3.3 The History of Adaptive Assistant Systems for Teaching and Learning

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When designing an Adaptive Assistant System for teaching and learning, a look at the history of these systems is informative. One of the interesting aspects is the impact of programming techniques that were fashionable at a time on the conceptualisation of Adaptive Assistant Systems.

If feedback is considered as a criterion for automated support in learning, the device presented by Pressey in 1923 was the first teaching machine In his paper, Pressey stated that the device should not replace the teacher, but "make her free for those inspirational and thought-stimulating activities which are, presumably, the real function of the teacher" [77]. Skinner, who picked up Pressey's design as well as the foundation in the theory of Thorndike, also considered this limitation of machine support in learning [92]. While Skinner applied feedback mainly as reinforcement in linear learning programs, Crowder's setting of intrinsic or branched programming offered a different feedback. His machine generated an individualized learning pathway [20] when a learner failed a test in a way that reflects the development of block-structured programming languages. The different learning pathways included additional content and explanations concerning the error, while individualization did not mean that the learner could make choices of his own.

This concept has become famous under the label programmed instructions [30] and is still used often. The concept is mainly based on tests that can be analyzed automatically. Today, this concept is called adaptive since current applications adjust the amount of tests, the available time for learning, the difficulty of questions, waiting times and hints while learning [53].

This first individual learning path component was extended by adaptive systems in the 1960s and 1970s [72]. Adaptive systems added a more sophisticated dialogue component to the programmed instruction systems and thus reflected the development of dialogue systems. This concept of adaptive systems is still developed today [34]. From a present-day perspective on programmed instruction, the connection between the actual machines and the theoretical concept is obscure on the one hand and many charges against behavioristic concepts are hardly sustainable on the other hand [52]. Maybe the second argument explains why behavioristic concepts are successfully applied in therapy today, but hardly in teaching and learning.

One example are the algorithms that have been developed by Brusilovsky et. al. [10, 47]. The system developed by Brusilovsky et al. is used to teach Java. The algorithms developed by Brusilovsky and Hsiao allow for setting test question parameters. Questions are calculated. According to test results, links for students are adapted by showing colorful targets. This matches the concept of branched programming.

While this concept is a good idea for an introduction to a programming language, it is hardly possible to calculate variations of test questions that can be analyzed by algorithms in other fields. Educational theories, for example, can not be taught that way. Additionally, epistemological questions have not been considered by Brusilovsky et. al, since differences among functional, procedural and object oriented programming are not taken into account. Different teaching methods are not considered at all. As a consequence, dynamic learning pathways can not be created. The system offers all information for free navigation and considers the freedom of the learner this way. But it can not be transferred into other fields. And it is not possible to design learning pathways that do not contain tests that can be analyzed by an algorithm with this concept.

A second group of concepts applies algorithms that are based on the idea of artificial intelligence and suggest Intelligent Tutoring Systems. It is necessary to say a word on the term artificial intelligence from an educational point of view here. First, as we already stated for learning, intelligence in the term artificial intelligence has another meaning than intelligence in the term human intelligence. Second, human intelligence has a different meaning than the term thinking in philosophy, while thinking does not mean the same as understanding or learning in education. What is comparably clear, is the definition of the term algorithm [58]. Considering the definition of algorithms it is clear, that neither understanding nor learning has anything to do with artificial intelligence.

Intelligent Tutoring Systems are based on algorithms. They are connected to the shift from batch processing to dialogue systems and problem solving theories. Additionally, extended computational power is used to Intelligent Tutoring Systems. The idea was first based on the concept for the General Problem Solver (GPS) [71], where the knowledge of problems and strategies to solve problems were separated. When the GPS failed for any relevant problem, the concept was replaced by expert systems [26]. The core architecture of the DENDRAL expert system [11] (knowledge base, explanation system, inference engine) became the starting point for SCHOLAR [12], which was build as a semantic network and based on the architecture of expert systems.

In this concept, limitations were hardly considered, and learners could only barely make own choices. Despite the effort invested in ITS there are hardly actually working systems available or real world applications reported. ITS seem to have failed due to the high effort necessary to develop such systems and the lack of theoretical foundations [91]. From our perspective, considerably basic educational problems like the theory-practice-transformation were not considered in the design of ITS.

In the last years, the successful application of recommender systems in marketing led to the idea of transferring the concept of those systems in the didactic field [23]. This often takes place in the context of informal learning processes [62]. The concepts seem to be related to constructivistic learning theories, while explicit references are rare. While most of the suggested systems are in the early stages of development, the expectations are high. At least, these expectations appear to be similar to the systems discussed before. Since the difference of marketing and didactics is not considered yet for recommender systems, similar problems can be expected as well.

With systems for programmed instruction, intelligent tutoring systems, adaptive learning environments, and pedagogical recommender systems concepts for automatic educational reasoning have been developed. These systems haven been developed for many decades. Despite the effort invested there are hardly actually working systems available or real world applications reported. Intelligent tutoring systems seem to have failed due to the high effort necessary to develop such systems and the lack of theoretical foundations [90]. This might be connected to one concept all the systems developed so far share: Developers assumed that learning is a formally describable and controllable process. Fortunately, this assumption is wrong.

Neither the General Problem Solver nor the Intelligent Tutoring Systems that were based on the General Problem Solver were useable or successful. [90]. This applies to current systems that are based on the same concept too. One example is the concept developed by Bredweg and Struss [9]. Based on an overview on qualitative reasoning they show that one strength of qualitative reasoning is the consideration of causality. They argue that this consideration of causality is a strength of the approach, since causality is essential for model building in scientific thinking. As a conclusion, they focus on the presentation of cause-and-effect-chains in artificial intelligence algorithms. This presentation is turned into educational objectives. Learners should learn the cause-and-effect-chain thinking by modeling causal relations with cybernetic qualitative intelligent algorithms.

That way, only one epistemological concept is considered. Unfortunately, this is not explicit - the epistemological position is not discussed by the authors. A reference to the theory of modeling [94] order representation theory [104] is missing as well. By doing so, the freedom of the learner that is connected to choosing an epistemological position is neglected. Since the necessity to reflect scientific methods is neglected as well, the approach can hardly be understood as scientific thinking. It is focused around the idea of an operative cybernetic control system. Since such a system is based on algorithms, it creates a self-contained world [58] and thus the illusion of a predictable and known future.

Another approach are algorithms, that conduct tests of learning styles and present content accordingly. One example for a study like that has been published by Lehmann [60]. It is based on the learning style inventory developed by Kolb [56]. Content has been prepared for a learning cycle that allows for the consideration of learning styles [60]. Learners have been tested. They were randomly spread on treatment groups so that the content was presented in a way optimized due to the results of the learning style test.

This study shows several problems: First, the research by Lehmann was based on an small incidential sample from a small basic population. The results can thus not be generalized. Second, there were hardly any relevant results. This is not astonishing, since designing content based on learning style inventories, that is on a perspective based on averages was not successful before [49, 50]. From a didactic perspective this was expected, since learning style theories do not take into account that learners do not learn content only, but also learn to learn [99], as we already stated.

The first adaptive systems have been developed in the 1960ies and 1970ies [73]. One contemporary example for an adaptive system is the approach suggested by Martens [63]. Marten's Tutoring Process Model (TPM) is a formal approach to the design of Adaptive Tutoring Systems. A prototype based on the concept has been developed. The prototype is not available any more and has not been used in other projects. This is a faith shared by many prototypes in the field of didactics [90].

Martens defines the tutor model as $TPM =< C,\ LM,\ show,\ enable >$ with $C =< Q,\ A,\ q_0,\ F,\ B,\ \delta,\ select,\ allow >$ and

Q: finite set of states
A: finite set of actions
$q_0 \in Q$:start state
$F \subset Q$: finite set of final states

B: finite set of bricks
δ: state transition function
$select$: select brick function
$allow$: select action function.

With this definition, building adaptive menu systems becomes possible. A learner model can be considered formally. Only elements to inform and to interact are considered as building blocks. Cooperations are missing. This limits the possibilities of the model. Similar limits exist in other models [14].

It can be concluded that educational problems are not sufficiently considered in the discussed approaches. The algorithms are limited to isolated cases and small content areas like Mathematics, Programming and Languages. In nearly all cases only standardized parts which are located at the beginning of curricula were considered. Many algorithms that are developed today fall behind the approaches discussed. They only use simple versions of programmed instruction. In some cases successful applications in certain subject didactics have been created. But none of the approaches designs the leeway in the communication among teachers and learners by considering media didactics.

Another point is that computer technology is neither capable of creating art nor able to play. Thus, computer technology can never replace teachers. Maybe it can simulate learners that make teachers happy but this has hardly been researched yet.

3.4 Conclusions

The argumentation in the first sections leads to a different status of Adaptive Assistant Systems. While previous concepts tried to replace teachers, we try to create tools for teachers. These tools are intended as toys that suggest to teachers to play with their teaching methods and the media they apply. If teachers play with teaching methods and media and offer differences and varieties, they again open up a playground where students can learn while playing with these teaching methods and media.

From this perspective, designing an Adaptive Assistant System places us in the position of designing tools for creating games. These tools can be used to create a playground for teachers that act as artists who create games for learners. Pictorially we create brushes and colors that are used by teachers to paint pictures that are shown to the learner. Thus the challenge is to design tools for the creation of teaching and learning processes that open up spaces for creative actions. The fact that the contradiction between compulsory rules and open creativity is unproblematically solved while actually playing games shows in turn that the association of gaming for teaching and learning is suitable.

It is obvious that a supplier of brushes and colors has hardly any control about the created artwork that will be presented to the audience. The only thing he can assume is that the color will be present in the artwork in which form ever. This is considerably the case if you think about something like audience participation in non scripted performance art. Since we consider Adaptive Assistant Systems as tools for teachers and not as a replacement for teachers and according to Herbart acting as a pedagogue is an art form it does not make any sense for developers of Adaptive Assistant Systems to even try to control learning environments and learning outcomes above all. A consequence of this is that learning outcomes can not be applied as a measurement for a successful design of an Adaptive Assistant System. Still, this measure has been applied as the only measure in recent decades. Thus it is necessary to develop new criteria for the success of Adaptive Assistant System. We assume that human beings do have an own free will, need to live in a community, and need to be understood as decision making agents. Freedom and the open future are considered as essential. Starting with this assumptions, the possibilities and limitations of computer technology in teaching and learning have to be considered.

If the possibilities and limitations are considered, computer technology can be used as an assistant system for teachers and learners. Since computer technology needs to be programmed, programmers have to be considered as teachers that set up the setting in which other people teach and learn. In this respect, their actions can be understood as a kind of policy making for teaching and learning. Designing, implementing and deploying software for teaching and learning is an educational act. Since the software is usually used as it is, software is an instrument to claim power.

In this respect, the balance of force and freedom as an basic educational problem needs to be considered. The developing freedom of learners has to be taken into account. From an educational point of view, the software for teaching and learning has to be designed in a way that suggests and allows learners to develop their freedom. This can be done by offering learners tools to increase control on their learning processes. Of course, this is a claim to power again and refers to the basis dialectic of freedom and force that is inevitable in education.

Instruments that support learners' control can consider the content and the learning process. Since our project aims at a content independent software, the learning process can be taken into account only. To do so, data about the learning process have to be collected and analyzed. The results have to be turned into recommendations for the learner. If the recommendations reproduce teachers input only, they are pointless. Adaptive Assistant Systems become relevant for education if they support creative behavior by the learner and thus support learners to create their own way of learning.

In INTUITEL, this is applied to Learning Pathways and Feedback. Learners should be supported in choosing from different learning pathways and in creating their own learning pathways. Feedback can be created by considering learners earlier behavior and by considering other learners behavior. This again can be used to create recommendations only. It has to be possible that learners deviate from recommendations issued by the software.

Finally, the freedom of teachers has to be considered as well. It has to be possible to express different content structures and arrange content according to different learning theories. At the end, it is necessary to include the possibility for teachers to try to force learners to learn in a certain way, while we can not predict which way this will be. Thus a structure to allow teachers to express different ideas of teaching is necessary too. These requirements can be matched by reasoners that are applied to dynamic hypertexts which are based on a didactic ontology and the collection of data about teachers and learners. In other terms: INTUITEL is about ontologies and reasoning in education.

6.4 Conclusion

We have defined four universal criteria a learning environment has to satisfy to be adaptive with respect to learning style, behavior and preferences of individual learners. Firstly, Didactic Factors have to be retrieved by measuring correlated indicators. Secondly, these factors have to be transformed into a machine-processable form. Thirdly, the Didactic Factors have to be annotated to learning content, together with didactic relations between pieces of learning content. Fourthly, the learning environment deduces the according instructional design from this formal representation.

INTUITEL satisfies the second, third and fourth of these requirements. With the Hypercube Database project we aim to close the gap to the first requirement, designing and developing a research tool for the analysis of learning histories. We model learning histories as spatio-temporal trajectories treating the time dimension as an immanent part of learning. Besides the learning content itself, the concept of the advanced hypercube also includes arbitrary additional data that may result from measured indicators. By this — inside the space of the advanced hypercube — data is lifted to a highly abstract level, mapped to purely geometric information.

This leads to a compact representation allowing us to analyze a wide range of data solely on the grounds of hyperpolylines, their spatio-temporal characteristics and their relations to each other. Not only is this a new application of a spatio-temporal database. It also offers a new approach for finding common learning pathways and Didactic Factors correlating with them. By this, we can predict learning pathways by observing a learners' current actions and retrieving the according Didactic Factors, which constitutes the enhancement of adaptive learning environments in the future.

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