Supporting Learner in Exploratory Learning Process in an Interactive Simulation based Learning System

Reinhard Oppermann*, Kinshuk*, Akihiro Kashihara**, Rossen Rashev* and Helmut Simm*

*GMD-FIT, Germany **I.S.I.R., Osaka University, Japan

Abstract

Learning-by-exploration is an effective way in the learning process, provided the educational system is capable of estimating the contextual requirements of the learners and of supporting them by providing facilities to keep the cognitive load at optimum level. Exploration Space Control methodology allows the systems to provide intelligent assistance to the learners by effectively presenting the information space and tools to explore that space in a way suitable for learners' current competence level. This paper describes the implementation of Exploration Space Control methodology in InterSim system, which aims to facilitate learning structure and functionality of organs and to improve appropriate skills in diagnosing and treating the related diseases.

Zusammenfassung

Lernen mittels Exploration ist eine effektive Form des Lernens vorausgesetzt, das Lehrsystem ist in der Lage, die Bedürfnisse des Lerners situationsgerecht einzuschätzen und ihnen durch Vorgabe eines adäquaten Niveaus cognitiver Belastung optimal zu entsprechen. Die Exploration Space Control Methodik ermöglicht es Systemen, den Lernenden intelligente Unterstützung zu bieten mittels angemessener Darstellung des Informationsraumes und mittels Werkzeugen, die eine dem aktuellen Wissenstand angepaßte Exploration dieses Informationsraumes erlauben. Dieser Beitrag beschreibt die Realisierung der Exploration Space Control Methodik im InterSim System, dessen Ziel es ist, das Lernen von Anatomie und Physiologie von Organen zu erleichtern und angemessene Fähigkeiten zur Diagnose und Behandlung ihrer Krankheiten zu entwickeln.

1 Introduction

The learning-by-exploration is an effective technique for learning [5], in particular for task oriented disciplines such as computer science and medicine. This technique not only provides skills of the domain but also the understanding of the embedded concepts ([2], [4],[7]). However, there are various considerations an educational system needs to take care to provide effective learning with the help of learning-by-exploration.

One primary way to support learning-by-exploration is to provide various techniques which enable the learners to explore domain concepts/knowledge to acquire cognitive and procedural skills. Current research on such techniques in educational systems include multimedia, hypermedia, simulation, demonstration and virtual reality, and the list of items is growing very fast due to extensive research going on in this field.

However, it is not an easy task for the learners to effectively explore the domain concepts/knowledge by themselves and develop adequate skills in domain related tasks. The extent and amount of complexity inherited in the techniques, provided by the educational system for exploration purposes, needs to depend on the learners' current level of competence and their current capacity to cope with cognitive load arising from such explorations. The systems should, therefore, be equipped with capabilities to assist the user in various tasks and to vary the extent and amount of complexity of exploration techniques. Typically, the system would need to limit the learning space (called exploration space) for the novice learner and would remove the restrictions gradually as the learner progresses in the learning process.

Current research on educational systems has proposed various intelligent assistant methods to support context based navigation, presentation tailoring etc. but these methods are not always sharable and reusable among researchers and developers as they do not correspond to a generalized protocol. [7] and [8] proposed a methodology, called Exploration Space Control (ESC for short), to generalize current intelligent methods of supporting exploration. This paper describes the use of ESC in the implementation of an interactive simulation based learning system, called InterSim.

In the following sections, we first give a summary of the ESC methodology. A detailed description of the methodology is given in [7] and [8]. Then we describe the use of ESC methodology in the implementation of the InterSim system, which aims to facilitate learning of structure and functionality of human ear and the acquisition of appropriate skills in diagnosing and treating the diseases. The paper finally concludes with identifying some research aspects which need further investigation.

2 Exploration Space Control

In most hypermedia systems, and simulation-based learning and training systems, learners learn a domain by accessing various information resources such as hypertext, demonstrations, simulations, and so on. In this sense, the exploration activity can be defined as manipulating these information resources to comprehend the information and to acquire domain concepts/knowledge.

Ideally, the learners should be free to explore since finding out domain concepts/knowledge by themselves would enhance their learning ([2], [5]). However, learners may not know what to and how to explore. They may also make excessive mental efforts to search and integrate the information from different information resources, which itself may cause cognitive overload [6]. The exploration space, in addition, may be quite wide so they may lose their ways.

Exploration Space Control (ESC) is a methodology encompassing various educational tasks which make it easier for the learner to explore domain material, for example, providing navigation in learners exploration paths ([1]) and information tailoring ([9]) to make the search and domain knowledge comprehension easier for the learner, restricting simulation parameters to make interpretation of the behavior of simulated results easier ([3]) and so on.

ESC methodology facilitates proper learning environment for all types of learners by controlling the extent of exploration space according not only to the domain complexity but also to the learners' competence, understanding levels, experiences, characteristics, etc. According to this methodology, the exploration space is restricted either in terms of the exploration tools and information to be presented or as recommending few choices according to the learners' perception and understanding level. This restriction/recommendation intends to reduce the learners' cognitive load. The purposes of ESC are as follows:

To facilitate active learning. This approach is suitable for the learners who have higher learning competence. The active learning is provided by reducing cognitive load as less as possible. The restrictions/recommendations are imposed only to protect the learners from cognitive overload.

To facilitate step-by-step learning. This approach is suitable for the learners who have lower learning competence. The step-by-step learning is provided by reducing cognitive load as much as possible. This approach gradually induces the learners to make exploration efforts.

The above mentioned purposes cover a whole spectrum of learners and the "active learning" and "step-by-step learning" are two extreme approaches covering that spectrum. The combination of these two approaches in varying quantity facilitates adequate learning for whole learner spectrum [6].

ESC is implemented at various levels of controls in the form of restrictions, warnings and suggestions imposed on learners, according to learner models and domain complexity. These control levels are as follows:

- **Embedding information.** This facilitates the creation of information space and involves scaffolding.
- **Limiting information resources.** Two kinds of controls are used to limit information resources:
  - Limiting the number of information resources to be presented to a learner at a particular moment.
  - Presenting information resources appropriate for looking into current domain material by a learner at a particular moment.
- **Limiting exploration paths.** For example, this can be done by restricting navigational paths in hypertext or by controlling various parameters in simulation environment. Two kinds of controls are used in the level:
  - Limiting the number of feasible exploration paths to be looked into.
  - Limiting the exploration paths which are unrelated to the current domain material.
- **Limiting information to be presented.** There are again two methods to provide such control:
  - Limiting the amount of information.
  - Adapting the contents of information to each learner.

Current technologies can be used to provide different kinds of controls as shown in Table 1.

Current Technologies	*Control Levels*
Scaffolding	Embedding information
Navigation	Limiting information resources & exploration paths
Problem ordering (Courseware)	Limiting exploration paths
Information tailoring	Limiting presented information
Simulation setting	Limiting exploration paths & presented information

Table 1: Relationships between current technologies and ESC.

3 Designing the educational systems

There are three main steps in designing the educational systems on the basis of ESC.

1) Learning goals which learners are expected to accomplish should be identified.
2) Scaffolding methods should be selected in the form of various information resources, taking into account the amount and contents of the information, and by considering various exploration operations to be used in and between each information resource. Examples of exploration operations include *Select* (selecting an information resource), *Trace* (tracing a sequential path within an exploration environment), *Interpret* (interpreting the results of previous actions, particularly useful in simulation environments) and *Apply* (to execute an action, such as application of changed parameters in a simulation).
3) Deciding which control level should be applied to which information resource.
   a) Deciding the purpose of ESC (support for active and/or step-by-step learning) so as to decide the guidelines for controlling exploration space.
   b) Deciding control levels (table 1) to restrict the exploration operations in the information resources.
   c) Deciding the application of controls according to learner models and domain models. Various factors which need to be considered in learner models are as follows:
      - Preferences - Knowledge Levels - Experiences
      - Competence - Exploration Process - Cognitive Load

   Possible factors to be considered in domain models include:
      - Knowledge type (Procedural/Declarative) - Granularity - Depth (Deep/Shallow).

4 Implementation of ESC in the InterSim project

The ESC methodology is being applied in the InterSim project for the system in the domain of ear. The objective of the system is to facilitate the learning of structural and functional aspects of healthy ear and related diseases, and to provide skills in the diagnosis and treatment of the diseases.

The design and development of the InterSim system on the basis of ESC includes the provision of several kinds of information resources for exploring ear and the provision of user interface to allow learners to make exploration operations. The system is aimed to facilitate active learning rather than step-by-step learning process. Figure 1 shows a partial view of conceptual layer of the learning material [8].

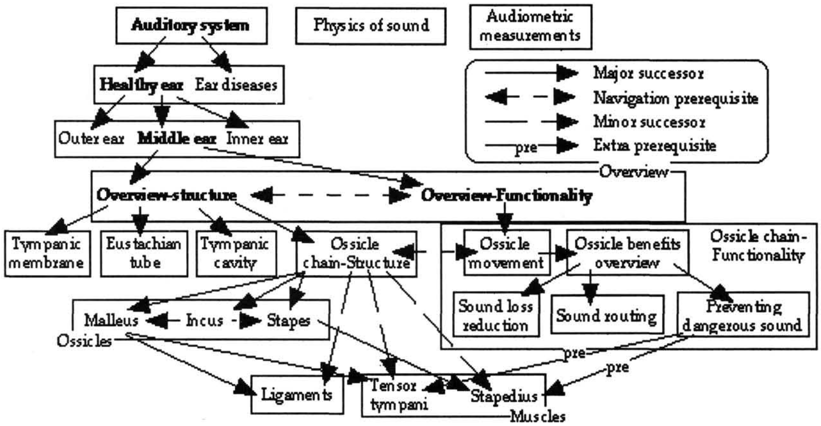

Figure 1: Partial conceptual layer of learning material for ear domain.

Various steps in the design of InterSim system according to ESC are as follows.

(1) Determination of learning goals.

There are two main goals in the InterSim system:

- Understanding the structure and functionality of ear.
- Acquiring appropriate skills in diagnosing and treating the related diseases.

(2) Scaffolding.

(a) Selecting and developing information resources:

I. For the first learning goal, the suitable information resources are Hypertext, Demonstration, Simulation and Problem Ordering.

- **Hypertext** gives learners the descriptions of structure, behaviour, and functionality of ear.
- **Demonstration** facility shows learners the behaviour of normal ear.
- **Simulation** facility enables learners to experiment on functionality of ear and to receive the simulated behaviour.
- **Problem Ordering** facility provides learners with a number of problems sequenced according to learners' competence level.

II. For the second learning goal, the suitable information resources are Simulations, Design and Problem Ordering.

- **Simulation** facility provides an exploration environment for diagnosing and treating the diseases.
- **Design** facility enables learners to introduce faults in the ear in order to deepen their understanding about interrelationships of various factors.
- **Problem Ordering** facility enables learners to solve (diagnosis and treatment) problems in order.

(b) Second step is to decide the control levels to restrict exploration operations in the information resources. For this purpose, we first consider which exploration operations are useful for the InterSim system:

I. For the first learning goal, suitable exploration operations within the above-mentioned information resources are shown in table 2.

Information Resources	*Exploration Operations*
Hypertext	Select & Trace
Demonstration	Interpret
Simulation	Apply & Interpret
Problem Ordering	Trace

Table 2: Suitable exploration operations for first learning goal.

The learners, for example, can select a hyperlink (including a part of image map) among many available to know the fine grained details of an structural part of ear, or can trace through the interrelated functionality of various parts. For example, figure 2 shows a partial screen for learning the structure of ossicle chain in middle ear. Each ossicle in the image is mouse sensitive. Taking mouse over an ossicle reveals the name of the ossicle, single clicking gives a short description and double click takes the learner to detailed explanation view of that ossicle.

Similarly, the activities shown in a demonstration need to be interpreted such as a muscle reflex needs to be related to the changes in various graphs. The learners need to apply various parameters in simulations and need to interpret the results. Within problem ordering, the learners need to trace through various parameters in order to solve the problems.

Since the learners can select one or more information resources and can integrate them for better understanding of the subject matter, the suitable exploration operations among above mentioned information resources are: Select, and Integrate. For example, the learners can select a static picture and a virtual reality scenario of tympanic cavity so as to have an spatial understanding of the cavity while still relating one part of cavity to another.

II. For the second learning goal, suitable exploration operations within the information resources are shown in table 3.

Information Resources	*Exploration Operations*
Simulation	Apply & Interpret
Design	Select, Apply, & Interpret
Problem Ordering	Trace

Table 3: Suitable exploration operations for first learning goal.

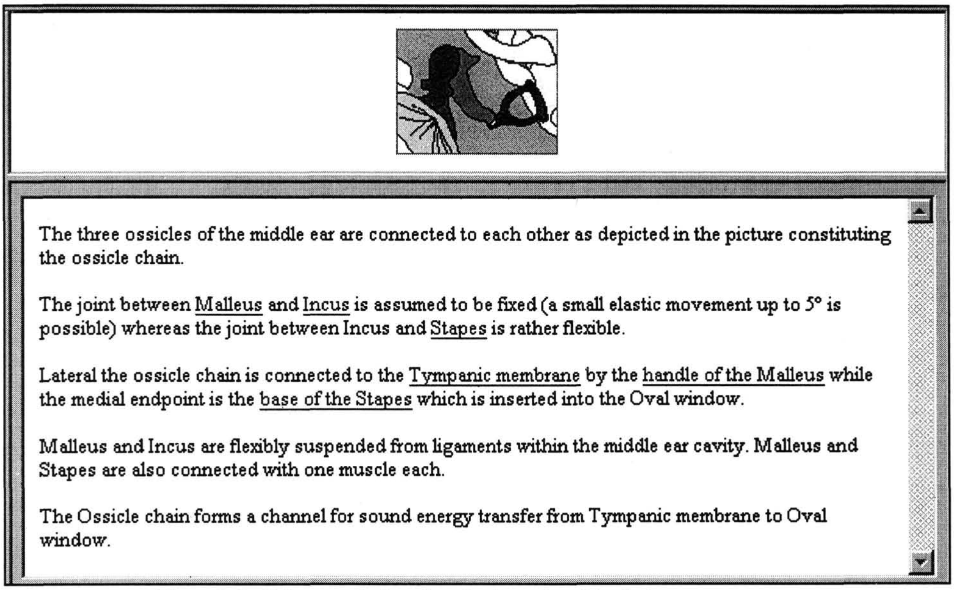

Figure 2: Partial screen for learning structure of ossicle chain.

For example, the learners can apply various causes for initiation of diseases and can interpret the results to see how one disease can advance. The learners can also select various parameters, change their values and apply them to a healthy ear to simulate a faulty ear and can interpret the results. Problem ordering requires the tracing of various relevant parameters in order to find the correct sequencing towards the solution.

For the second learning goal, the learners can not only select and integrate the information resources but also apply the results of one information resource to another. Therefore the suitable exploration operations among the information resources are: Select, Apply, Integrate. For example, the symptoms generated after selection and application of various treatment methods could then be integrated to another set of treatment methods to see the combined effect of one set on another.

(3) Deciding Control Levels.

(a) The first step is to decide the purpose of ESC. In the case of InterSim system, the purpose is to provide active learning support to the learners.

(b) The second step is to decide control levels (as shown in table 1). It is envisaged that all control levels are not suitable for both learning goals of the InterSim system. For first learning goal, the selected control levels are:

- **Limiting information resources**
- **Limiting exploration paths**
- **Limiting presented information**

For second learning goal, the selected control levels are:

- **Embedding information**
- **Limiting information resources**
- **Limiting exploration paths**

In InterSim system, these controls levels are implemented by activating, inactivating and recommending the choices in various controls in the interface, which allow the learners to select, trace, apply and so on while exploring. An important example in InterSim Ear system for control levels is the concept of "main path" and "excursions". While interacting with the system, the learner would explore along a main learning path within one knowledge module, and the system would provide intelligent support and guidance accordingly. Whenever the learner needs to deviate from that path to some loosely related unit of knowledge in some other domain module, the system would allow such excursion, but with limiting information resources, and the information presented in such excursions would also be limited to make it relevant with main learning path. The exploration paths in an excursion would also be limited for the sake of not letting the learner lost in hyperspace of excursions. For example, a learner, exploring the structure of middle ear, would be able to get an excursion in physics of sound to understand how the sound is travelled through the mechanical linkage of ossicles, but the information presented in the physics of sound would be tailored for better understanding of sound travel in ossicles. On the other hand, the learner, whose main learning path is physics of sound would be able to get the knowledge presentation in more depth.

(c) The third step is to decide how to control various information resources. As suggested in section 3, there are two ways to decide the application of controls: according to learner models and according to domain complexity. In InterSim system, it is assumed that the learner should access the complex domain material only when the competence level of the learner allows for this. Of course, learner can explicitly access any domain material, but in such cases, the system would not be able to recommend any preferred path to the learner. With this assumption, the implementation of ESC in InterSim system employs only learner models.

Following are the examples of each control level selected for two learning goals of the InterSim system.

First learning goal: Understanding the structure and functionality of ear

Example 1: Limiting information resources for understanding the structure and functionality of the ear.
- Restriction methods: Restricting the representation of various domain material in terms of complexity of representation (for example, static pictures Vs virtual reality scenarios)
- Exploration Experience: Low, Middle, High
- Cognitive load: High, Middle, Low
- The degree of limitation of multiple information resources for same domain material:
  - Strong when experience is low - Weak when experience is middle
  - No limitation when experience is high
- The degree of limitation of number of complex information resources:

- Strong when cognitive load is high - Weak when cognitive load is middle
- No limitation when cognitive load is low

Example 2: Limiting exploration paths for understanding the structure and functionality of the ear.

- Restriction methods: Restricting/ recommending buttons, combo box choices, anchors/ links to be used in exploring Hypertext to limit Select & Trace operations.
- Exploration Competence: Low, Middle, High
- Knowledge Levels: Low, Middle, High
- The degree of limitation of feasible paths:
  - Strong when competence is low - Weak when competence is middle
  - No limitation when competence is high
- The degree of limitation of unrelated paths:
  - Strong when knowledge level is low - Weak when knowledge level is middle
  - No limitation when knowledge level is high

Example 3: Limiting presented information for understanding the structure and functionality of the ear.

- Restriction methods: Restricting the presented information to the learner
- Exploration preferences: Low, Middle, High
- Knowledge levels: Low, Middle, High
- Cognitive load: High, Middle, Low
- The degree of limitation of type of presented information:
  - Strong when preference is low - Weak when preference is middle
  - No limitation when preference is high
- The degree of limitation of richness of presented information:
  - Strong when knowledge level is low - Weak when knowledge level is middle
  - No limitation when knowledge level is high
- The degree of limitation of amount of simultaneously presented information:
  - Strong when cognitive load is high - Weak when cognitive load is middle
  - No limitation when cognitive load is low

Second learning goal: Acquiring appropriate skills in diagnosing and treating the related diseases

Example 1: Embedding information for acquiring skills in diagnosing and treating the diseases.

- Restriction methods: Providing scaffolding so as to decrease domain complexity with regard to learner models (for example, first allowing the learner to semi-explore the disease development process in an animation wizard; then adding simulation capabilities to allow the full exploration; then adding extra simulation capabilities for diagnosis)
- Exploration Competence: Low, Middle, High
- The degree of scaffolding:
  - Strong when competence is low - Weak when competence is middle
  - No limitation when competence is high

Example 2: Limiting information resources for acquiring skills in diagnosing and treating the diseases.

- Restriction methods: Restricting the representation of various domain material in terms of complexity of representation (for example, first providing exploration of anatomic details of the diseased ear, and then gradually providing various relevant graphs and diagrams used in the diagnosis of the disease. Figure 3 shows an example user interface of a disease simulation in the system. The learners can explore ear with various multimedia objects (such as image maps), experiment on the ear by manipulating parameters, and interpret the results.)
- Exploration Experience: Low, Middle, High
- Cognitive load: High, Middle, Low
- The degree of limitation of multiple information resources for same domain material:
  - Strong when experience is low
  - Weak when experience is middle
  - No limitation when experience is high
- The degree of limitation of number of complex information resources:
  - Strong when cognitive load is high
  - Weak when cognitive load is middle
  - No limitation when cognitive load is low

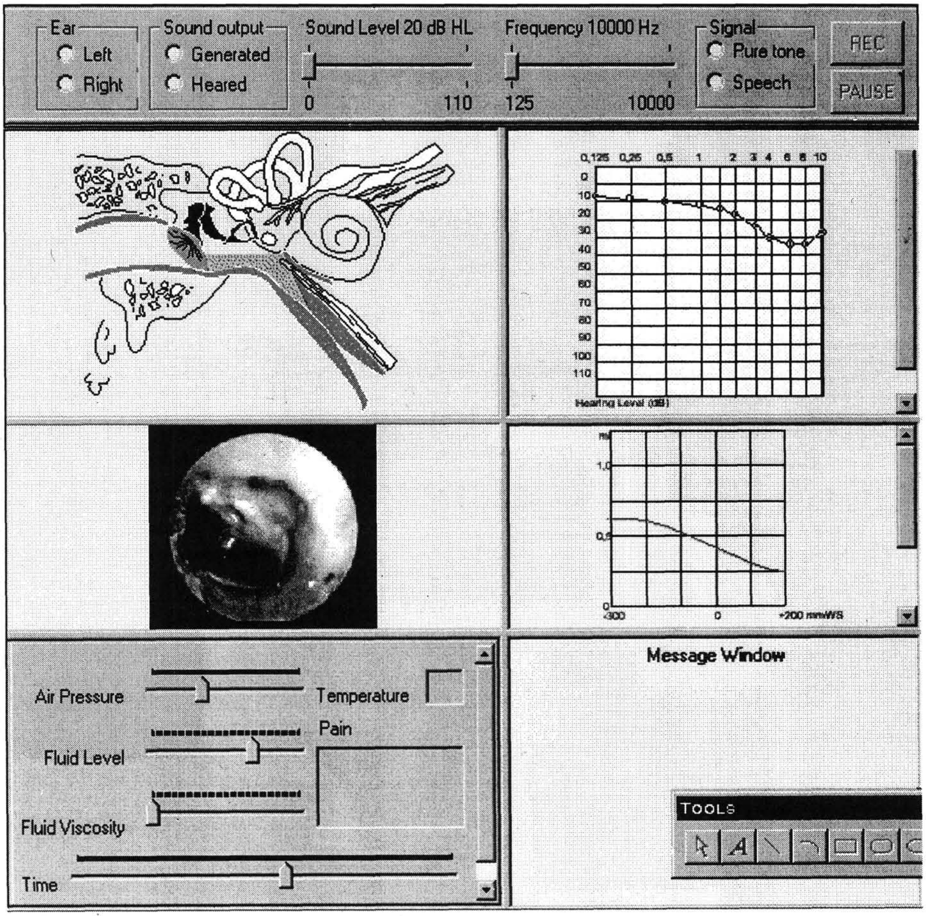

Figure 3: User Interface of a disease simulation in InterSim System.

Example 3: Limiting exploration paths for acquiring skills in diagnosing and treating the diseases.

- Restriction methods: Restricting various simulation operations to suit the learner models (for example, allowing the learner to explore the anatomy part of figure 3 to see the effects on the graph, and once the learner is capable of handling, providing the exploration activities in the graphs to see the effects in the anatomy part, and in other graphs.)
- Exploration Competence: Low, Middle, High
- Knowledge Levels: Low, Middle, High
- The degree of limitation of feasible paths:
  - Strong when competence is low
  - Weak when competence is middle
  - No limitation when competence is high

- The degree of limitation of unrelated paths:
  - Strong when knowledge level is low
  - Weak when knowledge level is middle
  - No limitation when knowledge level is high

5 Conclusions

The InterSim system is still at its prototyping stage and no formal user evaluations have yet been carried out. But formative evaluation of the system by medical practitioners has validated the effectiveness of the system in both domain knowledge and cognitive skills acquisition by the learners.

The implementation of Exploration Space Control (ESC) in the InterSim system has facilitated the adaptivity of the system towards the learner. The success in designing the InterSim system using ESC methodology has validated the applicability of the methodology in successful implementations of adaptive educational systems supporting learning-by-exploration. The ESC provides step-by-step procedure to determine the objectives of the educational systems and help in selecting the suitable technologies to be used in such systems.

Further research regarding ESC is to make it more generalised so that it could be used in developing any educational systems providing learning-by-exploration. This requires an intensive survey of development efforts of the systems available in the literature and identifying the potential and pitfalls in the methodologies by which they were developed. This would also provide an appraisal of ESC methodology as it stands in front of other methodologies.

6 References

[1] Boyle, C. & Encarnacion, A.O.: An Adaptive Hypertext Reading System. User Modeling and User-Adapted Interaction, 3(3) (1993), 193-208.

[2] Carroll, J., Mack, R., Lewis, C., Grischkowsky N., Robertson S.: Exploring exploring a word processor. Human-Computer Interaction, 1 (1985), 283-307.

[3] Eliot, C. & Woolf, B.P.: An Adaptive Student Centered Curriculum for an Intelligent Training System. User Modeling and User-Adapted Interaction, 5(1) (1995), 67-85.

[4] InterSim Project HomePage: http://zeus.gmd.de/projects/intersim.html, 1996.

[5] Kamouri, A., Kamouri, J., & Smith, K.: Training by Exploration: Facilitating the Transfer of Procedural Knowledge Through Analogical Reasoning. Man-Machine Studies, 24 (1986), 171-192.

[6] Kashihara, A., Hirashima, T. & Toyoda, J.: A cognitive load application in tutoring. User Modeling and User-Adapted Interaction, 4(4) (1995), 279-303.

[7] Kashihara,A., Kinshuk, Oppermann,R., Rashev,R., Simm,H.: An Exploration Space Control as Intelligent Assistance in Enabling Systems. Proc. of ICCE 97, 1997, 114-121.

[8] Kashihara A., Kinshuk, Oppermann R., Rashev R., Simm H. & Toyoda J.: Towards Sharable Intelligent Assistance for Learning-by-Exploration. SIG Technical Notes in Japanese Society for Artificial Intelligence, 1998, SIG-IES-9703, JSAI, Shizuoka, Japan, 1-6.

[9] Kobsa, A., Mueller, D., & Nill, A.: KN-AHS: An Adaptive Hypertext Client of the User Modeling System BGP-MS. Proc. of User Modeling 94, Hyannis, Mass., 1994, 99-105.

Authors' addresses

Prof. Dr. R. Oppermann, Dr. Kinshuk, Mr. R. Rashev & Mr. H. Simm
GMD-FIT, German National Research Center for Information Technology
Schloss Birlinghoven, 53754 St. Augustin
Germany
Email: {oppermann, kinshuk, rashev, simm}@gmd.de

Dr. A. Kashihara
The Institute of Scientific and Industrial Research
I. S. I. R., Osaka University
8-1, Mihogaoka, Ibaraki, Osaka, 567
Japan
Email: kasihara@ai.sanken.osaka-u.ac.jp