Research Article

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Begreifbare Learning Environments

A Framework of Interaction Design for Reflective Experience

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Abstract: We propose a framework of Interaction Design for Reflective Experience (RED). "Begreifbare" (graspable, in the sense of tangible and comprehensible) learning environments embody a designed experience that combines abstraction and concreteness, perception and cognition, and thus emphasizes both the impact of tangible, embodied interactions and the importance of symbols and signs for reflective experience. Our framework is based on the categories of space and experience, model and reflection.

Keywords: tangible interaction, education, digital learning

1 Introduction

In this paper, we present a framework of Interaction Design for Reflective Experience (RED). RED is a design approach that emphasizes the potential of digital media to interlink perceptible interfaces and programmability to evoke a reflexive attitude in learners, enabling them to anticipate, interpret, and reflect on the content of digital media and the media itself through an interactive process. This framework is suitable for "begreifbare"[1] learning environments, especially if "begreifbar" is understood as graspable in its dual sense of both tangible and comprehensible. Software developers build abstract models of reality that machines process automatically. How can the models used in programming software become tangible and comprehensible again?

We follow the constructionist approach proposed by Resnick and Silverman [23] for designing construction kits for children, but extend this approach beyond the specific application to construction kits. There exist several similar frameworks to ours:

1. Alissa Antle [3] described the "Child Tangible Interaction" design framework, which conceptualizes how the unique features of tangible and spatial interactive systems can be utilized to support the cognitive development of children under the age of 12.
2. Paulo Blikstein developed a framework for bifocal modeling that combines computer modeling, robotics, and real-world sensing based on "pilot studies that suggest a real-to-virtual reciprocity that spurs further inquiry toward deeper understanding of scientific phenomena" [4].
3. Mike Eisenberg developed principles for "Computationally-Enhanced Construction Kits for Children" [13].

Compared to the aforementioned, our framework offers a more abstract and general approach. It is embedded in constructionism [22] [15], learning by design [8] as an approach to digital learning, and action-oriented didactic approaches [27]. Based on the psychological theories of Edith Ackermann [1], we argue that the interaction design of the learning environment should provide rich sensory stimuli that enable learners to have constructive learning experiences with the subject matter at hand. At the same time, these sensory experiences should evoke reflection on the particular subject matter, because understanding requires not only exploration but also abstraction and model-building. Following Bolter and Grusin [5], we assume that interactive digital media have unique potential because of the special relationship that exists between abstract models implemented in software programs and in sensorily perceptible interfaces. The RED framework thus fosters "Begreifbarkeit", or graspability, a concept whose meaning encompasses not just tangibility but also comprehensibility [21].

Our ideas are based on an analysis of theoretical concepts and on the development of various prototypes fol-

1 We use the German word "begreifbar" here because it encapsulates and emphasizes the dual meanings of tangible and comprehensible.

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lowing a *design as research* [26] approach. By evaluating prototypes in the context of workshops with children, we sought to derive general principles for interaction design in digitized educational contexts [16] [14]. From these principles, we extracted the four categories of model, space, experience, and reflection, which are intertwined in circular as well as reciprocal relationships. Our concept of Interaction Design for Reflective Experience (RED) in digital media focuses on clarifying the relationship between the importance of experience and the prominence of symbols and signs for reflection. A core element of RED is questioning the concept of the invisible computer. Based on ideas proposed by Bolter and Gromala [6], we postulate an notion of transparency in which an awareness of the media fosters the learner's understanding in two dimensions:

1. It promotes *Computational Thinking* [28] and *Digital Literacy* [7].
2. It supports an in-depth understanding of the underlying subjects of learning.

In this paper, we present the framework and give a short explanation of its theoretical underpinnings. To make the abstract framework more understandable, we explain its concrete application in one workshop held as a case study.

2 Case Study: The Workshop "Pimp Your BMX"

We developed and evaluated our framework in a theory-driven iterative process through a series of workshops with children and adolescents, which followed a design-as-research approach. Describing this procedure in detail would go beyond the scope of this paper. Instead, we describe how our ideas played out in one workshop for 12-year-old children, "Pimp Your BMX", as a means of illustrating how our framework can be applied. The learning environment in this workshop consisted of an indoor skatepark and a "FabLab". The task was to teach BMX biking in a skatepark and to design, construct, and use gadgets that would be able to model one aspect of the movements involved in BMX biking. The approach was to create the prototype of a gadget, evaluate it in an iterative process, and improve it.

We started with an introduction to BMX biking in the skatepark. The coach instructed participants in their first exercises in riding and jumping. In the process, the participants immersed themselves in the movements involved in this athletic activity. Afterwards, they had to develop initial ideas for gadgets. During this first phase, there were no technical restrictions—the only limits were those of their own imagination. In the next phase, the available technology was presented for participants to explore: sensors, actuators, a Calliope[2] microprocessor, and the associated block-based programming environment. The participants experimented with pre-built gadgets, formulated hypotheses about the underlying algorithms, and were allowed to change the algorithms using the programming interface. Through these activities, they familiarized themselves with the technology that they would use for their own gadgets and the basics of programming. They then alternated between riding their bikes and constructing their gadgets, thereby improving their skills in biking and increasing the complexity or precision of their gadgets. This process was organized in such a way that participants could go through phases of "diving-in" (having experiences) and "stepping-out" (reflecting on experiences). At the end of the workshop, each group of participants showed their skills in BMX biking and presented the gadgets they had worked on. They had to demonstrate the model they originally had in mind, what they had been able to achieve, and how they did it.

A variety of bodily movements were involved in the construction process. While constructing the devices, the participants had an opportunity to consider a given movement from different points of view. They extracted mental models from physical measurements of movements and transformed these in a step-by-step process into a physical model that they implemented in their gadgets. One of the gadgets developed measured speed, and another measured the height of a jump. As such, the participants built a model *of* a sports movement (riding quickly, jumping high) and *for* the measurement of this movement.

As they constructed the gadget, a hybrid artifact incorporating both handmade and machine-made processes, the young participants learned digital literacy. But at the same time, and equally important, they also engaged in subject learning (about movement in sports). When they had to program their gadget, they first had to observe their own movements as they engaged in the sports activity to determine the requirements of the model that would build as a measurement tool. But in the process of design, as they improved their gadget, they had to focus on the model to derive the requirements for movement measurement in sports. They had to link the space of the skatepark to the space of the FabLab, and thus interconnect the physical and digital spaces.

2 https://www.calliope.cc/

3 The RED Framework

In order to examine the ideas outlined above, first, we analyzed how the models used in software development and in subject learning are intertwined. Second, we scrutinized how people experience and reflect on digital spaces within learning spaces (see Figure 1). Our underlying assumptions were that:

1. The individual's own development, programming, and implementation of models through thoughtful reflection enables the construction and experience of digital spaces.
2. Based on reflective experiences in the digital space, the programmable models and algorithms implemented in the digital space become accessible.

In the workshop "Pimp Your BMX", participants engaged in learning on two levels:

1. Participants had to develop their own gadgets for the BMX. In doing so, they gained insight into different perspectives on the digital space—not only the code space of the artifact, but also the surface of the programming environment—and developed an understanding of the relationship between the code space and the physical space.
2. As they experimented with the sensors and actuators, as well as with the Calliope programming environment, participants gained an understanding of the underlying algorithmic principles.

In both cases, the analysis of the model is intertwined with the analysis of the underlying subject matter. Based on these considerations, we developed the framework described below.

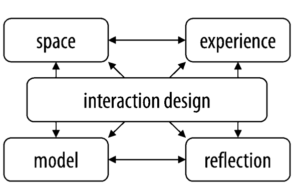

Figure 1: Interaction Design for Reflective Experience.

3.1 Space

Learning environments have diverse spatial qualities: the physical space of the learning environment, the physical space of the learners' everyday life, the representational space of networked digital devices, and the space of the specific subjects that students are learning, which can be programmed in the software [9]. The interaction design of learning environments therefore requires competence and skill in translating between heterogeneous perspectives, dimensions, and spatial representations [24]. In the BMX workshop, participants experienced different environments: the skatepark, the FabLab, and the programming environment. As they built their gadgets for the BMX, they had to represent the movements of the bikes in a programmable model and thereby bridge the gap between physical and virtual models. This required a theoretical concept of space. We opted for Henri Lefebvre's theory of the *production* of space, which explains the intermediation between the spheres of sense (meaning) and senses (perception), experience, and reflection [17].

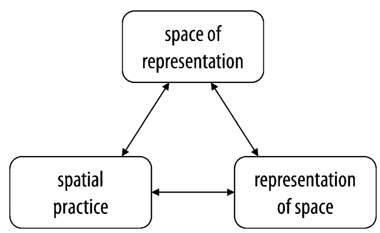

Figure 2: Lefebvre's Triad.

Key to Lefebvre's theory is the view that the production of space can be divided into three dialectically interconnected linguistic or semiotic dimensions or processes: the triad of "spatial practice" (e. g., the perceived interface of a mobile device), "representations of space," (e. g., the invisible program code), and "spaces of representation" (e. g., the Internet). Lefebvre defines a corresponding phenomenological triad: the "perceived", "conceived", and "lived" space. The children in the workshop experienced the "perceived space" of the skatepark by learning BMX biking, and they constructed a "conceived space" using the different model representations for the gadgets. Through multiple iterative experiences with various prototypes of the gadgets, they became immersed in the "lived space", a representation of space.

Building on Lefebvre's theory, one can derive several recommendations for interaction design in the subject learning context. Interaction designers of hybrid digital learning spaces should think of space not as an empty container to put things in, but as an environment that is historically constructed, in which complex transformations occur. They should therefore:

1. Design an open space for learning that promotes social interactions among learners, practitioners, and teachers.
2. Design a space of mixed realities, in which physical and virtual worlds unfold as they are experienced.
3. Design a space for programming and hacking.
4. Design a space for experience and reflection.

3.2 Model

Educational media or designed learning environments should have the evocative power to motivate learners to explore the models implemented or to construct and program their own models of objects, spaces, or processes. The interaction designer therefore needs a sophisticated model theory. For “software models”, a particularly useful model is Mahr’s theory, with its distinction between the “model of” and the “model for”. It enables differentiation between the domain of reality, which has to be observed in order to extract the requirements for the model, and the domain of the software application. Furthermore, models are conceived as artifacts that transport something from one place to another by certain means. The situation depicted in Figure 3 is that of the conception of model M (represented by the model object MO) as a model *of* A and *for* B, thereby carrying the cargo *from* A *to* B [18] [19] [20]. In this sense, the model object is “charged” or loaded with the cargo as an abstract description that can also be applied to a concrete object (which means “discharging” the model).

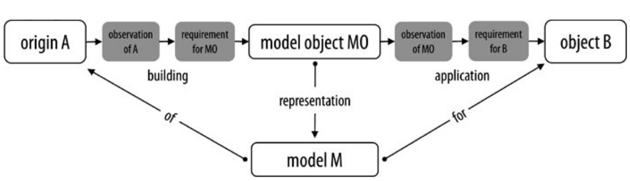

Figure 3: Modeling-Of and Modeling-For in Mahr’s Model Theory.

In our example of BMX biking, the gadget developed is a model *of* sports movements and a model *for* measuring sports movements. Computer sciences deal with abstract scientific models, which may at first appear to exist in a different dimension from the sensual and figurative realm. But when processed on a computer, these models are translated into visualizations, which constitute new forms of virtuality with which we can interact. When transferred into the realm of computer-processed digital environments, scientific models enable sensory experience of abstract relationships. Learners can only gain the ability to reflect on such questions when the design and programming of digital artifacts becomes part of the learning process.

Interaction designers of hybrid digital learning spaces should foster learners’ ability to transform mental models of the subjects they are learning into functional models for experimentation. Our results support the following recommendations:

1. Design possibilities so that the learners are aware of the difference between what the model object serves as a model *of*, and what applications it is a model *for*.
2. Design the learning environment in such a way that learners are aware not only of the model’s potential but also of its limits.
3. Design the program environment for learners in such a way that they can easily implement models of the subject they are learning.
4. Design digital simulations that allow learners easy access to important parameters of the model used to design the software.

3.3 Learning Through Experience and Reflection

In designing interactive learning environments, we refer to an understanding of learning as a process of interaction between individual and environment. Learning activities relate to both manipulating the material environment and cognitive processing. Experience and reflection play a crucial role in this context, because learning is conceived of as developing knowledge and competencies on the basis of experience.

3.3.1 Experience

Experience comes about through engagement with the world. John Dewey emphasizes the interactive and continuous nature of experience: the individual acts upon an object or an artifact, and the object has a “rebound” impact upon the individual. This continues ad infinitum: new experiences are influenced by former experiences and also affect future ones [11]. Experience “is ‘double-barreled’ in that it recognizes, in its primary integrity, no division between act and material, subject and object, but contains them both in an unanalyzed totality” [10]. Experience is gained through both explorative processes and planned, calculated approaches. Learning, as the development of subject-related cognitive structures, requires that the individual becomes consciously aware of experiences and then make these experiences meaningful through learning activities that use signs and symbols, e. g., anticipating, connecting, interpreting, reflecting, appropriating, and recounting [29]. Experiential learning therefore implies the need for learners to engage directly with their environment and to construct sense actively.

To design for experience, interaction designers of hybrid digital learning spaces should:

1. Design learning environments in such a way that they allow learners to experience the real context of the subject they are learning.
2. Design interactions with artifacts that allow learners to experiment and think with them.
3. Design situations that evoke reflection.

3.3.2 Reflection

As outlined above, knowledge is created through the transformation of experience: It results from the combined process of grasping experiences and constructing meaning out of them. We understand reflection as a meaning-making process, "that moves a learner from one experience into the next with a deeper understanding of its relationships with and connections to other experiences and ideas" [25]. This process is propelled by gaining distance from the experience ("stepping out") and acting in a symbolic manner, e. g., making a sketch, writing an observation, formulating a hypothesis, or identifying relationships to other experiences. This means reconstructing or restructuring the experience and integrating it into cognitive structures. This is what Dewey refers to as reflective experience [12].

Educational media should provide children with possibilities for rich experiences with objects, tools, and media in a learning space. The objects and tools should not only be tangible, they should also be understandable, i. e., begreifbar. Designers and developers should create media with the internal quality of stimulating learners' experiences with and reflection on the subject they are learning.

Reflective observation leads to abstract conceptualization. This points to the recomendations:

1. Design learning environments that facilitate phases of "diving in" and "stepping out".
2. Design for modeling and reflection by fostering iterative phases of improvement, whereby each new phase is based on reflection on the preceding phase.

4 Begreifbare Learning Spaces as Reflective Experience

Learning cannot be organized as a progressive movement from the concrete to the abstract, because knowledge always emerges from the "back-and-forth" between concrete action, development of visualizations and images, and abstract conceptions. Ackermann argues that cognitive growth has to be understood as an ongoing dance between "diving in" and "stepping out" [2], and describes this important alternation between engaged immersion (experience) and adopting a "God's-eye view" (reflective experience) using the example of perspective-taking, which is required to explain the appearance of an object from different vantage points.

Encouraging an ongoing dance between "diving in" and "stepping out" requires a design for reflective experience in educational media that allows learners to understand the relation between concretion and abstraction as a process of ongoing mediation, and not as a linear, progressive process. Interaction with educational media combines immersion in calculated worlds (digital space) with reflection on abstract models. The relationship between bodily interaction and symbolic comprehension goes beyond a mere dualistic combination, confrontation, or comparison between the sensual and the conceptual. It is neither an unambiguous conjunction between complementary spheres, nor an unambiguous disjunction between dissimilar or opposing spheres. We view this complex, multifaceted relationship as a chiasma: an intersection of abstraction, concretion, perception, and cognition.

For educational media, this means that designers have to configure interactive interfaces that allow an ongoing "dance" between assimilation and accommodation and that foster the experience of difference through the occurrence of unexpected, surprising events. Learning environments should allow for reflective experience on recursive algorithms in experimental systems. In such systems, the programmable medium should provide perceptible interfaces that make use of the potential for programming. They should not hide the gap between the concrete and the abstract, but rather configure abstract cognition and con-

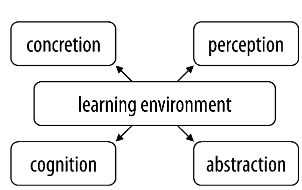

Figure 4: Chiasma of Experience and Reflection.

crete perception as an interwoven chiasma of abstraction, concretion, perception, and cognition.

5 Empirical Remarks and Conclusions

We presented a framework of Interaction Design for Reflective Experience in which we outlined the underlying theories and extracted principles for designing learning environments. We applied this framework in several real-world scenarios. The results of our evaluation, which cannot be reported on here in exhaustive detail, show that the iteration of designing, reflecting, implementation, and coding are conducive to even more detailed models. Both on the functional side, in particular in the form of programmed models, and on the mental side, a continuous improvement in the models can be observed. On the mental side, the ongoing alternation between "diving in" and "stepping out" and continued support for reflection in the "stepping out" phases using videos became evident in how the participants developed and planned their construction process, and in their posters depicting their design ideas.

The framework of Interaction Design for Reflective Experience (RED) in educational contexts presented here draws on a general approach to interaction design in learning environments. We discussed theoretical concepts of space, model, and reflected experience that can support interaction designers in investigating the fundamental relationships that arise in learning environments. We formulated basic principles for interaction design, but refrained from providing specific guidelines. Our framework is appropriate for the interaction design of environments to foster experience, especially for "begreifbare" learning environments. It is not applicable to teacher-focused, instructionist learning.

We discussed the framework of Interaction Design for Reflective Experience with experts in various workshops on the design of learning environments. We hope to receive continued feedback from this community in the future.

6 Selection and Participation of Children

All children participated voluntarily in the workshops. During each workshop, we placed cameras in the corners of the room and audio recorders on some of the tables to record the discussions and activities of each group. The tutors instructed the children, who were between 10 and 13 years of age, and guided them through the construction projects and BMX activities each day. All of the children gave verbal consent to participating, and their parents signed consent forms prior to video and audio data collection. All data were anonymized.

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