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Improving Conceptual Learning through Customized Knowledge Visualization

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***Abstract*—This paper describes a customized scaffolding approach to improve learner's conceptual understandings through knowledge visualization. We propose a framework to use natural language processing and graph based algorithms to automatic visualize individual learner's prior knowledge states, domain knowledge, new encountered concepts and to reveal the semantic relationships between them. Thus, we are able to help learners to solve their uncertainties of new merging ideas and concepts in their learning process in order to integrate new knowledge with their preconceptions.**

***Keywords*-visualization; knowledge representation; user interfaces**

I. Introduction

Many educational digital libraries have been developed to improve the science education in recent years by providing high quality educational resources for learners to build up their conceptual scientific understanding. With the vast amount of educational materials available, one key challenge for the learners is how to effectively locate and use the educational information available to fulfill their learning needs. This requires the learners to go beyond the ability to locate information and gains competence in seeking meaning and understanding [9]. To achieve this goal, the learners take actions to locate information about the general topic, read the relevant information and relate new information to what is already known. Kuhlthau' empirical study have shown that, when the learners explore on the information resources, they frequently feel confused, uncertain and doubtful because the new information encountered often not fits smoothly with their prior knowledge, and information from different sources frequently seems inconsistent and incompatible [9].

To address this challenge, we discuss the potential of visualizing learners' prior knowledge states and relating with domain knowledge to support learners' information seeking and knowledge integration process. We have been developing a "customized learning service for concept knowledge" [1]. This learning service aims to support learners' understanding of science through the automated diagnosis of learners' prior knowledge, misconceptions and to promote effective learning processes through the customized knowledge discovery and presentation. To support these customized services, we uses a rich and detailed conceptual learner model constructed using natural language processing techniques. This learner model comprises a learner knowledge model, a domain knowledge model and knowledge trace of what the learner knows about the domain. The details are reported in [1] [4]. In this article, we introduce our knowledge visualization approach to utilize this conceptual learner model to help learners to locate new concepts and to integrate them with their own knowledge. We have developed a visualization framework and algorithm to generate a representation of learners' current scientific understandings, domain concepts and their connections. Through this visualization, we are able to reveal: 1) the semantic relationships between the concepts in learners' own understanding; 2) the semantic relationships between learners' knowledge and domain knowledge; 3) the contextualization of new encountered information with learners' prior knowledge. With these revelations, we are able to help learners to solve their uncertainties of new merging ideas and concepts in their learning process and to integrate new knowledge with their preconceptions.

We use knowledge maps [11] to represent both the learner knowledge and the domain knowledge. Knowledge maps are a semiformal knowledge representation that uses a network layout containing richly descriptive statements in the nodes to capture concepts and ideas related to a domain, and a limited number of link types [8]. In the form of knowledge map, the learner model supports automated reasoning to detect student misconceptions, knowledge gaps and knowledge strengths and thus can be directly presented to the learner through knowledge visualization for inspection, reflection and modification.

In the remainder of this paper, we first describe how the knowledge visualization is used to improve learning process. We then describe our framework of automatic knowledge visualization generation. Next we discuss the scaffolding strategies to be used to guide the design of the visualization; and our implementation of visual components to support the identified strategies. Then we introduce a user interface embedded with the automatic generated visualization to illustrate how the learning environments can use our proposed services to scaffold learning process. Lastly, we discuss our findings and outline our future work in the area of knowledge

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visualization to improve learning.

II. Knowledge Visualization to Support Learning

Knowledge visualization lies at the intersection of information graphics, graphic design and cognitive science [10]. The most common objective for a knowledge visualization tool is to make an intellectual landscape visible. This landscape can serve as a common framework or context for the purpose of knowledge sharing, decision making and problem-solving [12]. It can also be used to map concepts as well as their relationships graphically. Given such a mapping, the learner can explore individual concepts and manipulate their relationships to find the desired result [7]. Such mapping is called knowledge maps. The graphical display of knowledge maps may assist learners in learning because they draw attention to the macrostructure of the content and encourage top down processing [3].

Several visualization tools have been developed to generate knowledge maps: Cmap Tools [2], Smart Ideas [6], and Knowledge Manager [5]. Cmap tool is a collaboration tool that provides a graphical user interface to construct concept maps; supports hyperlinks; and enables posting concept maps to the Web [2]. The learners are able to use these tools to draw concept maps by themselves. The researches and studies on using knowledge map in improving learning have clearly outlined the importance of automatic generation of knowledge maps from resources in certain scientific domain and from learner's own knowledge states. However, the current tools are very limited in such automatic generation. To my best knowledge, the current available tools of automatic generating knowledge maps use the general graph drawing techniques and treat the knowledge map as general graphs. Thus, the visualization results do not implement the important knowledge map visualizations features which are critical in supporting learning process and in fulfilling the learning requirements posed by the prior researches. In this paper, we report our approach to automatic generate domain knowledge, learners' prior knowledge and misconception as knowledge maps. Most important, with specific design strategies, our approach is able to preserve critical visual features and aesthetics of knowledge maps to support learning process during the automatic generation.

III. Knowledge Visualization Framework

The framework of the customized knowledge visualization is shown in Fig. 1. There are three conceptual layers in this framework: model layer, implementation layer and output layer. The model layer is used to describe the base models for the customized visualization. There is knowledge model which have domain and learners' knowledge represented as knowledge maps and learners' prior misconceptions. The details of generating knowledge model are reported in [4]. Besides knowledge model, there is resource model which have online information resources as instructions sources and how the online resources are related to learner knowledge and domain knowledge. The implementation layer is used to describe how to dynamic generate the visual representation of the knowledge map based on the learners' current learning needs and how to construct the resource network to contextualize the recommended online resources. The output layer describes what the learners actually see and how can they interact with in the interface. Besides the customized knowledge visualization, the learning path specifies the action patterns the learners can take using such interface.

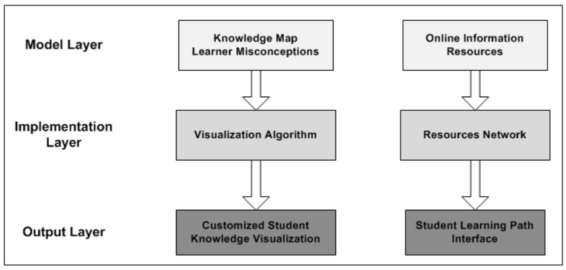

Figure 1. Customized Knowledge Visualization Framework

IV. Scaffolding Strategies

In order to understand how design experts use knowledge visualization to provide learning supports based on individual learner's need, a "Design Workshop" is conducted with user-centered design methods. Three core strategies are identified as guidance for the design and implementation of the customized knowledge visualization:

Knowledge map as central instruction

The design should provides the customized knowledge visualization through knowledge maps as center point. The visualizations are used to connect the learners' knowledge such as essays and the instruction such as recommended online resources. Through the interactions with knowledge map visualizations, the learners are able to find the connections between their learning needs and the instructions provided by the learning services.

Learning path integrated in the user interface

The design should provide a suggested learning path for the learners to advance on. The path should start with learners' own knowledge and then jump to related new domain knowledge which the customized learning services recommended based on the learners' knowledge needs. At the meanwhile, the design should also provide the flexibility to let the learners to control their own interaction patterns.

Knowledge expansion support

The visualization techniques are used in the interface as scaffolds for the learners to expand their knowledge states through the integrated visualization which combine the learners' knowledge with related domain knowledge.

V. Visualization Implementation

Following the guidance, we have implemented six visualization components to support the identified scaffolding strategies shown in Fig. 2

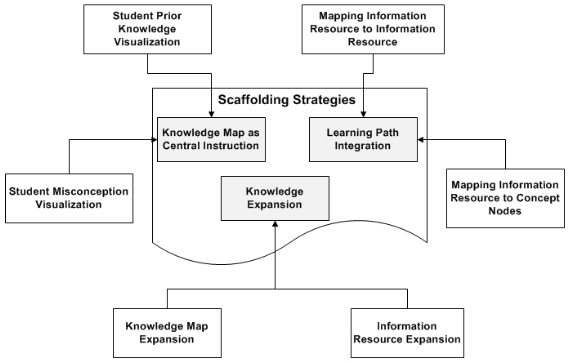

Figure 2. Visual Components to Support the Scaffolding Strategies

Student Prior knowledge Visualization

This visual component dynamically generates a visual representation of the learner's prior knowledge states. It identifies the core concepts of the current topics in student's own knowledge model. Then it visualizes these core concepts and the relationships between the core concepts and other related concepts in student's knowledge model.

Student Misconception Visualization

This visual component dynamically generates a visual representation of one particular student's misconception. It identifies the problematic concept nodes or missing concept node in student's own knowledge model in that particular misconception and visualizes these problematic/missing concepts nodes and how these concept nodes relate to other concept nodes both from that student's own knowledge model and domain knowledge model.

Knowledge Map Expansion

When the student is investigating a particular concept node from student own knowledge model, requested by student or automatically trigged, it dynamically expand the knowledge map by including the new concepts nodes from domain knowledge model which are related to the being investigated concept node into the current visualization.

Information Resource Expansion

When the student is investigating a new information resource, requested by student or automatically trigged, it dynamically expand the knowledge map by including the new concepts nodes from domain knowledge model and student own knowledge model which are corresponding to the recommendation of this information resource.

Mapping Information Resource to Concept Nodes

When the student is investigating a particular information resource, the concept nodes in the current visualization which are corresponding to the recommendation of that particular resource are dynamically generated.

Mapping Information Resource to Information Resource

When the student is working on the knowledge map visualization, the focusing concept node through student's interactivity (cursor moving/clicking) in the moment can be used to illustrate the relationship between different information resources.

VI. Learning Environment Example

Fig. 3 shows one screenshot of the user interface of a learning environment with embedded customized knowledge visualization.

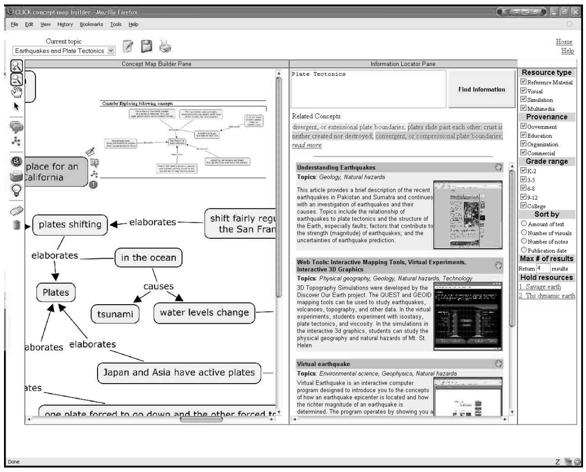

Figure 3. Learning Environment Example with embedded visualization

The center of the interface contains the knowledge visualization pane and information locator pane. This side-by-side presentation of knowledge map and keyword search window allow for contextualized construction of the knowledge map, which enhances the knowledge integration potentials of the activity. Additionally, the learner can drag and drop one or more concepts from the map into the search text box (right pane) to find digital library resources suitable for learning about the concept. In this screenshot, the knowledge visualization pane shows the learner current understanding of the scientific topic: "plate tectonics". It uses color scheme and small icons to highlight the learner's problematic understanding. Next to this problematic concept node, part of the domain knowledge corresponding to this particular learner misconception is shown. How the domain concepts are related to the misconception is revealed through this visualization. The information locator pane shows suggested digital library resources suitable for learning about this problematic concept. There are tool bars surrounding the two center panes which allow learners to manipulate the knowledge visualization; to get intelligent feedback about the visualization and to filter digital library resource search results.

VII. Conclusion

This research has explored the use of customized knowledge visualization to improve learning experiences. Through the survey of prior research and formative assessment studies, three scaffolding strategies have been identified as guidance for the design and implementation of the customized knowledge visualization. Based on the guidance, six key visualization components are developed to dynamically generate the customized visualizations. These visualizations provide a picture of a set of individual learner's own concepts and address the connection between them. They represent the relative knowledge, concepts and their semantic relationships to the learners to make the learners more aware of their current understanding and the process as they experience it. The visualizations also relate the new concept from information resource to learner's existing understanding; thus help to solve learner's uncertainties of new merging ideas and concepts in their learning process. Such visualizations are integrated into the learning environment user interface to support the scaffolding strategies.

In the user interface described in the previous section, it presents a suggested learning path for the learners to use our customized knowledge visualization services. However, the learners should also have flexibility to control their own learning action patterns. According to the literature of prior research, different learners may have different literacy skills and learning styles. In future work, it could investigate how to customize the learning paths based on such learners' characteristics and what learning effects may be achieved through the customization.

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