# An Analysis of Teaching Informatics by Means of Enactive-Haptic Representations

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Abstract: The subject of computer science is gaining more and more important. But how are computer science concepts taught? The use of enactive-haptic representation can be an option, which is however quite unknown in computer science education. Partly, this is due to the fact that enactive-haptic is a blurred concept, which is not easy to grasp in the context of digital technology. In this paper, the term enactive-haptic is analyzed in the context of computer science. The resulting model and its usage are sketched in this paper.

## 1 INTRODUCTION

Nowadays, a lot of people call for education in the field of Artificial Intelligence (AI) in school education, accompanied with the claim that kids should learn up-to-date technology (C. A. Heinze, 2010).

However, we have learned in different investigations, that first of all, teachers are not enough educated to teach AI, and second, AI in itself is not a technology but an application of technology. Our opinion is that schools should rather educate kids in the field of basic science insights and not hot topics, which occur and vanish over the course of time (just remember: AI has been a big thing in the 1970s).

Instead of marveling about the ”next big things”, students should understand timeless, fundamental ideas (Schwill, 1993) of computer science (or informatics, which in the German version is the most used term in Germany). To allow education of the fundamentals of computer science, an agreement has to be found, what these fundamentals are. In Germany, the politicians and Universities who educate computer science school teachers have a while ago agreed to a certain form of curriculum, which we call the Rahmenplan. Herein, it is fixed that shall be taught when and how. As modern technology develops over time, the University of Rostock and the country Mecklenburg-Western Pomerania have just recently agreed to make a modern form of this curriculum (Rahmenplan), which is putting the finger on the set of fundamental concepts, which very likely will be the main corpus of computer science in the next twenty years. Thus, we think it is currently more important in our perspective, that school kids understand what an algorithm is, instead of learning about AI (which in the core is also algorithms). Moreover, after so many years of computer science school education (we had this for over 30 years), we are sure that is useful to unlock from current tools. Thus, one insight resulting from this approach is that computer science education works best when the underlying concepts can potentially also be understood without any tools! This is called the unplugged approach (Gallenbacher, 2017).

However, even the unplugged approach does not come without didactic or instructional design. Thus, we looked closer at the different ways to offer material to school kids on the best interactive level. Here we find the traditional educational idea of distinguishing between enactive-haptic, iconic and symbolic (Bruner, 1970).

The use of enactive representations could be an appropriate way to get a deep understanding of abstract ideas. The use of enactivities in computer science has already been taken up by Bell (T. Bell, 2005) – for example Treasure Island or The Orange Game (T. Bell, 2005) – and Gallenbacher (Gallenbacher, 2017) – for example Binary Magic. Gallenbacher also hosted an exhibition on enactivities in computer sci-

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ence. (Hugh, 2010) At the University of Rostock, a pilot project was developed in which student teachers ”present computer science in an exciting way” (L. Göbel, 2019b) by using enactive-haptic representations.

However, investigating how teachers work in school and prepare their material, we were surprised to learn that the enactive-haptic approach is seldom used. The same was also observed some years ago by other researchers. In 2011 Kalbitz et al. published a paper about the use of the (Enactive-Iconic-Symbolic) EIS principle in computer science lessons by Berlin teachers. The data from 40 surveys showed a lack of using enactive representations, although the EIS principle was known by the teachers. Enactive methods were used less by the respondents than iconic methods. One reason was, that the teachers hardly knew of any alternatives (M. Kalbitz, 2011).

In the beginning, a literature study was conducted to determine the current state of research on enactive-haptic representations. After that, we came up with different categories or model of enactivity, which are described in this paper. We tried to make an order between the categories and the existing approaches, which was successful and will be described in the following.

## 2 THE ROOTS OF ENACTIVE-HAPTIC REPRESENTATION

First of all, it has to be clarified what enactive-haptic representation really is. As a second step, a survey will be conducted in which the focus will be on the use of enactive-haptic representations.

The concept of enactive-haptic representations in the classroom is based on the psychology of learning. Three main steps that over time led to the idea of enactive-haptic learning, are briefly outlined.

The first well-known approach can be traced back to Piaget described an approach to the cognitive development of children through the theory of genetic epistemology (genetic in this context means a kind of development, in this case, the cognitive development, but also the general epistemic development in human beings). Depending on the age of the child, four phases are distinguished – sensorimotor phase, preoperational phase, concrete-operational phase and formal-operational phase. ”Piaget was convinced that children ”construct” their schemata through their interaction with the environment”, said Mietzel (Mietzel, 1998). Thus, Piaget was one of the first who focuses on interaction with material as a means of learning, which directly leads to the creation of cognitive relations (admittedly, the concept of cognition stems from a later period, as Piaget’s first works were all related to behaviorism). As the second in the row, Aebli paid more attention to the process of education and teaching and abstracts from the age-specific model. He described three main stages: the concrete, the pictorial and the symbolic stage. In the concrete stage, work is done with concrete objects and materials. In the next stage – the pictorial stage – objects represented pictorially are operated with. In the symbolic stage, objects and operations are represented by signs. The stage transitions are realized by reflecting on one’s own activity, verbalizing the action, or by practice (Aebli, 1985).

This step-wise approach by Aebli was taken to a new level by Bruner, here the third one in our short history of ”enaction”. With his enactive-iconic-symbolic-principle (EIS), Bruner describes the different ways of representing knowledge and skills. A distinction is made between the enactive, iconic and symbolic levels of representation. The modes of representation refer to each other reciprocally and exist on the same level (Bruner, 1970).

And now, the relation becomes clear: enactive means in this sketched tradition that learning is best taking place by using the human senses to interact with the learning material. Enactive-haptic thus focuses on the usage of the sense haptic in the context of learning, which mainly means: touching and interacting with the material.

Coming to this point, we had to ask ourselves, how this can be realized in Computer Science education? This question has been answered by several other researchers before, mainly in realizing approaches like the unplugged model or other comparable ”hands-on” material. But still, the concept is somewhat hard to mediate to teachers-to-be. What confused them can be mainly reduced to aspects like what is meant by haptic in computer science is imitating the teacher’s enactive, must the kid find it out all by themselves, how much information must or can be embedded in the material, what can I do if a kid is stuck?

So, the process of clarifying the concepts of enactivity and representation requires a more detailed analysis. What is required is a collection of ways the school kids (the students) interact with the material, which also represents the way a learning gain is made, and which its core represents the advantage of the method in relation to other methods. The interaction level can contain attributes like imitate, try out, explore, listen, watch, try out and listen and the like. Additionally, a spacial level exists: here the distinction can be made by answering the question whether the room plays a role or not, and if it plays a role, then how can this be realized? We located two major levels in the investigated enactive-haptic examples, which led us to the distinction between the immediate level and the mediate level. The mediate level can itself be further separated into two additional levels, which are the first-order hybrid representation and the second-order hybrid representation. These will be explicated in the following.

The immediate level consists of the interaction level, which are touching, interaction with things, etc. Learning takes place by doing and the spacial level is given by the radius a student has for the interaction types. Entirety, minimally invasive and interpersonal representations are part of the immediate level.

The mediate level consists mainly of something we would call virtual. With this, we mean everything where the student has to internally visualize things without direct haptic feedback by an artefact. For this purpose, the student uses his or her auditive and visual sensory systems but has nothing to touch. The mediate level describes enactivities that are less direct. Regarding spatial representation, the objects referred to are not part of the student's environment. The computer can be a means of visualization, thus, the representation comes in form of a medium. Hybrid representations of first-order and second-order are part of the mediate level. Specifically, the students get visually in touch with the activity. Every activity from the immediate level can convert into the mediate level.

Figure 1 shows the different levels with their meaning.

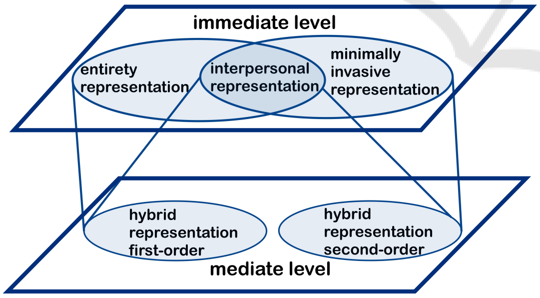

Figure 1: Representation of enactivity.

# 3 USING ENACTIVE-HAPTIC REPRESENTATION IN COMPUTER SCIENCE EDUCATION

This research examines the current state of the art of teaching computer science (or informatics) concepts by means of enactive-haptic representations.

## 3.1 Entirety Representation

View two examples ”Treasure Island” by Computer Science unplugged (T. Bell, 2005) or ”Von-Neumann-Principle experience” by Göbel, Hellmig (L. Göbel, 2019a).

Treasure Island is a ”game” to teach the concept of a finite state automaton. The classroom is constructed in a way that it represents different islands in an ocean. Pirate ships are sailing from island to island. The pirates take travelers – the students. That way the students want to sail to Treasure Island. From each island, only two different pirate ships are sailing. The students get a map on which they draw the route. (T. Bell, 2005)

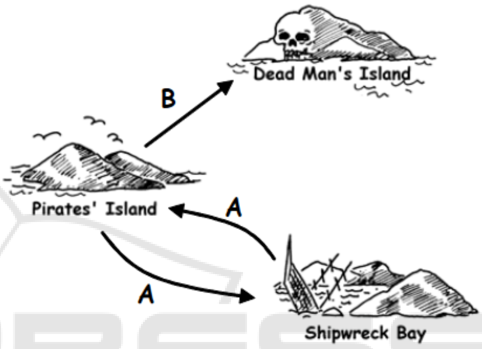

Figure 2: Part of the result map (T. Bell, 2005).

The result of the map shows a finite state automaton with two state transitions. After that activity, the teacher and students discuss the result and formalize the definition of a finite state automaton (T. Bell, 2005).

The experience of the von-Neumann-Principle is a ”theatrical performance”. The classroom symbolizes von Neumann's architecture. The students are elements of this architecture. They run through all stations. In that way, the students run a program of von Neumann architecture. They see that all tasks are processed one by one. So for example they can directly experience the von Neumann bottleneck. The teacher moderates this activity (L. Göbel, 2019a).

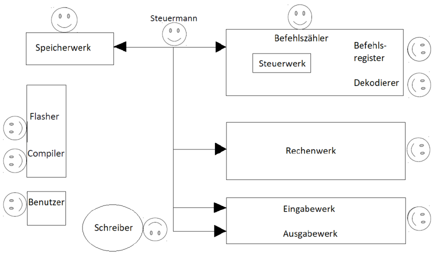

Figure 3: Classroom of the Von-Neumann-Principal experience (L. Göbel, 2019a).

After that ”theatrical performance”, the class summarize the concept of the von Neumann principle as a fundamental idea of computer science.
Both examples have a similarity. This representation describes the classroom or environment of the students as a part of the interaction dimension. The students are also a part of the interaction dimension, as they play the role of an entity of the ”simulation”. Mostly the teacher is a moderator or observer. After the ”theatrical performance”, the teacher (together with the students) evaluate the results and explicated the underlying computer science concept. That enactivity is called entirety representation in our analysis. It is taught in an immediate way. Things are directly (haptic) explored and bodily experienced.

### 3.2 Minimally Invasive Representation

The next examples are the magic trick of binary system by Gallenbacher (Gallenbacher, 2017) and text compression by Computer Science unplugged (T. Bell, 2005).
The magic trick is a paper model sheet of 36 cards with an ”X” and on the other side, an ”O”. A student orders 25 cards of the sheets in a random square. The last 11 cards are placed in a bigger square by the teacher or wizard. The teacher or wizard looks away while the students pull one card around. After that, the teacher or wizard shows the inverted card. The audience has to find out why the wizard knows that. The students have to develop their own theory about the trick. They have to check how many ”X” and ”O” are in a row and column. In this way, the students learn error detection and how many errors can be detected. (Gallenbacher, 2017)

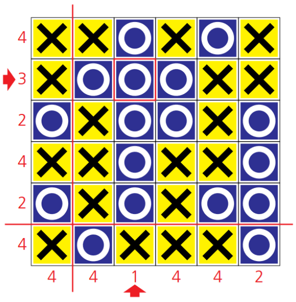

Figure 4: Error detection (Gallenbacher, 2017).

Error detection is included in the checksum algorithm. For example, credit cards have a certain number. This number includes a checksum algorithm. After finishing the test, these aspects are highlighted by the teacher who resumed the computer science explanation.

The second example is based on the limit of information. An efficient way to save or send information is compression. The activity starts with a poem. As a first step, the words can be compressed by putting arrows between identical patterns. In the next step, the students complete a text by using the pattern. So the text is compress(T. Bell, 2005).

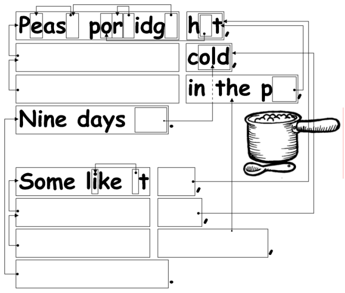

Figure 5: Text compression (T. Bell, 2005).

The compression of data is an important fact of data transfer, for example, the pictures in social media are compressed. Same as above, this is summed up after the experiment by the teacher and brought together to mediate the computer science concept.

The similarity of both examples is the way the material is used. The students edit the material at their desks. They can interact with haptic material individually or in a group. The teacher is a moderator or observer. This form of representation is called minimally invasive representation. It is teaching in an immediate way. The main difference to the first example is that the students are not part of a ”simulation”, and the haptic information has no additional bodily experience level.

### 3.3 Interpersonal Representation

Examples of interpersonal representation are the network by Helfrich (Helfrich, 2017) and the Orange Game by Computer Science unplugged (T. Bell, 2005).

The network by Helfrich uses pegs and flashcards. The students act as different routers which want to communicate with each other. So they write a flashcard with sender, addressee and a message. The flashcard is fixed with a peg on a thread. The network grows after every iteration. So the students learn the basic idea of communication between routers. (Helfrich, 2017)

This enactivity version shows different topologies of networks and how they route information. Real networks are built according to a certain topology, depending on their task. This information is provided again by the teacher after summing up the results. Usually, information about what a router is is given

Figure 6: Network design with peg and flashcard (Helfrich, 2017).

in a lesson before the enactive work.

The Orange Game mediates routing and deadlock in networks. A group of students sits in a circle. Each student has a number. There are two oranges (indeed the fruits are meant. Balls might do the same.) with the same number for each student. The oranges randomly distribute to the hands of the students. One student has only one orange. The students pass the oranges to their immediate neighbours till every student has their member oranges. (T. Bell, 2005)

The students learn that they have to work together and not be "greedy". (T. Bell, 2005) The fundamental idea of that game is the deadlock. The deadlock is part of processes.

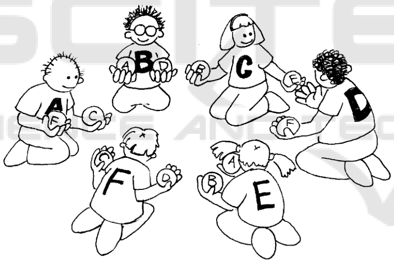

Figure 7: The Orange Game (T. Bell, 2005).

These examples focus on the haptic exchange of things between students. The environment of the students does not matter, thus it is a combination of entirety representation and minimally invasive representation. The students are a part of the activity. But the activity does not fill the complete room. The students can get allotted materials. This representation is called interpersonal representation.

### 3.4 Hybrid Representation First-Order

The next example is the treasure hunt by RWTH Aachen University. A website includes a simulation to find a treasure. The necessary material is hidden in different towns which are positions in the classroom. The students solve encodings. In that way, they learn how different coding systems work. The simulation at the computer supports the treasure hunt. (N. Bergner, 2020) The treasure hunt shows different symmetric encodings. Encoding is an important procedure to keep messages secret. The students learn how secure that procedure is.

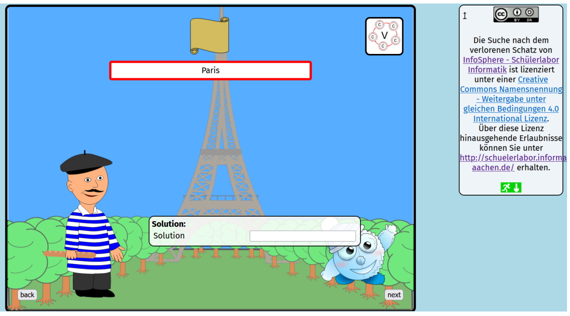

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Figure 8: Treasure hunt (N. Bergner, 2020).

That enactivity has a different level than the former examples. The computer is included in that activity. So, the level is switched. It is on a mediate level. Because of the shift of the haptic, it is a hybrid representation of the first-order. The first-order hybrid representation is a combination of the use of a computer and haptic material.

### 3.5 Hybrid Representation Second-Order

The last example is the movie "Technology on the Internet" by dandelion. The clip shows a haptic option of run-length encoding. There are little men who call the numbers "zero" or "one" dependent on the encoding. So the clip shows how a picture will send from a scanner through the internet. (ref, 2022)

The idea of that film shows an option of a compress to transfer data.

The film shows a haptic representation. This haptic is produced in the mind of the audience. They can imitate that encoding. That representation is at a mediate level. It is a combination between a video recording and an immediate level activity. So it is called hybrid representation second-order.

## 4 OUTLOOK

The term enactive-haptic representation has been the starting point of the research sketched in this paper. We have started with the insight, into why enactive-haptic realizations are so seldomly used in classroom settings. We came to the point that the overall concept might be too coarse-grained when it comes to computer science, as the main parts of the subject are abstract and not easy to grasp in a hands-on scenario.

After the first steps towards the categorizations, we resulted in different instructional (or didactical) models of education based on the enactive-haptic perspective. In each of the above sketched different approaches, it becomes quite clear, where interaction takes place, which role the spacial dimension has, and which forms of enactivity can be realized. The yet existing examples for educational scenarios all fit into the schema, as shown above. Starting from this point, all the necessary ingredients for developing different types of enactive lectures are available and thus might potentially be used for instructional design in computer science. However, what is still missing is the reality check. Thus, we are currently developing a questionnaire and potentially interviews with computer science teachers at schools. In contrast to Kalbitz et al. (M. Kalbitz, 2011) we will operate more differentiated by categorizing the enactivity and a higher number of cases.

When investigating the form of interaction the focus of the questionnaire is on the following questions: ”What is the state now?”, ”If enactive-haptic representations are used, why and how?” The term ”enactive-haptic” will probably be unknown, so the query must be made via other questions or methods. The scope of the teachers’ survey should include a spectrum of teachers as broad as possible, which allows a cross-sectional and longitudinal approach.

In the following, the methodological procedure will be worked out. Criteria for determining a selection of subjects must be formulated. First, there should be a preliminary study, from which a guided interview can be derived. Second, a survey is to be conducted in Mecklenburg-Western Pomerania, since this was the first federal state to introduce the compulsory subject of computer science and media education (R. Schwarz, 2022). It is possible to extend the survey to other federal states with the help of a questionnaire. Subsequently, an evaluation can be carried out, which should lead to the formation of hypotheses. An outlook for further research can be worked out. Furthermore, the results should show where further training is needed.

Another next step will be to detect how to educate teachers and teachers-to-be (i.e. students) in using enactive-haptic representations and realizations. One option could be targeted training and vocational training for teachers, where we have a broad experience in our lab.

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