AN EXPLORATION SPACE CONTROL AS INTELLIGENT ASSISTANCE IN ENABLING SYSTEMS

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Abstract: In order to support learning-by-exploration involving the understanding of domain concepts/knowledge and the skills in domain related tasks, it is necessary to provide facilities which enable learners to explore domain with less restriction, and to consider intelligent assistance which adequately limits the learning space (called exploration space). Although there have existed already such intelligent assistant methods such as navigation, information tailoring, etc., these are not always sharable and reusable among designers and developers. This paper proposes a new concept of Exploration Space Control to generalize the educational tasks of supporting exploration. Following this concept, this paper also provides preliminary vocabulary for describing Exploration Space Control and a design rationale for implementing Exploration Space Control as an intelligent component. In addition, the paper describes the application of the design rationale in InterSim project, which project aims to facilitate learning structure and functionality of organs and to improve appropriate skills in diagnosing and treating the related diseases.

1. INTRODUCTION

Exploring domain concepts/knowledge by oneself is an effective way of learning (Kamouri et al.,1986). In domains such as computer devices and medical discipline, the learning-by-exploration may involve not only understanding conceptual knowledge embedded in the domains but also acquiring skills in the domain related tasks (Carroll et al.,1985; InterSim Project,1996). In this paper, we focus on how to support such learning-by-exploration.

One primary way to the support of the learning-by-exploration is to provide facilities which enable learners to explore domain concepts/knowledge to acquire cognitive and procedural skills. These enabling facilities can be developed with current educational technologies such as multimedia, hypermedia, simulation, demonstration, etc. There actually exist educational systems that implement exploration environments where learners can look into domains with fewer restrictions. In this paper, we call these systems educational enabling systems.

However, it is not so easy for learners to find out domain concepts/knowledge by themselves and to develop the skills in the domain related tasks. Educational enabling systems should be accordingly equipped with intelligent assistance. In particular, it is necessary to adequately limit the learning space (called exploration space) where they would explore domains.

Current research on educational enabling systems has proposed intelligent assistant methods such as navigation, presentation tailoring, etc. However, these methods are not always sharable and reusable among researchers and developers although all of these systems aim at supporting learners' exploration activities. One approach toward the sharability and reusability is to provide designers with well-designed common vocabulary (ontology) that explicitly describes educational tasks domain-independently (Mizoguchi,Sinitsa,& Ikeda,1996). Such vocabulary gives the designers a guideline for synthesizing new educational enabling systems, then reduces the efforts to develop them.

In this paper, we propose a new concept of Exploration Space Control (ESC for short) to generalize the educational tasks of supporting exploration. Following this concept, the paper also provides preliminary vocabularies for describing ESC.

In the following sections, we first discuss the ESC methodology which facilitates proper exploration environments for all types of learners. Second, we describe a design rationale of this methodology which show how to design intelligent components in educational enabling systems. Following the design rationale, this paper next demonstrates the implementation of ESC in InterSim project. The InterSim project aims to facilitate learning organs in medical domain. Currently proposed domains are Ear, Brain and Loss of Consciousness, and preparation for prototype has been started for the ear domain. This paper will therefore concentrate on the application of enabling systems in facilitating the learning of structure and functionality of the ear and appropriate skills in diagnosing and treating the related diseases. The paper finally concludes with identifying some research aspects which need further investigation.

2. EXPLORATION SPACE CONTROL

2.1 Exploration

Exploration is a self-initiated learning activity. The purpose of exploration is to find out and comprehend concepts/knowledge embedded in target domain. 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 acquiring the skills.

In most hypermedia systems, simulation-based learning and training systems, learners would be provided with exploration environments where they can explore various paths to solve problems. Actually, they would 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 searching these information resources to comprehend the information and to acquire 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, apply, integration etc. This is called exploration space.

2.2 Educational Tasks for Exploration

Learners should be free to explore since finding out domain concepts/knowledge by themselves would enhance their learning (Carroll et al.,1985). 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 (Kashihara,Hirashima,& Toyoda,1995). The exploration space, in addition, may be quite wide so they may lose their ways. For instance, it is harder to learn something in case of complex domain such as learning of organs 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.

Current work on educational enabling systems has already proposed several teaching strategies for reducing difficulties in exploring domain material. For example, some hypermedia systems navigate the exploration paths that learners should follow (Boyle & Encarnacion, 1993; Kaplan,Fenwich,& Chen,1993), and tailor the information to be presented to them (Kobsa,Mueller,& Nill,1994). Such navigation and information tailoring contribute to making it easier for the learners to search and comprehend domain concepts and knowledge. Some simulation-based learning and training systems also restrict simulation parameters characterizing behaviour of objects such as organs and electric circuits (Eliot & Woolf,1995). This makes it easier to interpret the behaviour 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 gradual manner.

The purpose of these educational tasks 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, possible interpretation (comprehension) of the presented information. The parameter restriction for simulation would restrict the amount of presented information to be understood. The problem ordering would also restrict the scope of domain to be looked into at a time.

Exploration Space Control (ESC) is a general term for these educational tasks. To explain the concept of ESC, it would be necessary to explain what is an Exploration Space. The Exploration Space consists of "Information Space" and "Exploration Operations" where the information space can be specified by the extent of information resources to be given to a learner at a particular moment for example hypertext, simulations, demonstrations and so on; and exploration operations are the ways to access the information space such as by navigation, selection or so on.

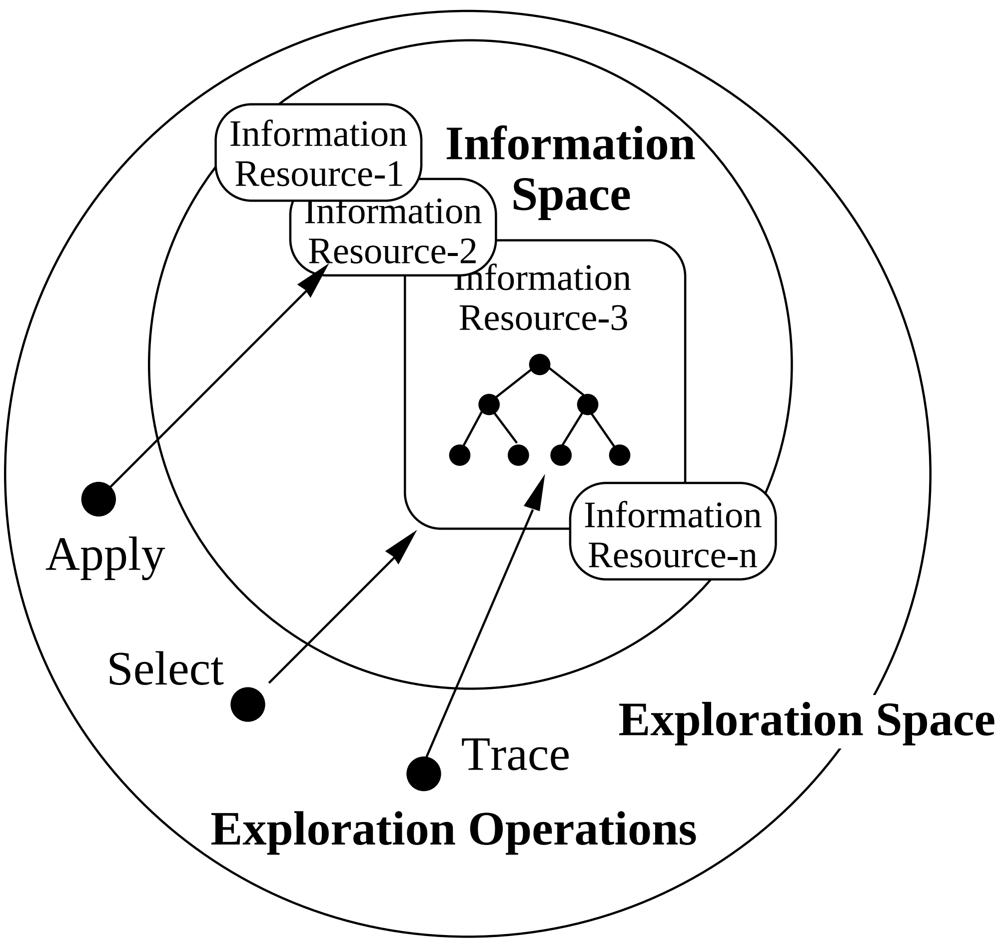

Figure 1: Components of Exploration Space Control.

ESC controls the extent of exploration space (see Figure 1) according not only to the domain complexity but also to the learners' competence, understanding levels, experiences, characteristics, etc.

Though ESCis a general term expressing tasks to support exploration, it is also a technology that integrates current technologies for exploration.

2.3 Overview of ESC

Exploration Space Control methodology would be 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 exploration space. Since the space would be too large for the learners, the system would either restrict the exploration tools and information to be presented or recommend few choices according to the learners' perception and understanding level. However, this restriction/recommendation intends to limit the exploration space, and to reduce the learners' cognitive load. This restriction/recommendation would be as less as possible, and would be reduced with learners' progress of subject matter understanding.

The purposes of ESC are as follows:

- ***to facilitate active learning***. This approach is suitable for the learners who have a 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 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 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 (Kashihara,Hirashima,& Toyoda,1995).

ESC is implemented at various levels of controls in the form of restrictions, warnings and suggestions imposed on learners according to their current status of subject understanding and capacity of exercising cognitive load. 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. This controls the amount of information resources to be presented to a learner at a particular moment.
  - Presenting information resources appropriate for looking into current domain material. This controls the types of information resources to be presented to 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. This control level is based on the context related to a learner and domain material. 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 non-feasible or 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.

Various current technologies can be used to provide different kinds of controls. Table 1 shows the relationships between Exploration Space Control and current technologies.

Current Technologies	Control Levels
Scaffolding	Embedding information
Navigation	Information resources & Exploration paths
Problem Ordering (Courseware)	Exploration paths
Information Tailoring	Presented information
Simulation Setting	Exploration paths & Presented information

Table 1: Relationships between ESC and Current Technologies.

3. DESIGN RATIONAL OF EXPLORATION SPACE CONTROL

There are three main steps in designing Exploration Space Control.

(1) At first the learning goals of the educational system should be identified and described in detail.

(2) Then the scaffolding methods should be selected. There are two steps for such selection:

(a) Selecting and developing various information resources necessary for accomplishing each learning goal. Few examples of various information resources, which could be selected, are Hypertext, Simulation, and Demonstration. The development of various information resources includes the decision about the information to be presented. Following list provides various criteria which should be taken into account during development phase.

- Amount of the information
- Contents of the information

Examples of contents are (i) Abstract/Concrete, (ii) Detail, and (iii) Theory/Example.

(b) Considering various exploration operations to be used in and between each information resource. Few examples of such operations are Select, Trace, Apply, Integrate, and Interpret (Understand).

(3) The next step in the design process of ESC involves the decision about which control level should be applied to which information resource. There are three steps in this process.

(a) Deciding the purpose of ESC:

- Supporting Active Learning
- Supporting Step-by-Step Learning

This step allows the designers to decide the ways of how to control exploration space.

(b) Deciding control levels to restrict the exploration operations in the information resources. Table 2 shows the relationships between ESC levels and exploration operations to be restricted in the levels.

Control Levels	Exploration Operations
Information resources	Select, Integrate
Exploration paths	Select, Trace, Apply
Presented information	Interpret, Understand

Table 2: Relationships between ESC and Exploration Operations.

(c) Deciding the application of controls according to learner models and domain models. This process facilitates control over the amount and contents of information to be explored. Various factors which need to be considered in learner models are as follows:
- Preferences
- Knowledge Levels
- Experiences
- Competence
- Exploration Process
- Cognitive Load (Mental Efforts)

Possible factors to be considered in domain models include:
- Type of knowledge
  - Procedural knowledge
  - Declarative knowledge
- Degree of detail (Granularity)
- Depth (Deep or Shallow)

4. EXPLORATION SPACE CONTROL AND INTERSIM PROJECT

The concept of Exploration Space Control is being applied in the InterSim project for the system in the domain of ear. The objectives of the system are to provide the competence in skills to medical students in the diagnosis and treatment of ear related diseases while facilitating the learning of structure and functionality of the organ. The main emphasis would be on the understanding of structural and functional aspects of the subject matter. The learning strategies in this domain would, therefore, require more visual, spatial and less abstract learning aids in structural and functionality understanding. The proposed application of the framework of ESC in InterSim project is shown in Figure 2.

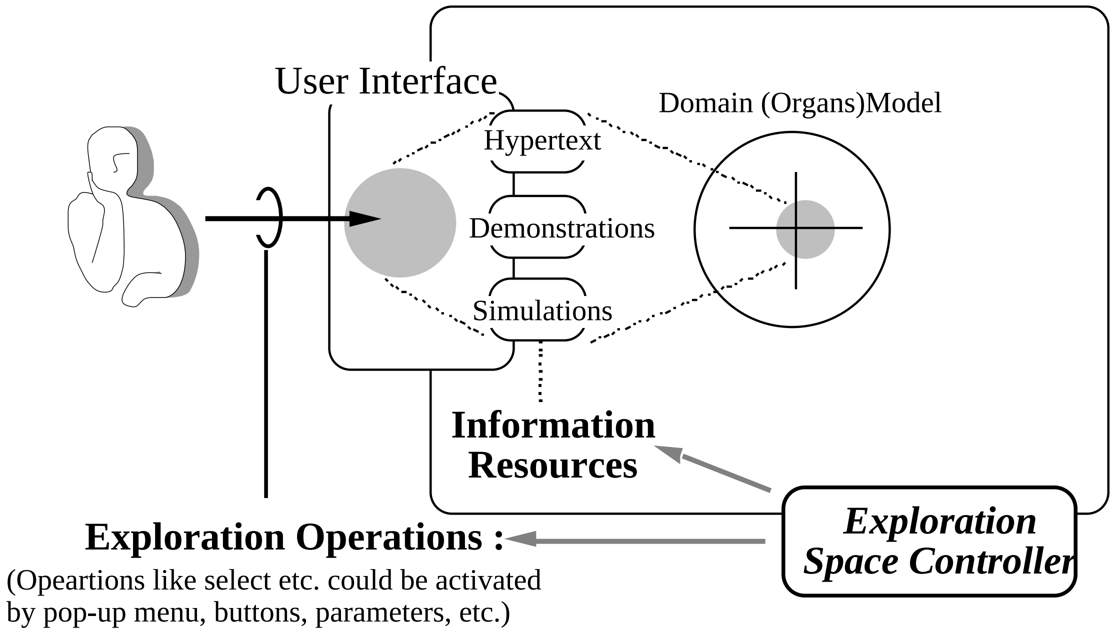

Figure 2: Exploration Space Control Implementation in InterSim Project.

The design and development of ESC for InterSim system will include the provision of several kinds of information resources for exploring the ear and the provision of user interfaces to allow learners to make exploration operations. Since the target audience for such systems are medical students or doctors in continuing medical education who already have the basic knowledge of the domain and who need to get competence in skills, the system is aimed to facilitate active learning rather than step-by-step learning process.

The following discussion provides a design plan of ESC for InterSim system in accordance to the design rationale described earlier. This description provides the conceptual design of the system and would benefit the system in its implementation. Various steps in the design process are as follows.

(1) Determination of learning goals.

There are two main goals of the InterSim system:

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

(2) Scaffolding.

The next step in the design rationale of ESC is to select various scaffolding methods.

(a) Selecting and developing information resources:

Since there are two aims of the InterSim system, both aims have different requirements towards the selection of information resources.

I. For understanding the structure and functionality of the ear, the suitable information resources are Hypertext, Demonstration, Simulation, Design 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 ear and to receive the simulated behaviour.
- Design facility enables learners to design and simulate faulty ear to deepen their understanding.
- Problem Ordering facility provides learners with a sequence of problems.

II. For acquiring skills in diagnosing and treating the related diseases, the suitable information resources are Simulations and Problem Ordering.

- Simulation facility provides an exploration environment for diagnosing and treating the diseases.

- Problem Ordering facility enables learners to solve (diagnosis and treatment) problems in order.

(b) Considering exploration operations:

I. For understanding the structure and functionality of ear, various suitable exploration operations within various information resources are as follows:

Exploration operations	***Information resources***
Select, Trace, Understand	Hypertext
Interpret	Demonstration
Apply, Interpret	Simulation
Select, Apply, Interpret	Design
Trace	Problem Ordering

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.

II. For acquiring skills in diagnosing and treating the diseases, suitable exploration operations within information resources are:

Exploration operations	***Information resources***
Apply, Interpret	Simulation
Select, Apply, Interpret	Design
Trace	Problem Ordering

In this case, 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 above mentioned information resources are: Select, Apply, Integrate.

(3) Deciding Control Levels.

The next step in the design process of ESC for InterSim system is to decide various control levels suitable to various information resources.

(a) The first step is to decide the purpose of ESC. In the context of InterSim project, the purpose is to provide Active Learning support.

(b) The second step is to decide various control levels. It is envisaged that all control levels are not suitable for InterSim application. Table 3 describes various control levels suitable for the two aims of the InterSim system.These controls 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.

Control levels	Operations in understanding structure and fanctionality of Ear.	Operations in acquiring skills in diagnosing and treating
Information resources	Select & Integrate among the information resources	Select & Integrate among the information resources
Exploration paths	Select, Apply, & Trace	Select, Apply, & Trace
Presented information	Understanding & Interpret	Interpret

Table 3: Control Levels for InterSim Project.

(c) The third step is to decide how to control various information resources. As suggested in the design rationale, there are two ways to decide the application of controls: according to learner models and according to domain complexity. Following examples are based on considering learner models in the InterSim system.

Example-1: Limiting exploration paths for understanding the structure and functionality of the ear.

Various aspects of limiting exploration paths are as follows:

- Restriction methods: Restricting 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-2: Limiting exploration paths for acquiring appropriate skills in diagnosing and treating the related diseases.

Various aspects of limiting exploration paths are as follows:

- Restriction methods: Restricting simulated parameters to limit Apply operation in Simulation.
- Exploration Competence: Low, Middle, High
- Knowledge Levels: Low, Middle, High
- The degree of the limitation of unrelated paths:
    - Strong when knowledge level is low, or when competence is low.
    - Weak when knowledge level is middle and competence is middle.
    - No limitation when others.

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

- Restriction methods: Tailoring information to be demonstrated or simulated to help learners interpret the demonstrated or simulated behaviour of ear.
- Knowledge Levels: Low, Middle, High
- The contents of presented information:
    - Overview of the behaviour of ear when knowledge level is low.
    - Intermediate detailed information of the behaviour when knowledge level is middle.
    - Full detailed information of the behaviour when knowledge level is high.

5. DISCUSSION AND CONCLUDING REMARKS

This paper demonstrated the application of Exploration Space Control approach in InterSim project. The evaluation of the InterSim system in the real working environment would verify the approach.

The concept of Exploration Space Control facilitates the designers of educational enabling systems to easily share and reuse the technologies which support the exploration in educational setting. It also enables the comparison of current educational enabling systems for supporting learning-by-exploration and facilitates the designers to extract the shortcomings of the systems. The design rationale of the Exploration Space Control makes it easier to build new educational enabling systems. It provides step-by-step procedure to determine the goals and objectives of the educational systems and help in selecting the suitable technologies to be used in such systems.

The next step in the Exploration Space Control development requires the structuring of the vocabulary for ontology of its description. Currently the vocabulary that we have presented in this paper is not sufficient and well-structured for defining Exploration Space Control. This therefore needs to be refined with the help of surveying the current literature on educational enabling systems. Once the ontological vocabularies are extracted, an explicit definition would be required to demonstrate the utility of such vocabulary by describing current educational enabling systems.

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