Abstract

Besides the often-cited advantages of independence of place and time, e-learning holds a further large degree of potential in comparison to conventional class teaching: Adaptivity in terms of content. This idea describes the ability of a teaching concept to offer support for the learner that is fully adapted to the individual knowledge level. The current contribution presents an innovative system to assure adaptivity with regard to content for an e-learning application. Robust Nonmetric Multidimensional Scaling (NMDS) allows the knowledge of a learner to be visualized as a knowledge map. These maps are especially sensitive to relational connections of the declarative knowledge contents, which are depicted in a two-dimensional space. Based on the comparison of a learner model with a target model (by means of Procrustes transformation), individual knowledge deficiencies can be detected. This constitutes the basis for specific feedback, learning recommendations, and individualized exercises. The delineated procedure is presented in the framework of the e-learning environment “Psychopathology Taught Online (PTO)”, within which it faces its first practical application.

Introduction: Concept and Requirements of Adaptive Knowledge Transfer

Computers offer considerable potential for an application as a flexible learning and teaching medium. Besides the possibility of designing lessons independently of place and time, and a number of other advantages, computerization (the employment of digital learning systems) provides the technical basis for an individually adapted learning process. Based on the reactions of a learner, intelligent software is able to dynamically adapt the lessons to the current knowledge level and hence optimally foster an individual’s learning. Such Adaptive Tutorial Systems (ATS) are characterized by algorithms, which react to the individual behavior of the user autonomously and in an appropriate manner (cf. Lesgold 1988a, 1988b; Lesgold, Eggan, Katz & Rao, 1992; Leutner, 1992; Rüschoff, 1989).

The challenge is to find an optimal balance between the learner’s need for support and the material offered in the teaching situation. Adaptivity in the learning process denotes, in its simplest meaning: The system meets the learner, based on a diagnosis of his or her learning status, where he or she is currently situated (Leutner, 1992, 1993, 2002). The tutorial system translates the knowledge diagnosis into corresponding teaching, for instance into giving feedback about the current knowledge level to the learner, into recommending contents which should be repeated, and/or into putting together exercises specifically tailored to the inadequately known contents. This ability of the tutorial system is the result of the employment of the knowledge expertise inherent in the system, which constitutes the above-mentioned “intelligence” of an ATS (Leutner, 1992). This procedure promises a fast learning progress. Repeated learning of already known contents is reduced to a minimum, which results in a higher efficiency compared to a learning curriculum structured in a linear fashion. Further advantages can be seen in the increased motivation and attention of the learner as a result of the feedback about the current knowledge level. The tutorial support facilitates the user’s feeling of being taken seriously and is able to tackle the difficult problem of finding the appropriate learning path. These arguments have an increased relevance in particular in asynchronous and non-cooperative applications of e-learning such as “Psychopathology Taught Online” (PTO), which will be used to demonstrate the implementation of adaptivity. In such an application, the tutorial support facilitates the semantically meaningful (intelligent) interaction of the allegedly passive, computer-based medium with the user. The aim is to (re)organize, stabilize and differentiate the cognitive structures of the learner, based on the detection of contents that are falsely known or not known and the resulting reactions to meet the briefly mentioned requirements and aims, the system has to comprise the following elements:

1 This procedure corresponds to the stimulus-centered approach (cf. Crowder, 1959; Leutner, 2002).
• Target model
• Image of the learner’s knowledge and diagnosis of the quality of knowledge
• Feedback and instructions on how to act

The following section explains how the various elements are implemented and how the adaptivity is accomplished by their interplay.

Implementation

Target Model

As described above, the “intelligence” of an ATS is constituted in the knowledge expertise inherent in the system. The expert model therefore represents a crucial element. There are various approaches for collecting data and translating it into such an expert model: One possibility, for instance, is an information retrieval technique such as automated text analysis. Another possibility is a data collection method that is based directly on expert opinions. It can be expected that the latter method would prove to be more resource consuming but would result in more stable expert models. For PTO, the expert model was calculated based on the judgments of leading experts in Switzerland and their collaborators and was visualized as a cognitive map (figure 1). The construction and implementation of such a cognitive map of experts and learners is described in detail in the section below.

![Cognitive Map](image)

Figure 1: Two-dimensionally scaled NMDS map based on similarity judgments. The dots represent the position of the mental disorders from the point of view of the experts (adapted and modified from Egli, Schlatter, Streule & Läge, 2006). The gray dots represent the examples described in the text.

Image of the Learner’s Knowledge and Diagnosis of the Quality of the Knowledge

The declarative factual knowledge of a person about a number of objects (in PTO: mental disorders = knowledge units) can be described as a “cognitive map” (Läge, 2001, Marx & Hejj, 1989, Marx & Läge, 1995). A cognitive map is a dimensional structure, which depicts the relations that a person perceives between the objects in the map as smaller and larger distances. This visualization allows inferences about individual memory representations to be made.
Relational, pairwise judgments (similarity judgments: SJ) of a person about a set of objects constitute the data basis of the knowledge diagnosis. The global SJ’s between the objects are built more or less automatically by a person, on the basis of the attributes that were considered and the differences in the characteristics of the attributes (cf. Klauer, 1989 and Smith, Shoben & Rips, 1974). These SJ’s are relatively independent of expertise, although it can be expected that the judgment of an expert should have a higher quality. An assessment of similarity measures the entire knowledge about two elements and is therefore efficient. Figure 2 shows the viewpoint of the user regarding the nine-point SJ scale. The task for the learner is to provide judgments on the basis of the memorized factual knowledge. One run of data collection containing 20 objects (=190 judgments) takes between 10 and 20 minutes according to experience.

The pairwise assessments are interpreted as distance values and are translated into a two-dimensional space by Nonmetric Multidimensional Scaling (NMDS; Borg & Groenen, 1997; Läge, 2001). The example in figure 1 shows the result of such a two-dimensionally calculated NMDS, based on expert judgments (expert model/target map). Closely positioned dots (i.e. disorders) were judged to be similar, while objects positioned far apart were judged not to be similar. For instance, anorexia nervosa (restricted eating) and bulimia nervosa (binge eating and vomiting) are similar disorders and belong to the same category of the WHO classification system ICD-10 (WHO, 2005). These two objects show only small discrepancies in terms of phenomenology, etiology, and other judgment criteria. The similarity, which was assessed to be very close, is reflected in the close position of these two disorders. Bulimia nervosa and dementia in Alzheimer’s disease, on the other hand, show few similarities with regard to the potential judgment criteria (such as phenomenology, etiology, etc.). The pronounced non-similarity that is consequently judged is therefore reflected in far apart positions of the two disorders.

The assessment of the quality of knowledge is achieved by comparison of a learner map with the target/expert map by means of Procrustes transformation (Gower & Dijksterhuis, 2004). In such a comparison, it is noticeable even without mathematical calculations which objects are well known by the learner (i.e. correctly positioned) and which ones are wrongly positioned (as an example, see figure 3). Of course, this distance information of the target/actual value comparison can also be expressed numerically. This is the basis for a fully automated analysis, which can be applied in computer-assisted education. The overall divergence is expressed as the AverageLoss (AvgLoss), which corresponds to the mean of the individual divergences (ObjectLoss; Läge, 2001).
Figure 3: Result of a Procrustes transformation of the knowledge map of a learner (gray dots) and the target/expert map (black dots). The overall divergence in this example corresponds to an AverageLoss of 0.36.

The Procrustes transformation is not dependent on different orientations of the object configurations resulting from the scaling algorithm of the NMDS in the maps compared. To put it simply, the Procrustes transformation rotates, mirrors, stretches, and compresses the learner map, while maintaining the object relations, in order to achieve a maximal fit with the target map. The remaining deviations between the corresponding objects are reflected as the ObjectLoss values. If the ObjectLoss of an object in the learner map exceeds a predefined criterion, the system interprets this as inadequate knowledge. More detailed criteria for the assessment of inadequate knowledge such as a violation of a cluster membership or similar, are possible but are not considered in the current concept.

NMDS and Procrustes transformation are adequate instruments for knowledge diagnosis primarily for a medium-level knowledge. If a person possesses only rudimentary knowledge, a knowledge diagnosis offers no advantage of adaptivity, because any learning recommendation is helpful for the learner. If the person already exhibits a well established, integrated and elaborated factual knowledge with few deficiencies, his or her map will not selectively differ from the target map in a significant and statistical way.

**Architecture, Feedback and Instructions How to Act in PTO**

PTO promotes basic and detailed knowledge in the field of mental disorders. It pursues a constructivist didactical approach and consists of three self-contained learning phases/curricula: Curriculum 1: Basic knowledge; Curriculum 2: Assimilative learning; Curriculum 3: Detailed and additional knowledge.

Curriculum 1 (C1) provides a structured overview of the field of knowledge based on a selection of 20 mental disorders. As argued above, an adaptive learning system is not maximally effective if students have no or only rudimentary knowledge. Therefore, the learners start by thoroughly studying the 20 disorders. After this learning phase, the relational knowledge structure of the learner concerning the 20 disorders is assessed by means of similarity judgments and cognitive maps. If the deviations (AverageLoss) resulting from the comparison of the learner with the expert structure (Procrustes transformation of the corresponding cognitive maps) exceed the predefined threshold, they are followed by three steps of didactical instructions on how to act: First, those disorders that exceed the a priori defined threshold of the ObjectLoss, which were therefore inadequately positioned in relation to the overall expert structure, are recommended for learning and repetition, respectively (adaptive
feedback as a learning recommendation). The second instructional step follows if after the repetition of the recommended disorders and the renewed knowledge diagnosis by cognitive maps, the AverageLoss still exceeds the threshold: Based on the orientation of the misplacement, the diagnosis allows specifically designed learning exercises to be constructed. The learner is asked to look for differences in the two contents if the positions of two disorders were significantly closer than in the expert model (depending on the criterion). Following the same logic, the learner is asked to look for similarities if the positions of the disorders were significantly further apart than in the expert model. The third instructional step follows if after working through the exercises, and the renewed knowledge diagnosis, the AverageLoss still exceeds the threshold: The learner then receives his or her current individual knowledge map as feedback about his or her cognitive representation in comparison with the expert representation. The knowledge is recurrently assessed until the deviation (AvgLoss) between learner and expert model are below the predefined criterion or until a certain number of knowledge diagnosis runs are completed. The learner can then enter the next Curriculum.

In Curriculum 2 (C2), the knowledge structure accurately built up beforehand is supplemented by the assimilative integration of 40 new mental disorders in explicit relation to the 20 disorders that have already been learned. This assimilative integration is also supported by the adaptivity of the tutorial system: New disorders are studied by the learner in groups of five disorders. After learning the disorders of a group, the relational knowledge of the learner is assessed, i.e. his or her cognitive map is compared with the respective expert model. As soon as one disorder falls below the threshold of the ObjectLoss, i.e. the disorder is correctly positioned, it is replaced by a new one. Thus, the theoretically derived advantages of assimilative learning put forward by Ausubel (1980/81, 2000) are implemented in PTO. The C2 learning contents are reduced to the amount and complexity that is necessary to properly position a disorder in the overview structure. During C1 and C2, the learning progress is monitored by a continuous relational knowledge diagnosis, and is adaptively guided until the cognitive representation of the student sufficiently matches the expert representation.

In Curriculum 3 (C3), some selected disorders are discussed in detail, and psychopathological knowledge that is not disorder-specific is taught. In C3, there are no adaptive measures implemented (cf. STREULE, EGLI, OBERHOLZER & LÄGE, 2005).

Concluding Remarks

The primary goal of a multimedia production in education need not be restricted to the digitalization of conventional teaching materials and their enrichment with multimedia. An added value of the computer as a learning medium can only be a result of the appropriate usage of the newly available possibilities. An important difference between a book and a computer or between teaching in class and a personally utilisable computer is its flexibility. The system is not rigid, but can adequately (“intelligently”) react to specific behaviors of a user. PTO achieves this intelligence by detecting cognitive structures of learners and by the comparison of these structures with the expert model. Additionally, the curricular architecture takes into account the current theory of assimilative learning to optimize the learning process for the student.

Adaptive knowledge transfer is conterminous with an individualization of knowledge acquisition. Just as a teacher in an individual teaching situation is able to adapt to the measured or observed strengths and weaknesses of the learner, the logic of adaptivity tries to do the same. It achieves this by NMDS and Procrustes transformation. Furthermore, this procedure goes beyond a mere reproduction of knowledge contents by focusing on the quality of the structural knowledge processing. Hence, the knowledge maps not only serve as passive blackboards, but also contain a didactical aspect, because the learner has to apply his or her entire knowledge to accomplish the diagnostic task.

References


