Design and Implementation of an Object Oriented Learning Activity System

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ABSTRACT

With the development of e-learning technology, many specifications of instructional design have been proposed to make learning activity sharable and reusable. With the specifications and sufficient learning resources, the researches further focus on how to provide learners more appropriate learning activities to improve their learning performance. In this paper, we aim to propose a model which can explicitly represent the knowledge of the mechanism to adapt both the learning activity navigation and content presentation according to learners' knowledge of concepts. In our proposed model, each learning unit object contains the learning items and the related concepts, which can be used to perform adaptive content selection, and the sequencing control of these learning unit objects can be explicitly represented as a directed graph to improve the understandability. Based on the learning sequencing graph, an Object Oriented Learning Activity system is implemented and used to design and perform the learning activity of Scaffolding Instruction, named "The evaporation, condensation and boil of water". The Evaluation results show that teachers can effectively design an adaptive learning activity based on concept and misconception hierarchy and the designed learning activity can really improve learners' learning efficacy by the OOLA system.

Keywords

E-Learning System, Adaptive Learning Activity, Graphic Model, Object Oriented Concept

Introduction

With the growth of Internet, e-learning has been globally accepted for making learners conveniently study at any time and any location. In recent years, in order to share and reuse learning resources among different e-learning systems, several standards, such as IMS (IMS 2001), IEEE LOM (IEEE 2002), SCORM (ADL 2004), AICC (AICC 1989) and ARIADNE (ARIADNE 2004) have been proposed. Moreover, Open Knowledge Initiative (O.K.I. 2007) was proposed, based on the concept of service oriented architecture (SOA) to define open, extensible service architecture and the inner components of E-learning platforms, so the modern learning management system can integrate diverse learning services to provide comprehensive learning activities. Based on these specifications, learning contents and services can be managed as learning objects for reusing and assembling. With the sufficient learning resources, the researches then focus on how to provide learners more appropriate learning activities to improve their learning performance.

Concept is an established framework of understanding an objects, events, or processes (Klausmeier 1979). The theory of Meaningful Learning, proposed by (Ausubel 1968), describes that the new knowledge must be constructed based on the learners’ prerequisite knowledge, named superordinate concept. (Gagne 1985) also suggested that prior knowledge is the necessary internal condition of learning. Thus, how to provide meaningful learning activities according to learners’ ability of concepts is an important and challenging issue to improve learning efficacy.

(Sleeman and Brown 1982) introduced the intelligent tutoring systems (ITS), which incorporate artificial intelligent technology to adapt learning sequence to improve learners’ learning performance. (Brusilovsky and Pesin 1998) defines two ways of adaptation in adaptive hypermedia: adaptive presentation to adapt the learning contents and adaptive navigation support to adapt the learning path to the knowledge level of learners. An adaptive learning system can separately maintain the two kinds of knowledge to facilitate maintaining and reusing previous design. Besides, how to make the internal learning objects in ITS reusable and sharable is also an important issue (ADL 2004).

Bayes Nets, based upon statistic methods (Mislevy, Almond et al. 1999; Desmarais and Gagnon 2006), have been used to decide adaptive learning sequence, but they are difficult to incorporate domain expertise of teachers for the
adaptive learning. Sequencing and Navigation in SCORM 2004 (ADL 2004) and Learning Design (IMSLD 2003) are the popular specifications to design adaptive learning activity, so many researches aimed to propose different models and authoring tools to ease the designing and authoring. Among these researches, using graphic models for adaptive learning activity design is an important direction, because teachers can design the complex adaptive sequence by the intuitive graphic representation. (Martens 2005) applied the definition of finite automata with learner model to describe adaptive learning sequence and presentation. (Chen, Huang et al. 2005; Huang, Chen et al. 2008; Wang, Huang et al. 2008) used Dynamic Fuzzy Petri Nets to represent the learning paths and remedial learning contents. (Chang, Hung et al. 2003; Lin, Chang et al. 2005) applied Inference Diagram to describe the courseware diagram and support the evaluation of learners’ learning performance. These models can effectively reduce the design cost of adaptive learning activities. (Martens 2005) further defined the learner model, transition function, and show function to describe the adaptive navigation support and presentation, but did not mention about how to determine the learning sequence and contents according to learners’ knowledge. It implies that teachers have to design the transition function and learner model by themselves in the real system. The model of Dynamic Fuzzy Petri Nets (Chen, Huang et al. 2005; Huang, Chen et al. 2008; Wang, Huang et al. 2008) and Inference Diagram (Chang, Hung et al. 2003; Lin, Chang et al. 2005) can determine the learning sequence only using single examination score, which can not represent the learners’ knowledge of concepts if multiple concepts could be learned in this activity.

To cope with the above issues, our idea is to explicitly represent the knowledge of the mechanism to adapt both the learning activity navigation and content presentation according to learners’ knowledge of concepts. Thus, we propose a novel model, named Learning Sequencing Graph (LSG), which includes global scope and local scope to describe the adaptive navigation support and adaptive contents presentation, respectively. In the global scope, the adaptive learning sequence is explicitly represented as a directed graph to improve the understandability, where the edges in the directed graph describe constraints of multiple concepts to guide learners to the appropriate learning path according to their knowledge of concepts. Under the global scope, the learning unit objects are defined within their own local scope, named learning unit scope. In learning unit scope, the concept matrix is defined to describe weights of concepts in learning items. These concept weights can be used to select the presented learning items to achieve adaptive presentation, and in the exam, the learners’ concept knowledge can be evaluated according to the concept weights of the test items. Thus, adaptive navigation support and adaptive presentation based on learners’ concept knowledge can be fully supported by the intuitive design in global and local scopes of LSG. The adaptive learning sequence, referring to multiple concepts, is more flexible to fulfill the needs of various pedagogical approaches. Moreover, because concepts are the interfaces between learning items and adaptive learning sequence, the learning sequence design does not have to be modified when replacing learning items or adding new learning items.

Accordingly, we design and implement an Object Oriented Learning Activity System (OOLA system), with a graphical authoring tool, which can assist teachers to design adaptive learning activity, and a web based learning system, which can steer learners learning using a rule inference engine. Therefore, teachers do not need to concern with the detailed implementation of the whole adaptive learning system, and they just need to design learning sequences and determine the presentation information using a graphical interface, and then the learning activity based on LSG can be automatically transformed to a rule class (Lin, Tseng et al. 2003), which can be conducted by the rule inference engine.

We compare the features of adaptive learning model, with SCORM SN, IMS LD, LAMS, and the related graph based learning models. The result shows that learning sequencing graph is better to represent adaptive learning. Moreover, we use OOLA system to design a learning activity “The evaporation, condensation and boil of water” based on Scaffolding Instruction, which can guide learners to study according to their prior knowledge and help learners correct their misconceptions. The teachers were also invited to evaluate the authors’ effectiveness of OOLA System, and the result shows that the OOLA System can help teachers to construct a correct adaptive learning activity easily.

**Related Work**

In this section, ADL SCORM, IMS LD, LAMS, and the related graph based learning model are introduced.
SCORM (Sharable Content Object Reference Model)

SCORM, proposed by the Advanced Distributed Learning (ADL) organization in 1997, is one of the most popular standards for learning contents. The SCORM specification is a composite of several specifications developed by international standards organizations, including IMS (IMS 2001), IEEE LOM (IEEE 2002), SCORM (ADL 2004), AICC (AICC 1989) and ARIADNE (ARIADNE 2004). In a nutshell, SCORM is a set of specifications for developing, packaging and delivering high-quality education and training materials whenever and wherever they are needed. The advantages of SCORM-compliant courses are reusable, accessible, interoperable, and durable.

In SCORM 2004, the Sequencing and Navigation (SN), referred from the Simple Sequencing Specification (IMSSS 2003) of IMS, applies sequencing rules, formatted as “if <condition set> Then <actions>” and navigation controls to the tree nodes of the activity tree, where the learning resources are linked to its leaves. As shown in Figure 1, “Organization”, “Item”, and learning resources, contained in an activity tree, are the tree’s root, internal nodes, and leaves, respectively. The learning activity will start from the root “Organization” to control the navigation and learning sequence of the children nodes, and then navigate the descendant nodes, Item1, Item1-1, resource1, Item1-2, resource2, Item2, Item2-1 in the sequence of left-to-right traversal, where the navigation sequence might be altered according to the firing of the attached sequencing rules, e.g., Sequencing rule1 will be triggered when Item1 is reached to change the default navigation sequences, such as skipping child nodes, retry the sub-tree.

IMS Learning Design Specification (LD)

The IMS Learning Design Specification (LD), which was firstly called Educational Modeling Language (EML) and proposed by Open University of the Netherlands, integrates learning contents, QTI test items (QTI 2001), and several predefined learning applications, Send-mail, Conference, monitor, and index-search, into the design of learning activities. These learning resources need different design to work cooperatively; pure learning contents can be linked by URL or files, the test outcomes of QTI test items must have the corresponding properties defined in LD, and the learning applications all have different definitions in LD, which make the modification of learning applications difficult.

An example of sequencing control in LD is shown in Figure 2, where the learning activity starts in Play1, and then the internal act, Act1-1, is fired to enter the Learning Activity1-1, and the contained learning resource, Resource1-1, would be provided to the learner. After finishing Learning Activity1-1, Act1-2, Activity Structure1-2 will be fired, and the sequence of activities, Learning Activity1-2-1, Support Activity1-2-2 with the corresponding learning resources, Resource1-2-1, Resource1-2-2, contained in Activity Structure1-2 will be fired subsequently. Then, Play2 is reached and the internal components, Act2-1, Learning Activity2-1, and Resource2-1 will be triggered. Besides, the Condition Rules and Notification1 are defined to show or hide some activities under some defined conditions. The sequencing control methods provided by IMS LD have various structures, such as linear sequence, if-then rules, and skip operations, whose complex structures definitions are too difficult to describe the pedagogical approaches.
The authoring system of adaptive learning activity

There are many authoring tools developed to construct the IMS LD compliant learning activity: Reload (Reload 2004) and CopperAuthor (CopperAuthor 2004) are the low-level tabular LD editors, so only the engineers and experts can use them easily. ASK-LDT (ITI-CERTH, n.d.) can construct only simple learning sequences, because only limited LD features can be supported. Although MOT+LD (Paquette, Léonard et al. 2006) is a graphical learning design editor, the teachers, without the knowledge of IMS LD, are still difficult to construct a learning activity. Collage (Hernández-Leo, Villasclaras-Fernández et al. 2006) uses the formulated patterns (CLFPs) to structure the learning activities according to pedagogical theories, but new patterns cannot be constructed.

The Learning Activity Management System (LAMS) (LAMS 2004) can be used to design a customized collaborative learning activity, where the teacher’s environment can monitor the learning status of students. Since only linear learning sequence can be designed by LAMS, the learning activity, designed by LAMS, cannot support adaptive navigation.

The graphic model of adaptive learning activity

Some graphic models are proposed to ease the adaptive learning sequence design: (Martens 2005) applied an extended definition of finite automata to describe adaptive learning sequence and presentation. A learner model, including the profile and knowledge, is defined to record the learner’s expertise and learning paths of various learning activities. The transition function can provide adaptive navigation support according to the learners’ actions, and the function of content selection can determine the learning contents based on the learner model to achieve adaptive presentation. The model can provide adaptation of both navigation support and presentation, but, since the detailed definitions of learner model, transition and content selection functions were not given, the problem of how to determine the adaptation based on learners’ knowledge of concepts is unsolved.

(Chen, Huang et al. 2005; Huang, Chen et al. 2008; Wang, Huang et al. 2008) used Dynamic Fuzzy Petri Nets (DFPN) to represent the behavior of tutoring agent, where the learning activity contains a main learning sequence. After a post test, the remedial learning contents can be shown if the score of test is lower than the threshold. This model can provide adaptive navigation support according to the single test score, but the presented contents are static in each learning unit.

(Chang, Hung et al. 2003; Lin, Chang et al. 2005) applied Inference Diagram to describe the courseware diagram and support the evaluation of learners’ learning performance. The learning sequence of each learner can be various with different score range after an examination. Similar to the researches of DFPN, adaptive navigation support is only based on single test score, and the presented contents in each learning units are also static.
Table 1 summarizes the discussion and shows the comparison of four major functionalities: Adaptive Navigation Support, Adaptive Presentation, Concept-based Adaptation, and Graphic Model.

**Table 1: Comparison of Adaptive Navigation Support, Adaptive Presentation, Concept-based Adaptation, and Graphic Model**

<table>
<thead>
<tr>
<th>Method</th>
<th>Adaptive Navigation Support</th>
<th>Adaptive Presentation</th>
<th>Concept-based Adaptation</th>
<th>Graphic Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCORM (ADL 2004)</td>
<td>Use Sequencing Rules to control learning sequence</td>
<td>Use Sequencing Rules to control content selection</td>
<td>Use Objectives and sequencing rules to perform adaptation</td>
<td>Not for authoring</td>
</tr>
<tr>
<td>IMS LD (IMSLD 2003)</td>
<td>Use rules to control learning sequence</td>
<td>Use rules to control learning sequence</td>
<td>Use property with rules to perform adaptation</td>
<td>Not for authoring</td>
</tr>
<tr>
<td>LAMS (LAMS 2004)</td>
<td>Only static learning sequence</td>
<td>Only static contents</td>
<td>No adaptation</td>
<td>Use a flow chart to represent learning sequence</td>
</tr>
<tr>
<td>Extended Finite Automata</td>
<td>Use transition function to control learning sequence</td>
<td>Use content selection function to select learning contents</td>
<td>No clear definition of concepts in learner model and adaptation mechanism</td>
<td>A graph of finite state machine</td>
</tr>
<tr>
<td>(Martens 2005)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Fuzzy Petri Nets</td>
<td>Dynamically provide remedial contents</td>
<td>Provide static learning contents in each learning unit</td>
<td>Only single test score is referred to perform adaptation</td>
<td>A graph of Petri nets</td>
</tr>
<tr>
<td>(Huang, Chen et al. 2008)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inference Diagram</td>
<td>Dynamically select learning sequence</td>
<td>Provide static learning contents in each learning unit</td>
<td>Only single test score is referred to perform adaptation</td>
<td>A graph of inference diagram</td>
</tr>
<tr>
<td>(Chang, Hung et al. 2003)</td>
<td></td>
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</tbody>
</table>

**Object Oriented Learning Activity System**

Based on the encapsulation concept of Object Oriented Methodology, the learning unit scope is defined to enhance the reusability under the global scope, in which the design of presentation, learning items, and the weight of corresponding concepts are encapsulated in the learning unit object, and the sequencing controls of a learning activity are explicitly represented as a directed graph to enhance the understandability, where the vertices are these learning unit objects and the edges are associated with the sequencing control rules. The learning sequencing graph of the designed learning activity can be used to automatically generate a rule class, which can be easily applied to control the learning sequence.

Based on learning sequencing graph, an Object Oriented Learning Activity System (OOLA System), including the designing and executing phases, is implemented, as shown in Figure 3. In the designing phase, an adaptive learning activity can be designed via the graphical authoring process to help teachers easily integrate various learning resources, provided by learning resource repositories, and a rule class generating method is also proposed to generate the rule class of learning sequencing controls. In the executing phase, the learning sequencing graph and the rule class are used in rule based adaptive learning method to conduct an adaptive learning to learners.
In the OOLA system, three kinds of learning resource repository are provided: learning content repository can retrieve and display SCORM compliant learning contents, test item bank can provide test items and perform examination, application program repository contains the registration of learning services, which are provide by other learning systems and can be executed and communicated via web services.

Figure 3: Designing phase and executing phase in OOLA System

Figure 4 illustrates the flowchart of rule based adaptive learning method. After the rule class and learning sequencing graph are loaded into the rule base, the starting learning unit object of the learning sequencing graph is fired. The learning items, included in the fired object, will be provided to learners using a proper display interface according to the type of the learning unit object. Since then, the inference process will be triggered by learners’ learning status information, including the latest learned learning unit name and concept scores, to find the next object until the final object is reached.

Figure 4: Flowchart of Rule based adaptive learning method
Definitions of Learning Sequencing Graph

The vertices and edges in the learning sequencing graph represent learning unit objects and learning sequencing controls, respectively. A vertex contains a set of learning items associated with the weights of corresponding concepts, which are defined as the concept matrix. There are three types of vertex in the matrix: learning content activity (NLA) contains learning items from learning content repository, learning application activity (NAP) contains learning services registration from application program repository, and examination activity (NEA) contains test items from test item repository. Each vertex also contains the time and duration limit to control the time segment of the learning activity. In order to skip the unnecessary learning items, which are already understood by the learner, the learner’s understanding ratio (ur_k), which means the understanding ratio of handling all the concepts contained in the learning item item_k, and the learning items skipping threshold (t_skip), used to judge if item_k can be skipped, are defined. A sequence of edges, with associated sequencing control rules, from sources to targets represent legal learning paths of the learners, where a sequencing control rule can contain a set of constraints to determine whether the learner can go to the next unit along the edge or not according to the learners’ ability of specific concepts.

Definition 1: Learning Sequencing Graph (LSG)

\[ \text{LSG} = (C, V, v_0, F, LM, E), \]

1. \( C = \{c_1, c_2, \ldots, c_m\} \) is a finite set of concepts.
2. \( V = \{v_1, v_2, \ldots, v_n\} \) is a finite set of nodes which represent the learning unit objects of a learning activity, where \( v_i = (\text{type}_i, M'_i, \text{duration}_i, \text{time}_i, t_{\text{skip}}_i) \).
   - \( \text{type}_i \in \{\text{NLA}, \text{NAP}, \text{NEA}\} \).
   - \( M'_i \) is a concept matrix, where \( M'_{jk} \) means the weights of concepts \( c_j \) in item_k, \( 0 \leq M'_{jk} \leq 1 \).
   - \( \text{duration}_i \) is the duration of \( v_i \) in minutes.
   - \( \text{time}_i \) is the leading time of \( v_i \) in minutes.
   - \( t_{\text{skip}}_i \) is the threshold of the understanding ratio (ur_k) to let learners ignore the learning items, if the contained knowledge is already handled.
3. \( v_0 \in V \) is the initial vertex of LSG.
4. \( F \subset V \) is a finite set of final vertex.
5. \( LM_x = \{cs^1_x, cs^2_x, \ldots, cs^m_x\} \), is a learner model of learner x, where \( cs^i_x \) is the learner’s ability about the concept \( c_i \).
6. \( E \subseteq V \times V \) is the finite set of directed edges, and \( \forall e_{ij} \in E, e_{ij} \) is a directed edge from \( v_i \) to \( v_j \), and the attached constraints are defined as \( \text{cst}_{ij} \).
   - \( \text{cst}_{ij} \subseteq \{\text{constraint}_1, \text{constraint}_2, \ldots\} \) is a subset of constraints.
   - \( \text{constraint}_m = (cs, op, \alpha) \) is a constraint of concept score, where
     - \( cs \in LM \) is a specific concept score.
     - \( op \in \{"\lt", "\leq", "\gt", "\geq", "\neq\} \).
     - \( \alpha \) is a threshold, \( 0 \leq \alpha \leq 1 \).

The following example is given to illustrate the definition of LSG.

Example 1: A learning activity to provide adaptive navigation support

As shown in Figure 5, this learning activity starts at an examination activity \( v_1 \) as pretest, containing three test items and two corresponding concepts, where \( v_1 \) having no leading time can be learned in 20 minutes, and its learning
items skipping threshold is defined as $\infty$ to allow all learning items to be provided to learners. After finishing the pretest, if all the concept scores are higher than 0.6, a learning application program $v_2$ will be fired for learners to discover more knowledge about the concepts; otherwise, a remedial instruction $v_3$ will be given to improve understanding of the missing concepts.

**Formula of Calculating Concept Score**

$\forall v_i$, type$_i \in$ N$_{EA}$, we can evaluate the learner’s concept score $c$s of the concept $c_j$ according to the sum of the weights of the passed test items. Let the passing attribute $\delta_k$, which is a Kronecker delta, represents the test result of item$_k$, where $\delta_k = 1$ if the learner passed this test item, and $\delta_k = 0$ if s/he failed.

The formula to calculate concept score of concept $c_j$: $CS_j = \frac{\sum_k \delta_k \times M^i_{jk}}{\sum_k M^i_{jk}}$

**Formula of Understanding Ratio ($ur_k$)**

Let $ur_k$ be the average of the weighted concept scores of item$_k$ of all concepts. Concept scores ($c$s), describing the learner’s abilities of concepts, are ranged from 0 to 1.

The formula to calculate understanding ratio: $ur_k = \frac{\sum_j c_{s_j} \times M_{jk}}{\sum_j M_{jk}}$

**Example 2: The running process of the learning activity in Example 1**

For the learning sequencing graph given in Figure 5, in step 1, the learner firstly enters to the pretest. If s/he passed in item$_1$ and item$_2$ but failed in item$_3$, the concept scores $c_{s_1} = 0.5 + 0.3 = 0.8$ and $c_{s_2} = 0.3 + 0.9 = 1$. Thus, in step 2, only the constraint rule of $e_{13}$ is fulfilled and s/he may pass the valid edge $e_{13}$ to enter the Remedial Instruction $v_3$, where two learning contents, item$_4$ and item$_5$, are provided with the understanding ratios.
Rule Class Generating Method

A learning sequencing graph can be considered as a knowledge object, and several learning activities can be combined to a large scale course. Therefore, we apply New Object oriented Rule Model (NORM) architecture (Tsai, Tseng et al. 1999; Wu 1999; Tsai and Tseng 2002; Lin, Tseng et al. 2003) to represent the guiding rules of learning sequencing graph. Based on Object Oriented Mechanism (Rumbaugh, Blaha et al. 1990; Booch 1991), NORM is a knowledge model of rule base, where the rules about the same knowledge domain are collected into a rule class (RC). Each rule class can include or refer to some other rule classes, and these relevant rule classes will form a set of rule objects (RO), which can be dynamically linked and perform cooperative inference. Therefore, in the rule class generating method, we can generate rule class by the following steps:

1. Generate a fact to record the name of last learned learning unit.
2. Generate a fact to store the name of next learning unit.
3. Generate facts to record the scores of all the concepts.
4. Generate a rule for each $e_{ij}$ to describe: “If the last learned learning unit is $v_i$ and the concept scores satisfy the constraint $c_{stij}$, the next learning unit is determined to be $v_j$”.

Example 3: Generate Rule Class from a learning sequencing graph

The rule class, generated from the learning sequencing graph in Figure 5, is shown as Rule Class 1. Firstly, the facts named “now” and “next” are generated to record the processed vertex and the next learning vertex. According to the $C$ in LSG, the facts, named “cs1”, “cs2”, corresponding to the concepts $c_1$ and $c_2$, respectively, are generated. Finally, the rules are generated according to the edges in $E$. $e_{12}$ connects from $v_1$ to $v_2$ with the constraint of “$cs_1 \geq 0.6$ and $cs_2 \geq 0.6$”, so the corresponding rule can be generated to describe that if fact “now” is $v_1$ and the constraint of $e_{12}$ is satisfied, then assign $v_2$ to the fact “next”. Similarly, the rule of $e_{13}$ can be generated to show the constrained path from $v_1$ to $v_3$.

<table>
<thead>
<tr>
<th>Rule Class 1: rule class of the simple example in Figure 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Facts:</strong></td>
</tr>
<tr>
<td>now: The name of the last learned learning unit.</td>
</tr>
<tr>
<td>next: The name of the next learning unit.</td>
</tr>
<tr>
<td>cs1: The score of concept c1.</td>
</tr>
<tr>
<td>cs2: The score of concept c2.</td>
</tr>
<tr>
<td><strong>Rules:</strong></td>
</tr>
<tr>
<td>$(e_{12})$ IF (now = $v_1$ and ( $cs_1 \geq 0.6$ and $cs_2 \geq 0.6$ ) ) THEN assign $v_2$ to next</td>
</tr>
<tr>
<td>$(e_{13})$ IF (now = $v_1$ and ( $cs_1 &lt; 0.6$ or $cs_2 &lt; 0.6$ ) ) THEN assign $v_3$ to next</td>
</tr>
</tbody>
</table>

Rule based Adaptive Learning Method

Algorithm 1 uses learning sequencing graph and the generated NORM rule class to conduct an adaptive learning, where inference process can be triggered by the latest learned vertex and concept scores to determine the next vertex to be fired, and learning items, contained in the next vertex, can be filtered, displayed according to the type and the threshold of the understanding ratio of this vertex. In Step 1, the initial vertex is processed in the first iteration. In Step 2.1, the learning items in the processed vertex will be hidden if the learner’s corresponding concept knowledge
is good enough to skip these learning items. In Step 2.2, different kinds of learning object units will be executed using different displayer, and if the type of vertex is examination activity, the concept scores will be recorded in learner model (LM) after testing. In Step 2.3, the inference process is triggered to find the next processed vertex according to the current processed vertex and concept scores in learner model. If the inferred vertex is a final vertex, the learning activity will be finished.

**Algorithm 1: Rule based Adaptive Learning Method (RAL)**

**Definition of Symbols:**
- \( v_{\text{now}} \): The vertex, which is processed in current iteration.
- **Input:** The learning sequencing graph and the corresponding rule class

**Step 1:** Assign \( v_0 \) to \( v_{\text{now}} \)

**Step 2:** Do while \( v_{\text{now}} \not\in F \)

1. **For** each \( \text{item}_k \in M_{\text{now}} \) in \( v_{\text{now}} \)
   - If understanding ratio \( u_{\text{rk}} < t_{\text{skip}_{\text{now}}} \) Then hide \( \text{item}_k \)
2. **If** \( v_{\text{now}} \in N_{\text{LA}} \) Then show learning items in SCORM compliant content displayer
   - Else if \( v_{\text{now}} \in N_{\text{AP}} \) Then show learning items in application program displayer
   - Else if \( v_{\text{now}} \in N_{\text{EA}} \) Then show learning items in test item displayer
   - Check answers and calculate concept scores \( c_{\text{j}} \) after finishing the test
   - Assign \( c_{\text{j}} \) into LM.
3. **2.3:** Trigger the inference process with inputted rule class:
   - Set name of \( v_{\text{now}} \) and \( c_{\text{j}} \) into the facts
   - Infer the next learning unit and set into \( v_{\text{now}} \)

End while

**Step 3:** The learning activity is finished

**Example 4:** Apply Rule based Adaptive Learning Method to the simple example in Figure 5

The behavior of rule based adaptive learning method, which is applied to the learning process in Example 2, is shown: In Step 1, the starting vertex, \( v_1 \), is assigned to \( v_{\text{now}} \). In the first iteration of Step 2, all learning items of \( v_1 \) can be shown because \( t_{\text{skip}_1} = \infty \), and they are shown in test item displayer because \( v_1 \in N_{\text{EA}} \). After exam, the concept scores \( c_{\text{S}_1} = 0.5 \), \( c_{\text{S}_2} = 1 \), and \( v_{\text{now}} = v_1 \) are assigned into the facts and the inferred next learning unit is \( v_3 \). In the second iteration of Step 2, \( \text{item}_4 \) is shown and \( \text{item}_5 \) will be hidden because \( u_{\text{r}_5} < t_{\text{skip}_2} \); and then these learning items are shown in SCORM compliant content displayer. After studying the learning unit, the next one will be inferred and iterations will be continued until the final vertex is gotten and the learning activity is finished.

**Comparing the Features of Adaptive Learning Model**

In Table 2, we compare the features of adaptive learning model, including adaptive navigation support, adaptive presentation, concept-based adaptation, and graphic Model, where ‘O’ means the feature is not difficult to be represented by this model, ‘△’ means it is moderately difficult to be represented, and ‘X’ means it is very difficult. In SCORM and IMS LD, the adaptive navigation support and adaptive presentation can be fully support, and the concepts can be implicitly defined in the variables, but the two specifications do not have a graphic model for designing. LAMS is a graphic authoring tool, but it can not support adaptive learning design. Extended Finite Automata is a graphic model to represent the adaptive mechanism, but no clear definition of concepts in adaptation mechanism. Dynamic Fuzzy Petri Nets and Inference Diagram are also graphic adaptive learning models, but their single criterion adaptation can not support adaptive navigation and presentation according to learners’ knowledge of concepts. Our proposed LSG is a model of directed graph, where adaptive navigation support and adaptive presentation can be design based on learners’ concepts in global and local scope, respectively, so LSG can perform all the features of adaptive learning model.
Table 2: The comparison table of Adaptive Navigation Support, Adaptive Presentation, Concept-based Adaptation, and Graphic Model

<table>
<thead>
<tr>
<th></th>
<th>Adaptive Navigation Support</th>
<th>Adaptive Presentation</th>
<th>Concept-based Adaptation</th>
<th>Graphic Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCORM(ADL 2004)</td>
<td>O</td>
<td>O</td>
<td>△</td>
<td>X</td>
</tr>
<tr>
<td>IMS LD(IMSLD 2003)</td>
<td>O</td>
<td>O</td>
<td>△</td>
<td>X</td>
</tr>
<tr>
<td>LAMS(LAMS 2004)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>Dynamic Fuzzy Petri Nets(Huang, Chen et al. 2008)</td>
<td>△</td>
<td>X</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>Inference Diagram(Chang, Hung et al. 2003)</td>
<td>△</td>
<td>X</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>LSG</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

Design a learning activity of Scaffolding Instruction

We have implemented an OOLA system and invited in-service teachers to design a scientific learning activity, named “The evaporation, condensation and boil of water” based upon the concept of Scaffolding Instruction (Raymond 2000). Scaffolding Instruction originates from the concept of “zone of proximal development (ZPD)”, proposed by (Vygotsky 1978), which means the distance between what learners can do by themselves and what they can be helped to achieve. The teaching strategy of Scaffolding Instruction provides individualized support, named Scaffolding, based on the learner’s ZPD (Chang, Chen et al. 2002). Thus, it is important to clearly evaluate the learners’ prior knowledge to provide scaffolding in learners’ ZPD. Besides, according to (Osborne and Cosgrove 1983), in the scientific learning about water cycle, some misconceptions are generated easily to confuse learners. These misconceptions can make learning more difficult, so in the adaptive learning activity, we aim to find the misconceptions and provide appropriate remedial instructions.

Before designing the learning activity, the scope of this learning activity was clearly defined in Figure 6. Based on the theory of (Gagne 1992), we organized the related concepts of water cycle in a concept hierarchy, shown in Figure 7, and collected the data of related misconceptions to construct a misconception hierarchy, shown in Figure 8. Accordingly, the knowledge evaluation test items were designed to evaluate the learners’ prior knowledge, and the regular learning contents were constructed to teach all related concepts. In order to help learners find and correct misconceptions, the diagnostic test items and the corresponding contents of remedial instruction were constructed. All the learning sequences were designed as flowcharts and further integrated learning resources to construct an online learning activity in OOLA system. This learning activity can be performed after a regular lecture of water cycle to improve the learners’ learning efficacy.
Figure 6: Flowchart of designing a learning activity in OOLA system

Figure 7: A partial concept hierarchy of freezing in water cycle

Figure 8: The partial misconception hierarchy of freezing in water cycle
In the strategy of the learning activity, shown in Figure 9, a course introduction is given as an advance organizer (Ausubel 1968), and then a pre test is given to evaluate the prior knowledge of the learner. If the learner has already understood the topic of this learning activity, an activity is provided to enhance the impression. Otherwise, learning contents are provided based on the learner’s prior knowledge. After the concept learning, a post test is given to evaluate the learner’s learning outcomes, and if any concept still cannot be handled, the diagnostic test is used to find the misconceptions, which will be remedied by the remedial instructions.

![Figure 9](image1.png)

**Figure 9**: The teaching strategy of the scaffolding instruction with misconception diagnosis

Accordingly, as shown in Figure 10, the flowcharts of knowledge evaluation test and concept learning in the learning activity were designed. In knowledge evaluation test, the exam about the most general concept $c_1$, named “Freezing”, is given to evaluate the overall knowledge of freezing. If $c_1$ is understood by learners, the learning services of search engine and file-upload service are provided for learners to find related data and upload the reports to teachers.

![Figure 10](image2.png)

**Figure 10**: A part of flowchart of learning activity “The evaporation, condensation and boil of water”
Otherwise, if $c_1$ cannot be totally understood, the evaluation test will drill down to evaluate the prerequisite concepts $c_{1,1}$, $c_{1,2}$, and $c_{1,3}$ in the lower level of concept hierarchy and the rest may be deduced by analogy until the concepts of weak understanding in the lowest level are evaluated. Then, the learning contents will be provided to construct knowledge from the lowest level concepts, evaluated in knowledge evaluation test, to the top level concept. In each learning unit object, the learning contents can be hidden if the learner has already had the knowledge. For example, in the matrix of second level contents, item$_1$ will be displayed only if the score of concept $c_{1,1}$ is lower than 0.6, and the item$_4$ will be shown only if the average score of $c_{1,1}$, $c_{1,2}$, and $c_{1,3}$ is very low.

As shown in Figure 11, after concept learning, a post test is given to evaluate the learning performance of all concepts. If any score of concept is still lower than 0.6, a corresponding diagnostic test will be provided to find out the misconceptions, which might cause the low learning performance. Then, the misconceptions can be remedied in the remedial instruction, and the next concept will be diagnosed subsequently.

![Figure 11: A part of flowchart of misconceptions diagnosis and remedial instructions](image)

This application shows how to evaluate a learner’s prior knowledge based on concept hierarchy by the mechanism of adaptive navigation support in OOLA system. In the concept learning, the adaptive presentation mechanism is performed based on the concept matrix to select the appropriate learning contents according to learner’s prior knowledge. Moreover, with misconception hierarchy, the learning activity can perform the corresponding diagnosis and remedial instruction for each misconception. Figure 12 is the screenshot of authoring tool of OOLA system.

![Figure 12: Screenshot of the authoring tool of OOLA system](image)
Evaluating the effectiveness of OOLA System in authoring

After questioning with questionnaires, the teachers’ comments said that this authoring methodology is effective and easy to use, because designing learning activities in the authoring tool of OOLA system is similar to drawing teaching flowcharts. Moreover, the cost of building learning materials can be largely reduced because all the learning contents can be reused in different learning activities by means of the three kinds of learning resource repositories. In the following, the teachers were invited to evaluate the effectiveness of constructing an adaptive learning activity. The result of the questionnaire is shown in Table 3.

<table>
<thead>
<tr>
<th>The main question of questionnaire</th>
<th>Experts’ result</th>
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</thead>
<tbody>
<tr>
<td>The teaching flowcharts can satisfy the requirements of pedagogical theories</td>
<td>86%</td>
</tr>
<tr>
<td>The three type of nodes in learning sequencing graph can satisfy the requirements of a learning activity</td>
<td>95%</td>
</tr>
<tr>
<td>The three type of nodes in learning sequencing graph can model the teaching flowcharts</td>
<td>90%</td>
</tr>
<tr>
<td>The learning sequencing graph can satisfy the requirements of pedagogical theories</td>
<td>87%</td>
</tr>
</tbody>
</table>

The experimental results show that the teaching flowcharts are easy to design for teachers and satisfy the requirements of pedagogical theories with 86% agreement, and that more than 87% of experts agree that learning sequencing graph can correctly model the teaching flowcharts and satisfy the requirements of the original pedagogical theories. Moreover, according to teachers’ comments, converting teaching flowcharts to learning sequencing graph is also easy. The detailed comments are summarized as follows:

**OOLA system can facilitate constructing adaptive learning sequence based on pedagogical theory.**
- The flexible teaching strategy can be applied in learning activity easily.
- The graphic user interface is intuitive to facilitate the complex authoring task.
- It is better to provide the learning sequence templates for popular teaching strategies.
- The concepts should be managed hierarchically in the system.

**OOLA system can facilitate designing remedial instruction to correct learners' misconceptions.**
- The comprehensive diagnostic test can be used to evaluate multiple concepts, so the appropriate feedback can be provided by the system.
- The online misconception diagnosis and corresponding remedial instruction can reduce the teachers’ teaching cost of giving feedback to students after examination.
- The misconception diagnosis and the following learning contents can drive students to perform self-learning.

**OOLA system can facilitate adaptive presentation in learning activity**
- It can reduce much designing cost to automatically determine the learning items of remedial instruction based on concept matrix.
- It can also reduce much designing cost to automatically select the test items in diagnostic tests based on concept matrix.

**It is easy to replace learning items or modify learning sequence using OOLA system.**
- It is convenient to replace and add learning items without modifying learning sequence.
- The learning object units can be used in many learning activity to reduce the design cost.

**The system can improve the learning performance**
- The learning interface of OOLA system is easy to use.
- OOLA system can drive the low-grade learners to learn more actively and independently.
- The some kinds of multimedia contents can not be displayed in OOLA system.
- In the learning interface, the students should be able to check the whole learning sequence and their learning progress.

**Other comments**
- It is necessary to add monitor mechanism in the learning system for teachers to understand the behaviors of students.
• OOLA system should add student-to-student and teacher-to-student interaction mechanism for collaborative learning.
• OOLA system should provide the functions of analysis and statistic of learner portfolio to help teachers understand the learners’ learning status.

Therefore, we may conclude that the authoring tool of OOLA System can help teachers to construct a learning activity with pedagogical theories easily and correctly, but some functions, such as concept management, learner portfolio analysis, multimedia contents support, and collaborative learning support, are needed to be improved.

The constructed learning activity “The evaporation, condensation and boil of water” was also used for 62 students of 5th graders in Taiwan to show that the learning activity, designed by OOLA system, can really improve the learners’ learning efficacy. The results show that the learning activity is effective for low-grade students, because the learning activity can help low-grade students find and resolve misconceptions.

Conclusion

In this paper, based on the theory of meaningful learning, we aimed to help teachers design learning activities, which can provide adaptive learning according to learners’ knowledge of concepts. Thus, based on the idea of adaptive hypermedia, we proposed a learning sequencing graph (LSG), including the design of adaptive navigation support and adaptive presentation in the global scope and the internal local scope, respectively. In the global scope, the adaptive learning sequence is explicitly represented as a directed graph to improve the understandability. Under the global scope, learning unit objects are defined to encapsulate the design of internal learning items and the related concept matrix in their local scopes. The concept matrix, defining the weights of concepts in each learning items, can be used to select learning items, according to learners’ concept scores, to perform adaptive presentation, and evaluate the learners’ learning performance of each concept after diagnostic test. In the LSG, the edges describe the constraints of multiple concepts to provide learners adaptive navigation support, and the three kinds of vertex can trigger various learning items, including learning contents, test items, and learning services.

Accordingly, OOLA system was implemented, where a graphical authoring tool is provided to help teachers design LSG intuitively, and the designed learning activity can be transformed to rule classes, which can be used to conduct adaptive learning in OOLA system. Some teachers have been involved in the project of constructing a learning activity “The evaporation, condensation and boil of water” based on Scaffolding Instruction, where the learners’ concepts can be evaluated in the knowledge evaluation test. After learning, the diagnostic tests and remedial instructions are provided to help learners correct their misconceptions. Finally, the effectiveness of authoring has been evaluated, and the results show that OOLA system can facilitate designing adaptive learning activity with remedial instructions, adaptive learning sequence, and adaptive content selection, based on pedagogical theory.

In the near future, the mechanism of concept ontology will be applied to OOLA system to support more intelligent adaptation of learning sequence and content selection, and more effective concept management. The knowledge based approach will also be applied to analyze learner portfolio to provide teachers better learning status analysis, and provide learners better feedback. Moreover, the types of learning resources will be extended to incorporate the necessary functions of collaborative and cooperative learning.

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References


