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A Cognitive Load Reduction Approach to Exploratory Learning and Its Application to an Interactive Simulation-based Learning System

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Abstract: Exploring domain concepts/knowledge is an effective way of learning particularly for task-oriented discipline. This exploratory learning is often accompanied by cognitive efforts to develop and apply the domain concepts/knowledge, which efforts would enhance learning effects. However, it is not so easy for learners to get good learning results. The cognitive efforts may cause cognitive overload. Some intelligent/adaptive support is therefore necessary. This paper describes a methodology for supporting exploratory learning which attempts to limit learning space, called exploration space, to adequately control the cognitive load the learners would face in their exploration process. We call this methodology 'Exploration Space Control' (ESC). In ESC, the extent of the exploration space is controlled according not only to the domain complexity, but also to the learners' competence, understanding levels, experiences, characteristics, etc. The control is done by restricting exploration tools provided in user interface, tailoring information to be presented, recommending a few among a number of choices, etc. This paper also demonstrates an application of ESC to an interactive simulation-based system in the domain of human ear. This system aims to enhance learning of the structure and functionality of the ear and to improve appropriate skills in diagnosing and treating the related diseases. The system also provides several kinds of information resources for exploring the ear and user interface with several exploration tools.

Keywords: Exploratory Learning, Exploration Space Control, Cognitive Load, and Intelligent Learning Environments

1. Introduction

Exploring domain concepts/knowledge is an effective way of learning (Carroll et al., 1985; Kamouri et al., 1986), particularly for task-oriented disciplines such as computer science and medicine. This exploratory learning may involve understanding conceptual knowledge embedded in domains, and acquiring skills in the domain-related tasks (Carroll et al., 1985).

Exploration is intrinsically a self-directed and constructive mental activity. This is often accompanied by cognitive efforts to develop and apply domain concepts/knowledge. The effectiveness of such cognitive efforts has been ascertained from a psychological point of view. For example, Carroll et al. pointed out that forcing learners to find out the information necessary to learn a word processor improved their learning better than directly presenting the same information (Carroll et al. 1985). However, it is not so easy for learners to get good results in exploratory learning. The cognitive efforts may cause cognitive overload. Some intelligent/adaptive support from the system is therefore necessary.

From an educational point of view, it is important to take the cognitive load into consideration which learners would bear in learning process. Most of current educational systems follow the basic idea that the cognitive load should be reduced as much as possible so that learners can learn with less difficulty. For example, previous work on curriculum claims that problems should be selected and sequenced so that learners can both solve the problems and master the problem-solving procedure readily (Halff, 1988). Although the exploratory learning may also call for this load reduction approach, it moreover requires another approach whose aim is to reduce the cognitive load on explorations as less as possible (Kashihara, Hirashima, and Toyoda, 1995). This would induce learners to make as many cognitive efforts to explore as possible (Kashihara et al., 1997). This approach would bring about better results in the exploratory learning. However, this must take care to adapt the load to each learner, which should not be beyond his/her capacity for exploratory learning since a too heavy load may discourage him/her to explore.

This paper describes a methodology for supporting exploratory learning with educational systems which are equipped with various technologies such as multimedia, hypermedia, simulation, demonstration, virtual reality, etc., for letting learners to explore domain concepts/knowledge. This methodology attempts to limit learning space, called exploration space, provided by these systems to adequately control the cognitive load the learners would face in their exploration process. We call this methodology 'Exploration Space Control' (ESC). The exploration space consists of information space and exploration operations to be given to the learners at a particular moment. The information space is specified by the extent of information resources which include learning content. The exploration operations are the ways to access the information resources such as search, selection, application, or so on. In ESC, the extent of the exploration space is controlled according not only to the domain complexity, but also to the learners' competence, understanding levels, experiences, characteristics, etc. The control is done by restricting exploration tools provided in user interface, tailoring information to be presented, recommending a few among a number of choices, etc.

ESC can adopt two extreme approaches: active learning support and step-by-step learning support. The former approach tries to limit the exploration space as less as possible to confront learners with as many efforts to explore as possible. This limitation intends to protect the learners from cognitive overload. The latter approach tries to limit the exploration space as much as possible, and gradually extend the space explored to let learners make exploration efforts. The combination of these two approaches in varying quantity can facilitate adequate exploratory learning for a whole spectrum of learning competence.

Current work on educational systems supporting exploratory learning has proposed several methods such as navigational aids, information tailoring, etc., for reducing cognitive load on explorations. However, these methods are not always identified with the methods of controlling the exploration space. In this paper, we address the issue of integrating and reorganising the existing methods from a view of the exploration space control.

This paper also demonstrates an application of ESC to an interactive simulation-based system in the domain of human ear. This system forms a part of InterSim project, which aims to enhance learning of the structure and functionality of organs in medical domain and to improve appropriate skills in diagnosing and treating the related diseases. The system provides several kinds of information resources for exploring the ear and user interface with several exploration tools. Since the target audience is medical students or doctors in continuing medical education who already have the basic knowledge of the ear and need to get competence in skills, the system mainly aims to facilitate active learning rather than step-by-step learning processes.

2. Exploration Space Control

2.1 Exploratory learning

Exploration is a self-directed mental activity. The purpose of exploration is to find out and comprehend concepts/knowledge embedded in target domain. It is therefore different from browsing or mere rote reading. In a domain such as medical discipline which requires both the understanding of conceptual knowledge and the competence in the domain related skills, the exploration may moreover involve applying the understood conceptual knowledge to certain problems/situations to acquire the cognitive skills. The skills are assumed to be developed in a constructive manner where the knowledge is constructed from what learners do in their experiential worlds (Akhras & Self, 1996).

The exploration activity is often accompanied by cognitive efforts to develop and apply domain concepts/knowledge. These efforts would contribute to enhancing their learning (Kashihara, Hirashima, and Toyoda, 1995).

In most educational hypermedia systems, simulation-based learning systems and simulation-based training systems, learners would be provided with exploration environments. Actually, they would learn domain by accessing various information resources supplied with hypertext, demonstrations, simulations, and so on. In this sense, the exploration activity in the educational systems can be defined as searching these information resources to comprehend the information and to acquire the domain concepts/knowledge. The comprehension and acquisition involve mutually integrating the information from different resources, and integrating new information into existing knowledge. The extent of the exploration activity can be specified by the extent of the information resources which explicitly or implicitly include the domain concepts/knowledge, and by exploration operations such as search, selection, application, integration etc. This is called exploration space.

2.2 Educational tasks needed

Learners should be normally free to explore since finding out domain concepts/knowledge by themselves would enhance their learning (Carroll et. al., 1985; Kamouri et. al., 1986). Hence learners should be able to explore various paths in an exploration environment. However, learners may make excessive cognitive efforts to search and integrate the information from different information resources, which itself may cause cognitive overload (Kashihara, Hirashima, and Toyoda 1995). The exploration space, in addition, may be quite wide so they may not know what to and how to explore and then may lose their ways. For instance, it is harder to learn something in case of complex domain such as learning of human organs in medical domain since the exploration space would be composed of a number of information resources. Therefore it may be necessary to adaptively control the exploration space to facilitate adequate learning.

There are two extremes of tasks to be performed by the exploration space control. The first one is to enable learners to explore as wide space as possible. This enables them to have as many efforts as possible in their exploration processes. The second one is to prevent learners from reaching a lot of impasses. Too many impasses would confuse the learners, decreasing their motivation to continue exploring. Help should be accordingly provided when necessary. These two extremes bring about the necessity to control the exploration space according to learners' levels of domain knowledge understanding so that they can make more efforts without too many impasses.

Current work on educational systems for supporting exploration has already proposed several methods for reducing difficulties in exploring instructional material. For example, some hypermedia systems navigate the exploration paths that learners should follow (Boyle & Encarnacion, 1993; Kaplan et. al., 1993) and tailor the information to be presented to them (Kobsa et. al., 1994). Such navigation and information tailoring contribute to making it easier for the learners to search and comprehend domain concepts/knowledge. Some simulation-based learning and training systems also restrict simulation parameters characterizing behavior of objects such as organs and electric circuits (Eliot & Woolf, 1995). This makes it easier to interpret the behavior from simulated results. In addition, some systems sequence the problems in such ways which focus learners' attention on specific parts of the domain (Halff, 1988). Such problem ordering allows the learners to get a good understanding of the domain in a gradual manner.

The aims of these methods can be viewed as controlling the exploration space to be looked into by the learners. The navigation would restrict possible paths to be searched in information resources; the information tailoring, and possible interpretation (comprehension) of the presented information. The parameter restriction for simulation would restrict the amount of presented information which needs to be understood. The problem ordering would also restrict the scope of domain to be looked into at a time. However, these methods are not always identified with each other as the methods of controlling the exploration space. In this paper, we also address the issues of integrating and reorganising these methods from a view of the exploration space control.

2.3 Framework

Figure 1 shows an exploration space. As explained earlier in 'Introduction' section, the exploration space consists of information space (the extent of information resources to be given to learners at a particular moment) and exploration operations (the ways to access the information space). The information resources include learning content. The exploration operations are similar to the ones used in a user interface such as mouse-clicking a button, selecting a link, etc.

Exploration Space Control (ESC) methodology controls the extent of the exploration space to be presented according to domain complexity and learners' competence, understanding levels, experiences, characteristics, etc. ESC can be accordingly employed to facilitate proper learning environment for all types of learners. According to this methodology, the learners would be able to use several tools through suitable graphical user interface to explore the learning contents. Since the overall space of learning content would be too large for the learners, typically the ESC would either restrict the exploration tools and information to be presented or recommend few choices according to the learner's perception and understanding level. However, the ESC would try to keep this restriction/recommendation as less as possible, and would reduce it with learner's progress of subject matter understanding.

In the following sections, we explain the purposes, control levels, design considerations, and methods of ESC in detail.

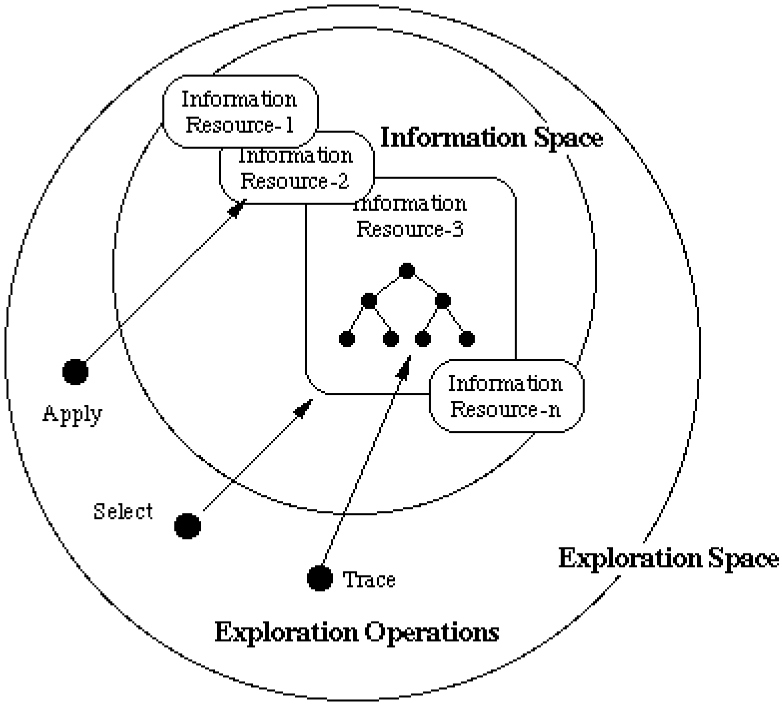

Figure 1: Components of Exploration Space.

2.3.1 Purposes

The purposes of ESC are as follows:

- *to facilitate active learning.* This approach is suitable for the learners who have higher learning competence at a given point of time in a particular learning content. The active learning is provided by reducing cognitive load, which the learners would have to face (or overcome) for learning. The reduction in cognitive load is kept as less as possible in this approach and 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 a 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 cognitive 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 (Kashihara et. al, 1995). Although ESC can adopt these two approaches, the active learning support is assumed to be more important than the step-by-step learning support since the exploratory learning demands active participation of the learners.

2.3.2 Control levels

Various levels of controlling an exploration space exist, in the form of restrictions, warnings, and suggestions imposed on learners, according to learner models and domain complexity. The control levels, which are to be considered in ESC, are as follows:

- **Embedding information.** This facilitates the creation of information space and involves scaffolding. What learners learn by exploration depends on the contents embedded in information resources. What kind of and how much information should be embedded depends on educational goals which mean what educational systems expect learners to learn. In order to support understanding conceptual domain knowledge, for example, it is necessary to provide some information in the form of texts, figures, demonstration and so on, which explains the conceptual knowledge. In order to support acquiring domain-related skills, on the other hand, it is additionally necessary to provide simulation environment.
- **Limiting information resources.** When the information space includes various resources, learners may have difficulties in deciding which information resource should be visited, and in integrating the information from different resources. It is therefore necessary to limit the information resources which are to be presented to the learner in that situation. For example, only simulation environment could be made available if learners should focus on applying domain knowledge to acquire skills. Two kinds of controls are used at this level:
  - Limiting the number of information resources. This controls the amount of information resources to be presented.
  - Presenting information resources appropriate for looking into current domain material. This controls the types of information resources to be presented.
- **Limiting exploration paths.** When an information resource has a complicated structure of information, learners would have difficulty in finding out and comprehending domain concepts/knowledge. Therefore, it is necessary to limit the exploration paths in

the information resource. For example, the paths should be limited by restricting navigational paths in hypertext or by controlling various parameters in simulation environment. Two kinds of controls are used in this level:

- Limiting the number of feasible exploration paths to be looked into.
- Limiting the exploration paths which are non-feasible or unrelated to the current domain material.

- **Limiting information to be presented.** When the information included in an information resource is complicated and hard to comprehend for learners, it is necessary to limit and tailor the contents of information to be presented to them according to their capacity to comprehend. For example, more concrete and detailed information would be presented if learners are expected to have lower capacity to comprehend. There are two methods to provide such control:
  - Limiting the amount of information.
  - Adapting the contents of information to each learner.

2.3.3 Design considerations

Figure 2 shows an overview of the control structure in ESC methodology. This control can be represented with two axes: "what to control" and "how to control". In this section, we shall consider how to decide what to control, and how to limit the exploration space at that level. Figure 3 shows three main steps for this issue.

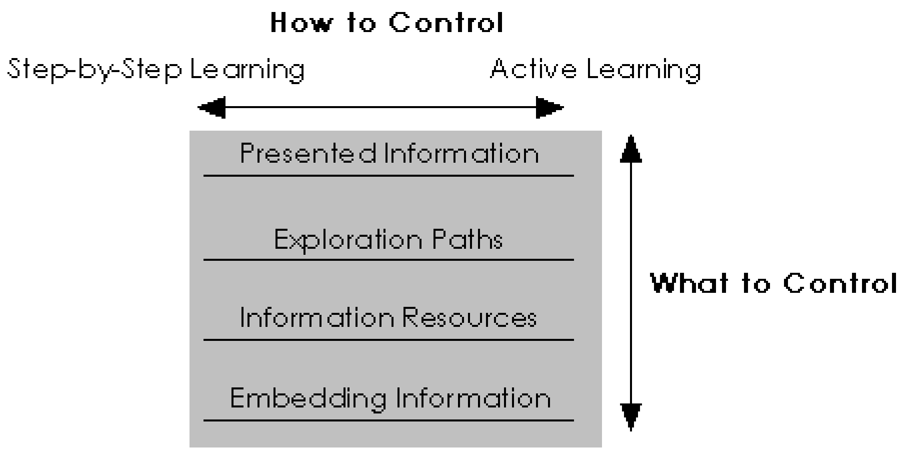

Figure 2: Overview of ESC

(1) Embedding information

a. Identifying educational goals

b. Selecting and developing information resources with the decision of:

- Amount of information
- Contents of information
  - Abstract / Concrete - Detail - Theory / Example

and with:

  - Hypertext - Simulation - Demonstration...

c. Providing exploration tools

(2) Deciding what to limit in the information space according to:

- The number of information resources
  If the number is large, *limiting information resources* should be considered
- The structure of information in an information resource
  If the structure is complicated, *limiting exploration paths* should be considered
- The comprehensibility of information to be presented
  If the comprehensibility is low, *limiting information to be presented* should be considered

(3) Deciding how to limit the information space according to:

- The purposes of ESC:
  - Active learning support - Step-by-step learning support
- Learner models representing:
  - Preferences - Knowledge levels - Experiences
  - Competence - Exploration processes - Cognitive load

Figure 3: Considerations in Designing ESC.

First of all, embedding information in information resources is indispensable for all educational systems supporting exploratory learning. This requires identifying educational goals which these systems expect learners to accomplish, and then selecting and developing various information resources necessary for carrying out each educational goal with various technologies such as hypertext, simulation, demonstration, etc. The development of the information resources includes the decision about the amount and contents of information to be embedded. This decision should be done in consideration of the models of the target learners. If a quite novice would become the target learner, for example, it is necessary to embed more concrete and detailed information, and more examples. The information embedding, in addition, requires providing several tools for exploring the information resources and for integrating the information from different resources.

Second, what to control in the information resources mainly depends on the domain complexity. The domain complexity can be viewed as the amount and contents of the embedded information. If there are many information resources in the exploration space, *limiting information resources* should be considered. If an information resource has a complicated structure of information, *limiting exploration paths* should be considered. If the information embedded in an information resource is hard to understand, *limiting information to be presented* should be considered.

Third, how to limit information resources, exploration paths, or presented information depends on the purposes of ESC and the models of the target learners. In supporting active learning, the information space should be limited as less as possible so that the learners can make as many efforts to explore as possible. In this case, the limitation of the amount of resources, paths, or presented information should be first considered since learners can think of the contents by themselves. In supporting step-by-step learning, on the other hand, the information resources, exploration paths, or presented information should be limited as much as possible. In this case, it is necessary not only to limit their amount but also to limit them to the appropriate ones for learners so that the learners can make as few efforts as possible. The extent of these limitation should be decided in consideration of the learner models representing various factors such as preference, knowledge levels, experiences, competence, exploration processes, cognitive load, etc. Fundamentally, the lower the knowledge levels, competence, etc. are, the larger the extent of the limitation is.

2.3.4 Methods

Let us next discuss what are the existing methods for supporting exploratory learning control. Table 1 summarises the relationships between ESC and the existing methods.

There are two representative methods of embedding information: Scaffolding and Enabling. Scaffolding methods mainly embed domain concepts/knowledge to assist learners in forming or acquiring the domain concepts/knowledge. Enabling methods, on the other hand, provide an environment where learners can operate objects to get skills.

Regarding the control of information resources, there is hardly any method in current work. Since most educational systems include single or a couple of information resources, they are hardly aware of the necessity to limit the information resources to be presented to learners. In complex domain such as learning of human organs in medicine, however, it becomes important to control the information resources to be presented.

There are a lot of existing methods for controlling exploration paths and presented information (Brusilovsky, 1996). Current educational systems usually present adaptive help with these methods so that learners can explore the information space with fewer exploration efforts. However, it is possible to use the same methods to let learners make more efforts without cognitive overload so as to support active learning as discussed in section 2.3.3. We will demonstrate this kind of control in section 4 while discussing the implementation of ESC in InterSim project. Before that, we shall discuss the related work to ESC in the following section.

Control Levels	Current Methods
Embedding information	Scaffolding, Enabling
Information resources	
Exploration paths	Navigational aids, Simulation setting, Problem ordering (Courseware)
Information to be presented	Information tailoring, Information ordering

Table 1: Relationships between ESC and current methods.

3. Related work

Literature provides various other methodologies to support exploratory learning process of a learner. In this section, we discuss the relationships of ESC with two prominent methodologies namely cognitive apprenticeship (Collins, Brown, and Newman, 1989) and guided discovery (Elsom-Cook, 1990).

3.1 Cognitive apprenticeship

The purpose of the cognitive apprenticeship is mainly to provide learners the skills of the domain. In the educational systems with this methodology, learners are usually expected to first observe and imitate problem-solving processes as performed by a master, and to try out the same processes (Looi and Tan, 1998). They can compare their solution with the master's one, and get some feedback from the master. The learners are then expected to solve other similar problems by themselves. During the problem-solving, they can reflect on their own solutions with the master's advice. The feedback and advice from the master are gradually reduced as the learner's competence increases.

At the early stages of the learning process, the cognitive apprenticeship methodology strongly restricts a learning space regardless of the learners' capability of learning so that they can focus on the observation and imitation of the master's solution. Although the learners can explore the solution by themselves at the later stages, the exploration is fairly biased by the master's solution and advice. This kind of support corresponds to the step-by-step learning support in ESC. Still, ESC provides not only this kind of learning support but also an exploration environment where user control does not lend for the exploration activities to be much biased. For example, ESC can provide learners with an exploration environment where they can first solve a problem by themselves, then observe/imitate a master's solution without the master's advice, then select and solve other similar problems by themselves.

3.2 Guided discovery

The main purpose of the guided discovery methodology is to lead learners to discover domain concepts with various learning facilities such as simulation, demonstration environments, and so on. In general, discovering some concepts by observing physical or mathematical phenomena is extremely difficult without guidance. The guided discovery methodology accordingly focuses on how to guide learners in their own discovery.

Most educational systems with this methodology, such as microworlds, usually take notice that learners can find domain concepts without too much difficulty. These systems particularly focus on how to embed and structure information in simulation environments so as to reduce the difficulty in discovering domain concepts. For example, some physical phenomena are represented visually in the way that learners can find out physical concepts from the representation. However, it is not so easy to discover the concepts even with the embedded information. The systems then present adaptive and stepwise guidance/feedback during their explorations.

In this methodology, however, there are few methods of changing the degree of the difficulty in discovering domain concepts according to learners' capability of learning. ESC can be seen as an attempt to address this issue by controlling the exploration space to be given to learners.

4. ESC in InterSim project

The ESC methodology is being applied in the InterSim project for the system in the domain of human 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 human ear and the provision of user interface to allow learners to make exploration operations. The system is aimed for medical students with special interest in domain of human ear and for doctors in continuing education who want to specialize in the field. These users are assumed to be motivated to learn and having background knowledge of the domain, and therefore the system facilitates active learning rather than step-by-step learning process.

4.1. Design approach

4.1.1. Embedding information

Once the target users of the system are identified, the next step in the design process required determining the domain content, which these users are expected to comprehend, and embed that content in the system. To follow the recommendations of ESC regarding amount and content of information to be presented to the learner at a time, the domain content has been structured in a network of 'views' where a view consists of a domain unit (or concept). The views are interconnected according to the semantic relations among various domain concepts. Figure 4 shows a partial view of the domain content structure.

The embedding process of the domain content, as recommended by ESC, required three main steps to follow (please refer figure 3).

a. The first step was to identify educational goals of the system. Two main goals were identified:

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

b. The next step was to select and develop information resources by deciding two factors:

- Amount of information
- Contents of information

At the same time, the decisions were needed for the techniques (for example, hypertext, simulations and so on) to be used to present the information for both educational goals.

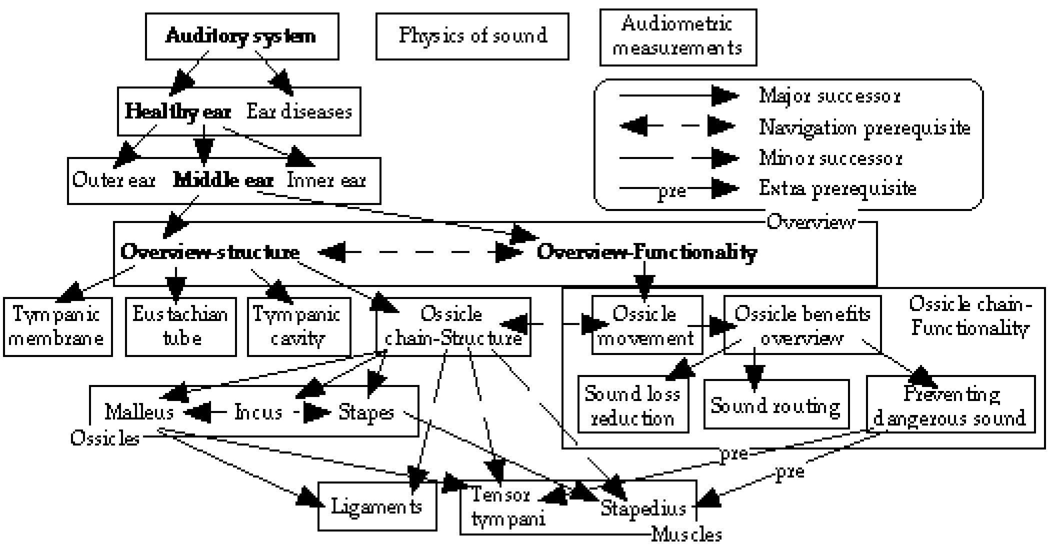

Figure 4: Partial conceptual layer of learning material for ear domain.

First education goal

To fulfil the first educational goal of understanding the structure and functionality of human ear, the domain content needed to be rather conceptual and more observation based to provide a mental map of the domain content, rather than attempting to give any cognitive skills. This did not mean that the presentation would only be receptive and not interactive, but any task oriented knowledge and experience based learning was not the major focus. After analyzing the content for adequate amount and content of the information as recommended by ESC, it became clear that the content needs to be arranged differently in different phases of a learner's learning process. As explained in section 4, all the learners of the InterSim system are assumed to be active type, so no consideration is given for passive or receptive learners.

For a novice learner, the views would be rather explanatory, covering details, and both theory and examples of the domain, and generally divided in two complimentary parts: graphic visualization and textual/audio part. Graphic part would contain static pictures, animations, simulations, virtual reality scenarios and so on, whereas textual/audio part would contain concepts and supplementary information for the current graphic visualization (figure 5).

For an intermediate learner, who has been to such an explanatory view, learning by problem solving views would be presented which would contain problems based on those explanatory views, the learner has already visited. The problems in this section would assess learner's theoretical understanding.

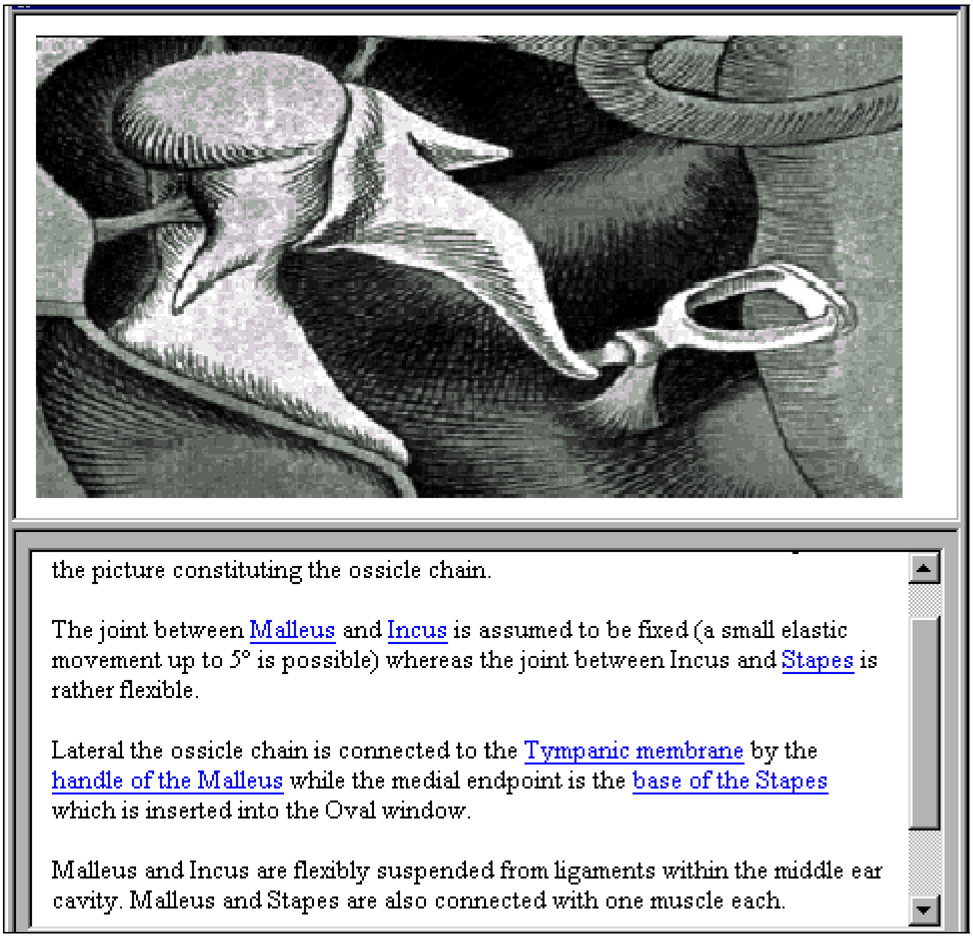

Figure 5: An example view of structure of ossicle chain.

For a learner, who has shown expertise in a particular concept by successfully solving the problems related to that domain content, the revisit to the domain content would require summarized representation of what that learner has already learnt, for revision purposes. Such a view would be rather abstract, containing schematic representation of previously elaborated graphic representation, key points in text or audio form, along with a link to explanatory presentation which was presented in earlier visit, if learner wishes to go in details again.

An analysis of the domain content for first educational goal revealed that the suitable information resources for such content are Hypertext, Demonstration, Simulation and Problem Ordering.

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

Second education goal

For the second educational goal of acquiring appropriate cognitive skills in diagnosing and treating the related diseases, the major focus was needed on application of theory into practice and on decision making. Analysis of domain content for second educational goal from ESC recommendations point of view suggested that cognitive skill development would require an overview of all major decision possibilities for diagnosis and treatments as well as a fine grained insight of each disease in detail. Therefore the domain content was structured in three different sections, with little overlap of content to give seamless transition from one section to another, and each section with a different focus: *symptoms* oriented section, for recognizing diseases and their variations from symptoms; *development* oriented section, to get experience of how diseases can advance and possibly convert to another diseases, and what diagnosis and interpretations of diagnosis are required to differentiate among these possibilities; and *disease* oriented section, for detailed knowledge of particular diseases, and specific treatments.

The domain content in *symptom* and *development* oriented sections has been then structured in the form of flowcharts, with each node and path containing specific details of that particular area (figure 6).

The content in *disease* oriented section is structured in self-contained small inter-linked views (for example, introduction, phases, cases and treatment) for each disease. These small self-contained islands provide detailed information about particular diseases and also present the learners various specific, rare and notorious cases of the field so as to equip them with cognitive skills which generally are acquired after years of experience. This approach allows learners with different conceptual levels to acquire skills at a cognitive level appropriate for them.

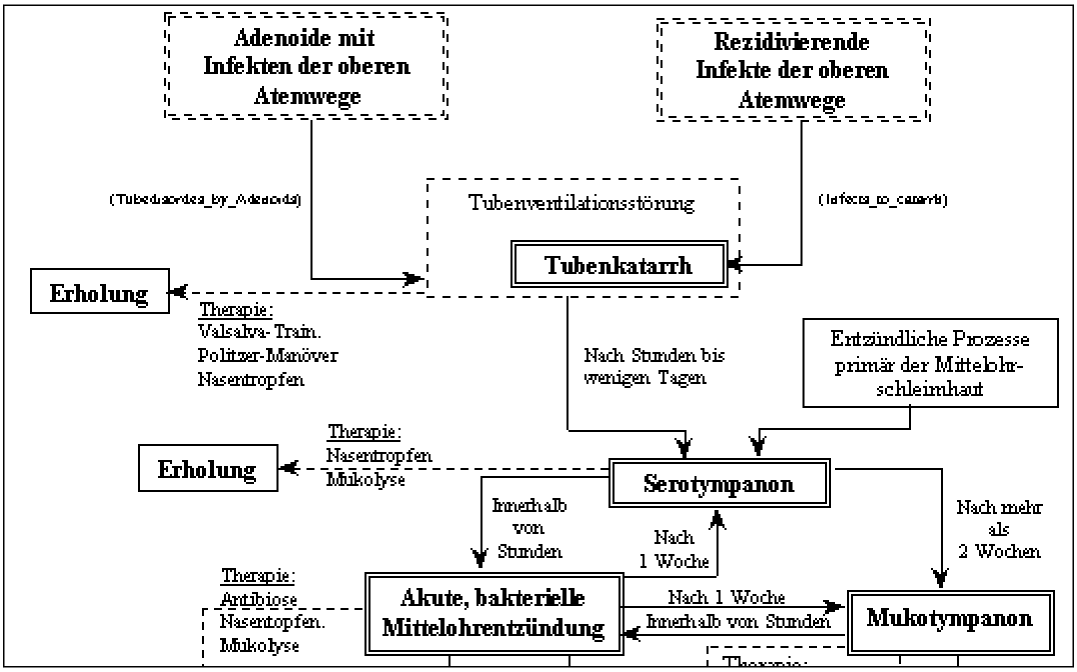

Figure 6: A partial flowchart of development oriented section (German version).

The novice learners can first get basics of diseases in *disease* oriented section. Once getting the fundamentals, the intermediate learners can visualize the relationships among various diseases in *development* oriented section. Once the learner is ready with intricacies of the diseases, experience in diagnosing and interpreting the symptoms of patients, as is the case in real practice, could be achieved in *symptoms* oriented section. At each stage, learners are advised to attempt problems related to that particular section in order to identify any mis- or missing conceptions in obtained knowledge and cognitive skills.

The next step in the design process for second educational goal according to ESC is to select appropriate information resources. After analyzing the domain content, it was decided that to develop cognitive skills, the domain content demands simulations, design and problem ordering information resources.

- **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.

Once the actual domain content was specified and information resources were identified for each part of the system, it was rather easy task to provide exploration tools as recommended by ESC. For example, the system provides textual links and image maps (sensitive parts in static pictures) to explore Hypertext and Hypermedia. Animations and demonstrations (guided tours) are explored by various controls provided on control panel. Simulations are provided with various tools (in the form of icons), sensitive objects for selection and controls to change simulation parameters. Buttons, combo-boxes, radio buttons and some other standard controls are used to facilitate general navigation.

The restrictions imposed on the number and type of exploration tools to be provided to the learner at a given point of time according to ESC becomes a part of system's adaptive guidance strategy, as explained later in the paper.

4.1.2. Deciding the limits of information space

ESC recommends limiting the information space available to the learner for exploration at a given point of time according to three factors:

(i) limiting information resources, if the number of information resources is large in a particular domain content;

(ii) limiting exploration paths, if the structure of particular domain content is complicated; and

(iii) limiting information to be presented, if a particular domain content is hard to understand.

In InterSim system, the information space is limited by activating, inactivating and recommending the choices in various controls in the interface, dynamic presentation of navigation aids as part of system guidance, and changing the domain content presentation in views according to learner's competence level and / or current context.

An important example in InterSim system for limiting the information space 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 domain content in more depth.

4.1.3. Deciding how to limit the information space

The third step is to decide how to limit the information space. ESC recommends limitation of information space according to two factors:

(i) the purpose of ESC in the system; whether ESC is used for active learning or for step-by-step learning support. As explained in section 4, the users of InterSim system are medical students with special interest in human ear studies, and doctors in continuing education. These users are supposed to be motivated to learn and explore, and assumed to have some background knowledge of the domain. Therefore ESC in InterSim system is used for active learning.

(ii) the presentation of following attributes in learner models:

- Preferences
- Knowledge levels
- Experiences
- Competence
- Exploration processes
- Cognitive load

The InterSim system therefore employs learner models, which contain above attributes of learner to facilitate proper adaptation in guidance, advice and recommendations as prescribed by ESC. The learner models are enhanced overlay type where the enhancement is multi-fold: the models not only keep the learner's progress through domain content, but also specific preferences, and information regarding meta-learning aspects (such as familiarity with interface etc.). The progress through each unit of domain content is recorded as three stepped competence:

a. *Initial level:*	No competence
b. *Intermediate level:*	Content observed by the learner, but related problems not attempted (or not attempted successfully)
c. *Expert level:*	Learner showed competence in domain content by attempting related problems successfully.

A learner can explicitly access the problems of a particular domain unit, and a successful attempt will update the learner model to record expertise in that particular domain content. Further system recommendations would then consider this fact. An unsuccessful attempt would bring-up an advice from the system to go to the units which are prerequisites for the attempted problem.

The presentation of above attributes in the InterSim learner models are as follows:

- Preferences:

The models reflect various preferences of learner, for example, towards the interface representation of graphic visualization of domain content. One such example is pictures with or without names. Although learner can explicitly decide, but if learner has not shown any explicit preference, the system tries to infer the preference from learner's interaction with the system. The inference can take place from the fact that learner switches the pictures from name to no-name or vice-versa in a deciding manner, or learner demands name list (a dialog showing the names of all parts in the picture; clicking on the name highlights the part in the picture) repeatedly.

- Knowledge levels:

This attribute is recorded as part of learner's competence in various domain units, and the effect reflects in the content representation by the system to the learner. If the learner has shown high knowledge level in a particular unit, the revisit to the unit would cause the system to provide a summarized representation rather than the detailed presentation shown to the learner in earlier visits.

- Experiences

This attribute is recorded in the learner models in terms of what kind of representation learner has received for a particular domain unit. As explained earlier in section 4.2, the learner can be presented a domain unit either as a main learning unit, or as excursion. Another advantage of this attribute is to identify any analogy-based explanations which could be presented to the learner for better understanding. Such explanations could either be domain-based (for example, variations of Acute Otitis Media disease), or meta-learning related interface representation based (for example, desktop virtual reality scenarios and interactive movies).

- Competence

This attribute is solely related to the second educational goal of the InterSim system, namely, acquiring appropriate cognitive skills in diagnosing and treating the related diseases. It helps the system identifying the situations when the learner has shown competence in one type of cognitive skills so that the system can advice to proceed to another type. For example, if a learner correctly diagnoses the diseases based on the structure of tympanic membrane (or otoscopy), the system can then advice to attempt the diagnosis based on audiograms and tympanograms to get cognitive skills related to the interpretation of graphs.

- Exploration processes

The InterSim system records this attribute for the meta-learning processes, specifically in relation to the complex tasks which require intermediate intervention of the system to get the learner familiar with the interface representations. The intervention gradually reduces with learner's increasing familiarity with the system. For example, for a new learner, who is not familiar with a certain type of simulation environment within the system (for example, figure 7), the system provides detailed contextual help in using various tools and controls. Once the learner gets accustomed with the environment, the system reduces the amount of help in that and similar environments.

- Cognitive load

  This attribute is recorded on the basis of learner's performance in the system (as observed in problem solving views), and interactions with various interface components. For example, if the learner is repeatedly unsuccessful in a particular domain unit assessment, the system assumes the cognitive load to be too high for the learner for that amount of complexity as exhibited in that domain unit. The system then recommends the learner to either go in a less complex unit, or to use interface based help features, such as pictures with names or name-lists.

4.2. Experiences in system design

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 designers of the system found the ESC methodology quite helpful in designing the system. The most difficult tasks of sorting theoretical background and decisions regarding domain content presentations for learner's various levels of competence, were simplified by ESC. Since the system was designed only for active learning process, the benefits of ESC for step-by-step learning could not be verified. A great advantage which designers felt was that ESC, though providing a detailed procedure for system design, did not restrict the designers in using various interface components. Also, this independence of using any such components within ESC allows inclusion of new technology as it develops, without making the ESC methodology itself obsolete.

Though in InterSim system, the attributes of learner models provided adequate adaptivity, the designers felt that this area may need expansion for gaining similar adequacy in other systems. For example, 'motivation' could be one important factor in 'step-by-step' learning because the learners are not assumed to be initiators of learning process. A system design, based on 'step-by-step' learning, can only verify if 'motivation' needs to be taken as additional attribute, or can be inferred from already existing ones.

5. Conclusions

The implementation of 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.

ESC has been found useful in not only providing adequate domain knowledge but also cognitive skills of the disciplines, and therefore should be applicable for a large number of disciplines. But further research is needed to make it more generalised so that it could be used in developing other 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.

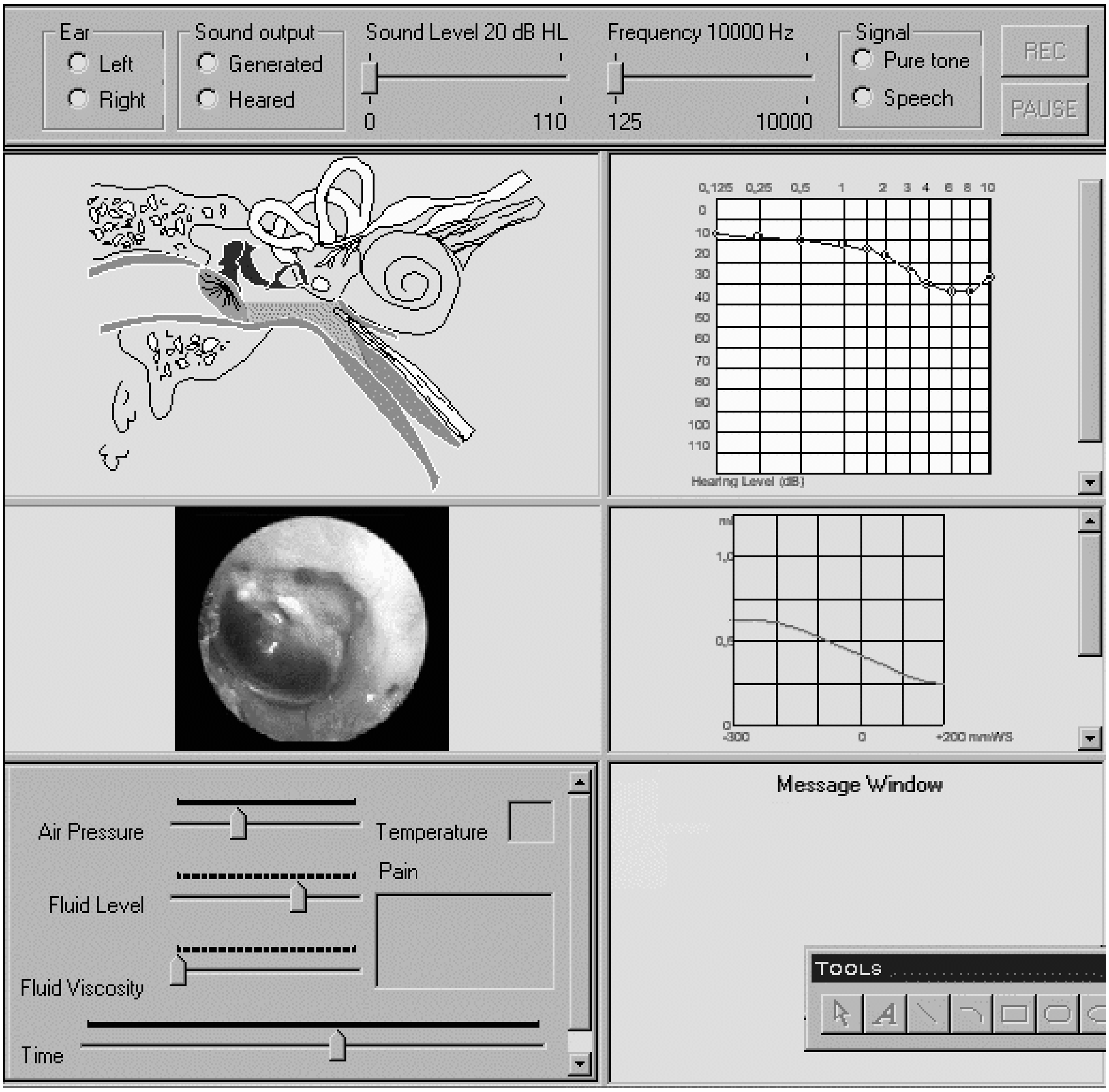

Figure 7: User Interface of a disease simulation in InterSim System.

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