concepts of informatics proper play a minor role within the competence model for primary education (cmp. http://www.digikomp.at/mod/page/view.php?id=29764).

2.2 Current Development in Europe: A Change of Perspective

The Austrian reference model for Digital Competences complies with recommendations of the European Union from 2006. Nevertheless, the discourse on educational matters regarding informatics is evolving. In February 2013 a workgroup report on perspectives of informatics

education in Europe states that although "[…] teaching [of digital literacy] should start in the first grade and students should be familiar with the basic skills by age 12, […] teaching digital literacy […] is not enough to prepare the citizenry for the Information Society Europe has decided to become […]". Furthermore, "[…] the general population must in addition to digital literacy understand the basics of the underlying discipline, informatics." [JIE, p. 9].
This report highlights that

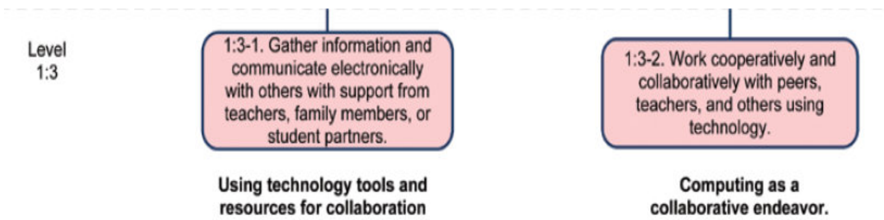
- "informatics fosters creativity by illustrating the variety of ways to approach and solve a problem",
- "informatics is constructive as designing alorithms is engineering work, producing visible (if virtual) artifacts",
- "informatics helps master complexity",

and demands these skills to be taught particularly in the secondary, but in the primary school curriculum as well! Besides being a necessary skill, informatics has to be considered "[…] an invaluable tool for developing essential conceptual skills […]". Referring to the concept of computational thinking ([Wi06, BS11]) these conceptual skills comprise problem solving techniques like "[…] automating solutions through algorithmic thinking" and intellectual practices like "[…] confidence in dealing with complexity". Like the Austrian reference model these recommendations regard both digital competences and concepts of informatics. Nevertheless, even at primary level the balance between the far ends of informatics spectrum is shifted in favour of informatics proper.

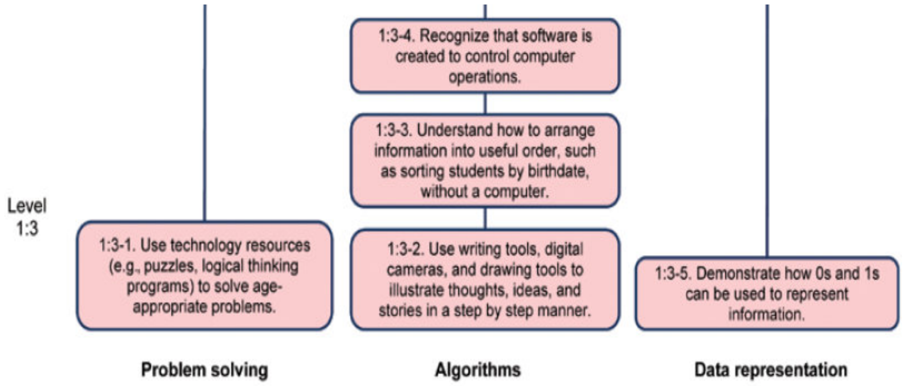
2.3 CSTA K–12 Standards: Five Strands to Structure Informatics Education

This viewpoint upon informatics education and, in particular, the notion of computational thinking connect the suggestions of the European workgroup on informatics education to K-12 computer science standards issued by the CSTA standards task force. There, besides of collaboration, computing practice and programming, computers and communications devices, and community, global, and ethical impacts, computational thinking is one of five "complementary and essential strands" serving as guidelines for informatics education throughout all grades in K-12 education [CSTA11]. The first four grades, corresponding to primary education in Austria, are part of (educational) level 1, where informatics education emphasizes "computer science and me" and where "[learning experiences] should be designed with a focus on active learning, creativity, and exploration and will often be embedded within other curricular areas such as social science, language arts, mathematics and science." Considering possible roles of informatics education at primary level it is of special interest that the standards list age appropriate topics and/or areas of interest for all grades, for example for grades 1 to 3:

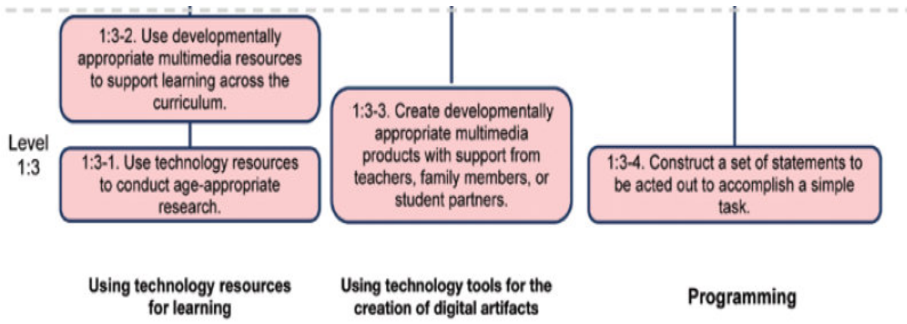
- "collaboration":

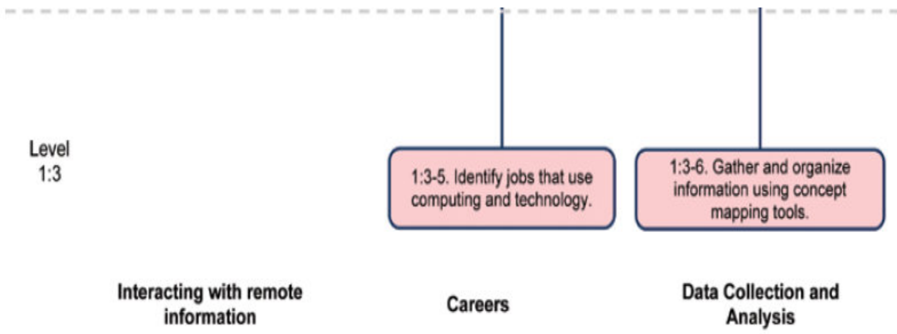


- ”computational thinking”:

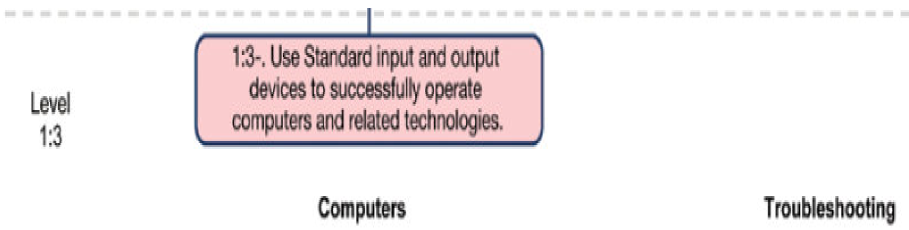


- “computing practice and programming”:





- “computers and communications devices”:



Figures 2 to 5: Lowest level of CSTA K-12 standards scaffolding charts [CSTA11, pp. 55].

Concluding from the distribution of competences, at primary age the CSTA standards emphasize the basic understanding of operating principles of a computer over extensive use of digital devices, particularly emphasizing planning and describing of actions in a step-by-step manner as an early stage of computational thinking. This point of view is underlined by example activities provided within the standards paper: Most of these activities at level 1 refer to Computer Science Unplugged, an initiative that provides tasks and activities for learning basics about data representation or algorithms without using a computer [BW05], while another example activity guides the learners to develop a series of step-by-step directions to control simple behavior of a Scratch sprite (see [Sc13] for further information regarding the MIT Scratch project).

However, the outstanding feature of CSTA recommendations for informatics education at primary level can be found in a collection of computational thinking teacher resources where computational thinking is presented as a "skill that most teachers are already building in their classrooms, but may not know it." In other words: Basic concepts of informatics are not necessarily add-ons to but already part of common educational practice in primary schools. In [CSTA11a, pp12] this important fact is illustrated by a learning experience that suggests how computational thinking can be combined with language learning in primary education.

3 A Proposal for Including Informatics at Primary Level (in Austria)

Why do we teach? These days, a quite common answer might be: "We are teaching to enable (young) people to master their present life situation in a more competent way." Traces of that point of view can be found in currucular recommendations stating that learners should see a purpose in what they are expected to learn, or even more, that they should be able to apply what they have learnt, most probably in their everyday life. Of course this point of view has its right. But there exists at least another one which might result in an answer like: "We are teaching to provide learners with a foundation for later learning as well." Seeing primary education as a basis for all subsequent learning processes highlights this latter point of view as a guideline when choosing from existing approaches to introduce informatics into primary education.

3.1 Planning Downwards – Building Upwards

The proposed Austrian reference model for digital competences at primary level favours skills that provide instant benefit for the learners: They are expected to learn how to use standard software on basis of entering and formatting text, creating and adding pictures, or using spreadsheet programs for age appropriate calculations. Furthermore they are expected to learn how to operate digital communication devices, how to cooperate digitally and what to take care of when communicating digitally.

All of that has not been part of primary education for learners who are now attending secondary school forms in Austria. It is true that most of these are rather careless about digital traces they leave behind when surfing the internet or using social web services. But these learners know how to operate digital devices or how to use everyday software tools quite well. Nevertheless many of them

- have poor reading comprehension,
- have problems to produce meaningful passages of text by themselves,
- are unable to learn by following written step-by-step instructions,
- and lack basic problem solving strategies like dissecting a big problem into smaller solvable parts.

These four issues concerrn manipulation of information, which is the realm of informatics. Hence, from the viewpoint of teaching practitioners at secondary level these (missing) basic competences have to be addressed when thinking about informatics at primary level. Furthermore, all of these issues refer to aspects of computational thinking: According to [Wi06] and [BS11], “computational thinking is way that humans, not computers think”, a problem-solving process that includes (selection):

- Formulating problems in a way that enables us to use a computer and other tools to help solve them.
- Logically organizing and analyzing data.
- Automating solutions through a series of ordered steps,

and is, amongst others, supported by confidence in dealing with complexity, or the ability to communicate and work with others to achieve a common goal or solution. This makes computational thinking the appropriate concept to augment and to complement the sketched digital literacy-based approach to consider informatics competences in primary education.

But we also have to look at it from the other side: Starting off from what is needed at secondary level and stating what shall be introduced at primary level to provide necessary prerequisites is “planning downwards”. While planning downwards is important to define the goals, it clearly has to be accompanied by “building upwards” from the current situation at primary level. Bearing in mind, that at primary level informatics has to be integrated into other curricular areas, we not only have to consider relevant topics from the range of informatics that do fit in, but also

- prerequisites, capabilities and current development of the learners, which also include
- learning habits that correlate to prior learning experiences from other areas of study;
- goals of curricular areas where informatics content and/or practices might fit in or be able to connect to,
- and the availability of both technical and human resources to establish informatics at primary level.

3.2 New (?) Topics, Existing Goals and Common Practice

[BS11] and [CSTA11a] list the following core computational thinking concepts and capabilities associated with computational thinking:

- data collection, data analysis, and data representation
- problem decomposition, and abstraction
- algorithms and procedures, and automation
- parallelization, and simulation.

Further information is provided about how these concepts relate to existing subject matters (Figure 6) and how to gradually improve in different areas of computational thinking (see Figures 6 and 7, highlighting the concept “algorithms and procedures”).

CT Concept, Capability	CS	Math	Science	Social Studies	Language Arts

Algorithms & procedures	Study classic algorithms; implement an algorithm for a problem area	Do long division, factoring; do carries in addition or subtraction	Do an experimental procedure		Write instructions

Figure 6: Traces of computational thinking in various subject matters (snippet, [BS11, p. 52])

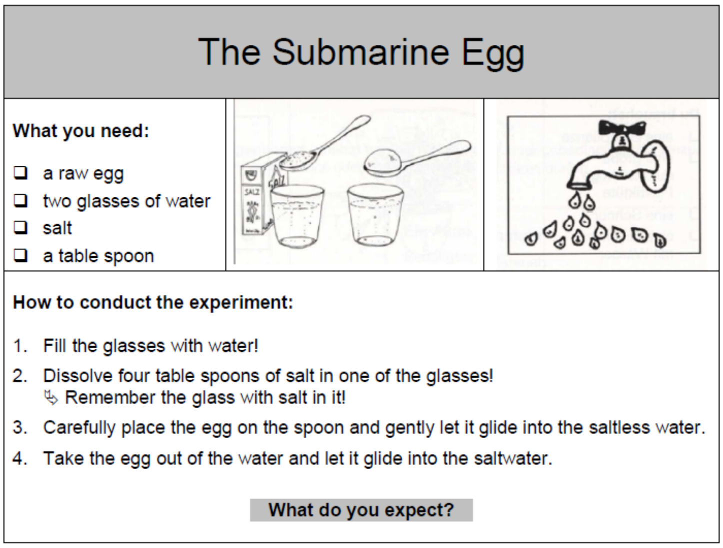
	Definition	Grades PK to 2	Grades 3 to 5	Grades 6 to 8
Algorithms & Procedures	Series of ordered steps taken to solve a problem or achieve some end.	Create a set of directions from the school to the major landmarks in the neighborhood.	Design a board game and write instructions to play. Test instructions on peers trying to play the game. Refine instructions with feedback from peers who played the game.	Program a robot to find its way out of a maze such that given any maze, the robot could exit successfully within a specified time period.

Figure 7: Snippet of the computational thinking progression chart provided in [CSTA11a, p. 9]

Hence it should be quite clear what to consider when augmenting primary education with computational thinking. But how do these suggestions comply with educational practice at primary level in Austria?

In Austria, traditional primary education focuses on basic literacy and numeracy, augmented with education in arts, music, sports and with selected topics about the world around us [BMU12], nowadays including "Computers and the like" which covers basics about computer hardware and the internet [Ba11, pp 50]. However, computational thinking rather connects to basic literacy in the first place: As pointed at before, reading and writing represent the children's' first contact with processing and structuring of information. Moreover, the 2012 National Report on Education for Austria, states that "[…] competence in reading is one of the most important basic skills that have to be acquired throughout the first years in school. Being the foundation for all subsequent learning processes, this competence shall be trained in all curricular areas with various methodical approaches to proceed from a basal reading competence of accurate and fluent reading at word and sentence level to reading comprehension skills, including reading for informational acquisition and use." [BL13, pp130]. In primary education, computational thinking can be seen as one of those various methodical approaches.

According to the Austrian curriculum for primary schools, accuracy and fluency in reading should have been acquired at the end of the second grade. During the third grade pupils should gradually improve reading comprehension, for instance, by becoming able to reproduce the correct sequence of action by drawing a series of pictures or by writing text [BMU12]. These curricular regulations prove the words of the CSTA teacher resources true: When dealing with basic literacy, preparatory exercises regarding computational thinking are already common practice in primary schools. For instance, in second grade pupils learn about step-by-step order by following folding instructions, e.g. for origami models. In doing so, they are introduced to algorithmic thinking. This also applies if they accurately follow written instructions when conducting simple science experiments. (Figure 8).


The Submarine Egg

What you need:

- a raw egg
- two glasses of water
- salt
- a table spoon

How to conduct the experiment:

1. Fill the glasses with water!
2. Dissolve four table spoons of salt in one of the glasses!
   ↳ Remember the glass with salt in it!
3. Carefully place the egg on the spoon and gently let it glide into the saltless water.
4. Take the egg out of the water and let it glide into the saltwater.

What do you expect?

Figure 8: A set of instructions to conduct a simple science experiment.

Following step-by-step instructions is kind of consuming algorithms. This is an important step in learning as the learners get to know how algorithms look like. But learners at primary level become producers of sequential descriptions as well when they find the correct sequence of pictures telling a story, when they retell the story in correct order by themselves, or when they translate a written story into a sequence of pictures. Combining all of these basic skills, at the end of the second grade (some) pupils even invent (short) stories by themselves and "tell" the plot of the story by drawing and/or writing a storyboard by hand, hence without the need of computers.

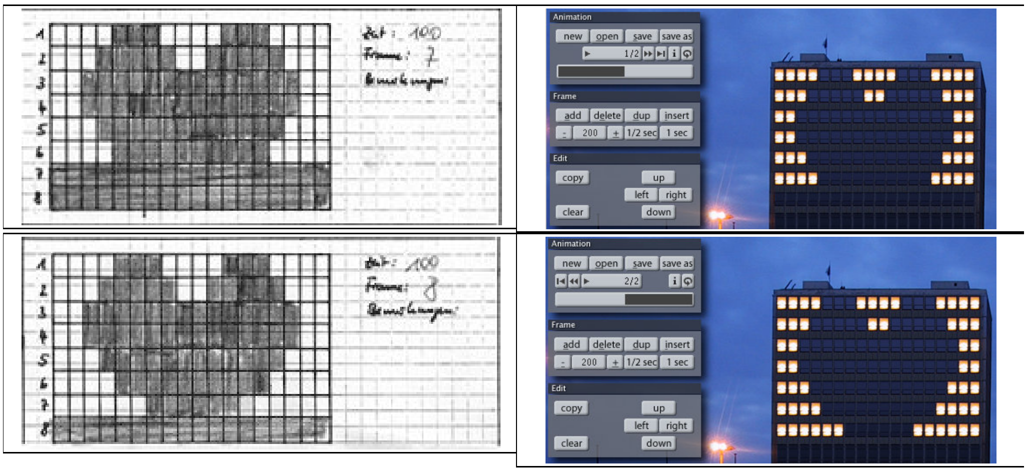
The common practice to have the learners draw simple flipbooks during their arts lessons completes from the view of the author the solid basis for "building upwards" to include informatics/computational thinking in primary education in Austria.

3.3 Tailoring Computational Thinking to Connect to Austrian Primary Education

Omitting the use of computers or other digital media, at least part-time, is nothing new when coaching informatics learning processes. Projects like Computer Science Unplugged [BW05], Exploring and Discovering Informatics [BM13] or the international Bebras contest on Informatics and Computer Fluency[128] provide examples how to comprehend basic concepts of informatics or how to discover problem solving strategies related to informatics in an unplugged way. Nevertheless, activities where learners start from and build on their imagination to develop algorithms meaningful to themselves have great potential to go beyond the important process of unplugged understanding. These activities introduce a distinct unplugged phase of planning and thinking and prepare for using computers, thus combine algorithms with automation. This step is essential for doing algorithms the informatics way, as C. Duchâteau puts it: "[…] the step of handing a task to a software based performer to have it solved is at the heart of algorithmics […]", because "A well set problem in this field must include the description of the task but also the complete and precise indication of the abilities of the performer that will carry it on. Otherwise it is impossible to write the procedure: You cannot have something done by someone (here something) if you do not know what he (it) can do." [Du93]. In other words: Computational thinking has to result in computational doing. This goes for primary education as well and requires choosing appropriate software.

[128] See: Bebras Contest at http://bebras.org/

A vast amount of experiences reported by others[129] and example activities in [CSTA11, CSTA11a] suggest Scratch to be the software of choice when introducing computational thinking. Furthermore, case studies regarding the principles of Northern Ireland's Using ICT initiative indicate how to connect to unplugged "algorithmic" activities like those already present in Austrian primary schools (see, for instance [NIC12], project 'The Egyptians'/St Colmcille's Primary School, Claudy). Additionally, the software Blinkenpaint[130][131] might be used in the first place to extend unplugged flipbook experiences when introducing computer based automation of sequential action. This software provides a 18 x 8 matrix of "windows", which can be clicked to switch the light on or off. Combining a series of blinkenpaint pictures produces a blinkenpaint movie (Figures 9 to 12).



Figures 9 to 12: Blinkenpaint storyboard[4] and corresponding movie (snippet)

Thinking of competences that lack at secondary level, a first approach to tailor computational thinking to Austrian primary education follows the maxim "imagine, think and plan first before you switch on the computer". Building on propedeutic exercises in the second grade, like those sketched above, it proposes the smooth introduction of computers in the third grade, accompanied and preceded by activities for "unplugged understanding" (see above), and further preparatory unplugged planning activities regarding the following areas (see [AGH13]):

Reading Comprehension (equals: Unplugged Processing of Information):

- Pupils read texts regarding topics of informatics (e.g. parts of computer hardware, people doing informatics) and answer questions referring to the reading content (see [Sch07] or [Fer11] for examples from other subject areas, at secondary level, though).
- Pupils read descriptions of simple computational algorithms and execute the algorithm "by hand" to demonstrate understanding.

Modularization/Face to Face Collaboration:

- Group-based summarizing of a story: Pupils are divided into groups, read or listen to a story longer than usual and have to summarize the plot. Each of the pupils is responsible for summarizing a specific part of the story. Aligning the summaries of the single parts yields a summary of the whole story. To avoid peculiarities at the interfaces, the first and the last sentence of each of the partial summaries can be provided.

[129] see, for instance, http://scratched.media.mit.edu/
[130] see http://blinkenlights.net/blinkenlights/blinkenpaint or
[131] http://www.sn.schule.de/~fischer/zeichen/blinkenlights/blinkenlights/blinken022.htm

- Group-based invention of a story with a given beginning and a given end: Pupils are divided into groups and each group member is responsible for one sequential part of the plot. In preparation for implementing the story with Scratch each group member should provide a drawing of the background and a description of the plot so that each group member is able to implement a part of the story invented by one of his or her colleagues as well.

Algorithmization/Formalization → Automation:

- Pupils provide a sequence of precise and unambiguous instructions for "everyday activities", for instance when giving directions to find the way (see unplugged exercises in [BW05] or [BM13] for further examples), or directing a robot (which is a common task of the Bebras contest on Informatics and Computer Fluency 132).
- Pupils develop step by step directions to calculate according to a known mathematical algorithm (e.g. adding, subtracting).
- Pupils describe movements by aligning Scratch-blocks that have been printed on paper and test each others "program".
- Pupils describe the action of a story by aligning Scratch-blocks that have been printed on paper.
- Pupils draw flipbooks to animate movements of stick-figures.
- Pupils draw flipbooks to animate images drawn in a matrix of 18 times 8 cells ("pixels") to prepare for the use of the Blinkenpaint-software.
- Basics of Computer Usage.
- Pupils deal with various forms of representing data using trees, e.g. a family tree, parts of the phylogenetic tree of animals, and the directory tree to organize data.
- Pupils learn how to navigate within the directory tree to load and store programs.

3.4 Too Little of Computer?

Digital devices are valuable tools to automate solutions imagined and properly described by humans. However, for various reasons computers play a minor role within the proposed computational thinking-based introduction of informatics into primary education.

Although there are some Austrian primary schools where classrooms are equipped with a sufficient number of computer workstations to focus on computer skills, this still is rather the exception. In most cases, only one or two computers are available for a whole class, which makes the computer at primary education an exceptional tool which has to be used deliberately on a time sharing basis. While a situation like that might be considered to be a drawback by media experts, it is a benefit when aiming at having the learners think and plan before turning to the computer. With a limited resource, learners have to have a precise plan what to do with the computer during the granted time-slot and there is little to no time left for dawdling. "Building upwards" this way meets the intentions of "planning downwards" form secondary levels point of view.

Second, an approach like that has great potential to motivate teaching practitioners at primary schools to engage in introducing fundamentals of informatics into teaching practice. With informatics not having been part of their teacher training, most teachers identify informatics with using a computer where they rely on their everyday skills to handle standard software

[132] See Bebras Contest at http://bebras.org/

tools. But from the viewpoint of informatics didactics introducing informatics at primary level has to go beyond that scope, which, in the minds of many teachers at primary schools, means to pass control on the process of teaching and learning to some – from their point of view – uncontrollable device. Raising the awareness that informatics stretches beyond computer usage, part of which is already part of teaching practice at primary schools, reducing the use of digital devices to the amount necessary and choosing easy to use software that makes it easy to get started (for both teachers and pupils) have to be considered important preconditions to raise acceptance for introducing informatics among primary teachers and to reduce the necessary amount of teacher retraining.

Most important, a media-reduced approach towards informatics complies with findings of brain research. M. Gurian and K. Stevens tailor these findings to the needs of teaching and learning at school and state: “Computers are an important element in the ultimate classroom, yet it is essential to be cautious about computer use for children under nine”. [GS11] They point out that

- “[…] attention-span problems in the present generation may be due to early brain attachment to mechanical stimulation […].”
- “Imagination functions of the brain […] do not grow as richly when young brains are attached to mechanical stimulants.”
- “Reading and writing functions […] develop more slowly if young brains are mechanized too early […].”

and recommend: “Often, a second- or third-graders’ brain is getting more than enough screen time at home and does not need more than a few hours of “computer research time per week at school.”

4 Resume and Outlook

Perception of the digital world is shaped by the view upon it provided by digital media and the way they are used. From the author’s perspective, among young people common use of digital media is confined to solving everyday “problems” concerned with communication or entertainment and needs hardly more than pressing appropriate buttons. Learning about new features is either a matter of trial and error or happens by means of show and tell among peers. In most cases, deep thought does not comply with the young generations view upon digital devices, the digital world and, correspondingly, informatics. Hence it is both desirable and necessary to develop a culture of informatics which centers around the awareness of digital devices (including the computer) being creativity-supporting tools. At the same time it has to be understood, that digital creativity typically has to be accompanied by understanding, thinking and planning. The decreasing age of first use of digital media suggest to start building such culture of informatics at primary age by putting the imaginatory power of children and the use of their brains into the first place and, consequently, by putting the use of digital media into the second place.

The proposed approach sketches a way to do so and will be put to the test throughout the upcoming academic year as a joint project between a school class at primary level and a class from a higher vocational school (higher secondary level). Learners at secondary level will only have the taste to introduce the younger childern to basics of computer use and to the software Scratch, respectively, while coaching of preparatory activities and further use of Scratch to enrich traditional learning will lie with the responsible primary school teacher.

This intended division of roles points at necessary advances in teacher professional development when considering topics of informatics proper at primary level. In the long term teachers at primary schools should be able to use the computer beyond todays common scope of ready-to-use software for special purposes or of everyday application software. To achieve this, future primary teacher education has to consider age appropriate aspects of informatics didactics. This includes a basic knowledge about the interactions between software, hardware, and networks, but profound knowledge about the possibilities of meaningful interaction between digital devices and children at primary school age. The latter includes deep pedagogical understanding about how and when to use computers to sustainably foster the children's productive creativity when dealing with digital devices and/or media.

Missing this point might indeed cause "Europe [becoming] a mere consumer of technologies designed elsewhere, running on devices also manufactured elsewhere." [JIE13]

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