Creating Individualized Learning Paths for Self-regulated Online Learners: An Ontology-Driven Approach

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Abstract. This study extends the ontology-supported modeling of prior studies in learning path personalization to an ontology-driven modeling approach to create a mechanism of online learning path adaptivity. This mechanism is especially applicable for self-regulated learners such as those in flipped learning context. The proposed ontology modeling is based on a conceptualization of education being the function of the triplet of knowledge structure (guide), knowledge content (material), and instruction (teaching). In addition, this study defines cognitive learning as the mapping of the learner's personal knowledge structure to the domain knowledge structure. Furthermore, online learning is viewed as the interaction between the learning management system and the learner. With these conceptualizations, a domain ontology is constructed based on the Common Core State Standards (CCSS) for Mathematics curriculum guide; and a task ontology is constructed to model the problem of learning path adaptivity by including the teaching activity, learning material, and the learner classes. In the case experiment, the Protégé tool is used to construct the ontologies and the semantic rules. The experiment results show that the created mechanism of ontological learning path adaptivity has successfully guided the learner to pre-requisite learning activities and learning objects for remedial learning when current learning activities result in unsatisfactory assessment results.

Keywords: e-Learning, Self-regulated learning, Learning path, Ontology.

1 Introduction

Conventional educational systems deliver learning experiences mainly through classroom instruction and homework assignments, in which instruction is passed from teachers to students. This is no longer the only option when e-learning is becoming more available and viable. In e-learning, learning can happen in between the learning management system (LMS) and the learner without intervention from the teacher.

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This is especially true in the recent MOOCs phenomenon, and with even greater pedagogical implication in flipped learning, in which classroom teaching and self-regulated learning are “flipped” (Bishop & Verleger, 2013).

Human learning, especially the learning that involves school education, can be seen as the interaction between instruction (typically from the teacher) and learning (of the learner). From the teaching side, education is about “what to teach” and “how to teach” by the curriculum with the materials such as the textbooks, which are what connect teaching to learning. Conceptually, therefore, teaching can be understood to have three dimensions of Guide (the curriculum that guides the teaching), Material (the materials used to teach), and Teach (the action of teaching). The conceptualization of the (G, M, T) triplet is important in e-learning because they are weaved together to interact with the learner. When (G, M, T) is embedded in online learning environment, learning can be the interaction between the LMS and the learner. That is, when the learner is mastery of the concepts and the relations among the concepts, learning is considered successful. In the context of online embedment of (G, M, T), learning object sequencing becomes critical in that personalized adaptive learning could be more effective than conventional one-size-fit-all teaching. This is especially critical in flipped learning when self-regulated learning is facilitated by individualized learning path.

Learning path research is important not only because of learner facilitation, but also because it implies, pedagogically, the existence of a domain knowledge for learner to route through and learn from. Based on the conceptualization of the (G, M, T) triplet, this study aims to create a mechanism of adaptive learning path recommendation. The United States Common Core State Standards (CCSS) for Mathematics (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010) is formalized as the knowledge domain for modeling and case study. To create adaptive learning paths, a task ontology with flipped learning pedagogy design is constructed. Sematic rules for learning path recommendation are then created to enable knowledge inference and therefore adaptivity mediating between the domain ontology and the knowledge structure of the learner. The domain ontology, task ontology, and sematic rules form the knowledge base with the mechanism of adaptive learning path recommendation.

2 Review of Literature

Major research efforts in learning path personalization and content sequencing have been on LMS-related specifications and learning systems modeling. The technical specifications efforts, represented by SCORM (Sharable Content Object Reference Framework), were led by ADL (Advanced Distributed Learning) initiative, IMS Global Learning Consortium, and the IEEE Learning Technology Standards Committee. SCORM was the de facto standard for LMS and e-learning content interoperability. Other specifications such as Learning Object Metadata (LOM), Learning Design (LD), and Learning Information Profile (LIP) by IMS have also been well received. However, in terms of learning path adaptivity, SCORM enabled platform interoperability from a system-centered view at the cost of learning object sequencing (de Marcos, Pagés, Martinez, & Gutierrez, 2007). As indicated, these learning standards have been important foundations for implementing learning object repository (LOR) in LMS, but are not precise or comprehensive enough for personalizing learning paths (Devedzic, Jovanovic, & Gasevic, 2007).

In contrast to the works in technical specifications, studies in adaptive hypermedia services (AHS) focus on systems modeling. The AHS stream of learning path studies are mainly based on the Dexter reference model (Halasz, Schwartz, Grønbæk, & Trigg, 1994). AHS stresses the flexibility for personalizing content sequencing with major contributions from De Bra (1999), Karampiperis (2006), and Cristea (2003). AHS is ontology-based (Crampes & Ranwez, 2000) and uses modeling of domain, user, and teaching along with pedagogical rules for course adaptation. The modeling approaches allow for flexibility in the design of flows and thus the creation of learner-centered personalized learning paths.

The use of ontological design approaches for learning path adaptivity has attracted attention from researchers due to the recent strive of W3C and semantic web (Cristea & de Mooij, 2003). As indicated, semantic content recommendation in e-learning has the potential of enhancing the efficiency and effectiveness of e-learning (Yu, Nakamura, Jang, Kajita, & Mase, 2007). Many learning path researchers have therefore turned to ontological approach as their research progresses. For example, Karampiperis & Sampson (2006) proposed the use of a competence description ontology for learning object sequencing; Chen (2009) proposed the use of ontology modeling for individual learning path planning; along with others (De Bra, Aroyo, & Chepegin, 2006; Gaeta, Orciuoli, & Ritrovato, 2009), however, the advantages of ontology-driven approach such as concept consistency, classified taxonomy, and computing inference (Chu, Lee, & Tsai, 2011) have not be fully implemented.

3 Design of Knowledge Model

Major research design components of this study includes: (1) a domain ontology for establishing common knowledge concepts and instances using *is-a* relations to express the knowledge categorization structure and to provide a standard terminology set for ontology communication; (2) a task ontology to establish an objective-oriented knowledge framework using *has*-a relations to express the combination of questions; and (3) semantic rules to develop the rules for inferring implicit knowledge.

3.1 Building a Domain Ontology

In this study, CCSS_Math is used as the Guide. Because the knowledge model of an ontology is often represented by conceptual structure, therefore the content of the description-based knowledge model needs to be dissembled and reassembled to obtain its composite concepts, the properties of concepts, and the instances of concepts. Through analysis, the CCSS_Math can be simplified as a regular expression: CCSS.Math.Content.[Grade.Domain.Cluster.Standard]. For example, standard "*CCSS.Math.Content.3.NBT.A.1*" can be dissembled as the following structure:

- Grade: The first symbol uses a digit to denote the grade level of elementary school. For example, ‘3’ represents the third grade.
- Domain: The second symbol uses an abbreviation to denote a subject. For example, “NBT” represents “*Number and Operations in Base Ten*” of mathematics.
- Cluster: The third symbol uses a letter to denote a group of what students should understand and be able to do. For example, “A” denotes the first cluster of “3. NBT.” The description of Cluster A is “*Use place value understanding and properties of operations to perform multi-digit arithmetic.*”
- Standard: The forth symbol uses a digit to define a specific item of what students should understand and be able to do. For example, “1” denotes the first standard of “3. NBT.A.” Here the standard description is “*Use place value understanding to round whole numbers to the nearest 10 or 100.*”

Domain_CCSS_Math

- Cluster:{has_Description, has_Grade, has_Standards, has_Math_Subject, is_MathDomain }
- Common _Terms
  - Grade_Detail
  - Math_Subject_Detail: { has_Grade, has_Field_Detail }
- Grade_Content: { has_Grade, has_MathDomain }
- MathDomain:{ has_Grade, has_Math_Subject, is_Grade_Contents, has_Cluster }
- Standard:{has_Description, has_Grade, has_Math_Subject, is_Cluster, has_Seqno }

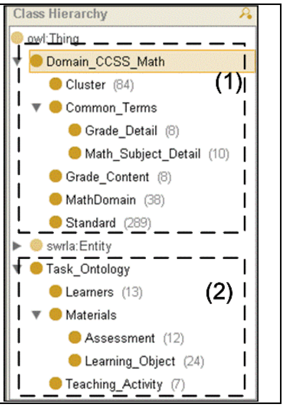


Fig. 1. The conceptual structure, properties, and instances of Domain Ontology

According to the above analysis and dissembling, the structure of CCSS_Math is described as four concepts: `Grade_Content`, `MathDomain`, `Cluster`, and `Standard`. In addition, common terms such as grade year (`Grade`) and content topics (`Math_Subject`) are set as standard terminology of concepts. Under each concept, necessary properties are established to describe the content of the concept. Figure 1 depicts the development results of `Domain_CCSS_Math` (domain ontology). On the left are the concepts and descriptive properties; while on the right is the conceptual structure of the knowledge model edited by Protégé editor: block (1) include the concepts and properties, with the number of instances contained in the concepts. This study established concept instances, including 8 instances under the concept of `Grade_Content`, 38 instances under `MathDomain` (combining grade and mathematic topics), 84 instances under `Cluster`, and 289 instances under `Standard`. In addition, the concept `Math_Subject_Detail` include 10 instances.

3.2 Building a Task Ontology

The objective of the task ontology of this study is to solve the problem of how the learner can use the LMS to precede online learning. To facilitate the conceptual development of the learner, the aforementioned (G, M, T) relationship needs to be completed. Therefore the Task Ontology needs to include the conceptual design of teaching (T) and Material (M). As depicted in block (2) of Fig. 1, three concepts are defined under the task ontology: `Learners`, `Teaching Activity`, and `Material`. Under each concept, necessary properties should be established to describe the content of the concept. Table 1 shows the design of concepts in the task ontology and the corresponding properties. The property is denoted by the following attributes:

1. Name: denotes the name of the property
2. Type: denote the data type and known/unknown attributes. Data type denotes a property as general data or object; while known/unknown denotes a property as asserted or inferred.
3. Range: Denotes the type or scope of the property value. For example, if the Type is denoted as data, then it needs to be further noted as int, string, or float; if the Type is denoted as object, then the acceptable conceptual source needs to be noted.
4. Rule: If the value in Type is denoted as inferred, then the property value needs to be obtained through inference.

Table 1 describes the concepts and the corresponding property design. Due to the fact that the learning is in between the LMS and the learner, the concept of Learners is added. The usages of the properties in the concepts are:

- `Materials`: Providing areas for notification by material producers or assessment developers. Under the sub-concept Assessment, two properties are included: The property that describes name (`has_Assessment_Name`) and the property that denotes cluster (`is_CCSS_Cluster`). Under the sub-concept of Learning object, three properties are included: The property that describes name (`has_LOName`), the property that denotes cluster (`is_CCSS_Cluster`), and the to-be-inferred property of materials with same cluster (`has_Same_LO`);
- `Teaching_Activity`: Providing instructors the arrangement of teaching activities. In the property designs, the first three properties need to be denoted, including the corresponding cluster of each instructional activity (`is_CCSS_Cluster`), the corresponding cluster of the next instructional activity, (`has_Next_Cluster`) and the corresponding cluster of the prerequisite instructional activity (`has_Prerequisite`). These clusters must be connected to the `Domain_CCSS_Math`. Other four properties are to be obtained through inference, including obtaining assessment (`has_Assessment`), obtaining same level learning objects (`has_Available_LO`), obtaining the description of cluster (`has_Cluster_Desc`), and obtaining the description of standards (`has_Standards_Desc`).
- `Learners`: Providing learners with self-regulated learning activities. Among the eight property designs, the first two properties need to be asserted: The learner's (as a person) name property (`has_PName`) and the current Teaching Activity (`has_TActivity`) as assigned by the instructor. Based on the known factual knowledge, the corresponding assessment (`has_Assessment`) and same level

instructional materials (`has_Available_LO`) properties can be inferred. On the learner assessment results, the fifth property (`has_AlreadyKnow`) can be obtained. If the value is "*NO*," then the inference for the followed three properties will continue, including `has_Pre_TActivity`, `has_Pre_LO`, and `has_Pre_Assessment`.

Table 1. Detailed design of Task Ontology

Concept		Property			
		Name	Type	Range	Rule
Materials	Assessment	has_Assessment_Name	Data/Asserted	(string)	
		is_CCSS_Cluster	Object/Asserted	Cluster	
	Learning Object	has_LOName	Data/Asserted	(string)	
		is_CCSS_Cluster	Object/Asserted	Cluster	
		has_Same_LO	Object/Inferred	Learning_Object	Rule (1)
Teaching_Activity		is_CCSS_Cluster	Object/Asserted	Cluster	
		has_Prerequisite	Object/Asserted	Cluster	
		has_Next_Cluster	Object/Asserted	Cluster	
		has_Assessment	Object/Inferred	Assessment	Rule (2)
		has_Available_LO	Object/Inferred	Learning_Object	Rule (2)
		has_Cluster_Desc	Data/Inferred	(string)	Rule (3)
		has_Standards_Desc	Data/Inferred	(string)	Rule (4)
Learners		has_PName	Data/Asserted	(string)	
		has_TActivity	Object/Asserted	Teaching_Activity	
		has_Available_LO	Object/Inferred	Learning_Object	Rule (6)
		has_Assessment	Object/Inferred	Assessment	Rule (7)
		has_AlreadyKnow	Data/Asserted	(string)/YES/NO	
		has_Pre_TActivity	Object/Inferred	Teaching_Activity	Rule (8)
		has_Pre_LO	Object/Inferred	Learning_Object	Rule (9)
		has_Pre_Assessment	Object/Inferred	Assessment	Rule (10)

3.3 Developing Inference Rules

Among the properties in the task ontology of Table 1, ten properties are denoted as "Inferred" in the "Type" column and therefore need to develop inference mechanism to obtain the property values. Since properties are used to describe instances, Semantic Web Rule Language (SWRL) therefore can be used to enable inference in the instance layer. The SWRL-based rules are presented in the format of "Premise → Consequence" logic formula. A Premise is usually formed by connecting multiple atoms. According to Chi (2010), the Rule Analysis Form (RAF) can be used to facilitate the development of the rules. RAF simulates the order of problem-solving steps to achieve the purpose of problem-solving through combining the known facts. The rules are first stated in colloquial statement by steps and then listed as ordered formula in a format of {Goal (Problem): Step1; Step2;.. .., Stepn}. Table 2 lists all

SWRL-based rules developed following the RAF procedure. The above deduction steps can be written as"(atom1 ∧… ∧ atomn)→ Consequence." All the rules are edited using the Protégé SWRLTab editor.

Table 2. List of SWRL-based rules

Rule Name	SWRL Rules
Rule-1: Find same learning objects	Learning_Object (?x) ∧ is_CCSS_Cluster (?x, ?a1) ∧ Learning_Object (?y) ∧ is_CCSS_Cluster (?y, ?a1) ∧ differentFrom(?x, ?y) → has_Same_LO(?x, ?y)
Rule-2: Find corresponding assessment	Teaching_Activity(?x) ∧ is_CCSS_Cluster(?x, ?a) ∧ Assessment (?y) ∧ is_CCSS_Cluster(?y, ?a) → has_Assessment(?x, ?y)
Rule-3: Find available learning objects	Teaching_Activity(?x) ∧ is_CCSS_Cluster(?x, ?y) ∧ Learning_Object (?z) ∧ is_CCSS_Cluster(?z, ?y) → has_Available_LO(?x, ?z)
Rule-4: Find cluster's description	Teaching_Activity(?x) ∧ is_CCSS_Cluster(?x, ?y) ∧ Cluster(?y) ∧ has_Description(?y, ?z) →has_Cluster_Desc(?x, ?z)
Rule-5: Find standard's description	Teaching_Activity(?x) ∧ is_CCSS_Cluster(?x, ?y) ∧ Cluster(?y) ∧ has_Standards (?y, ?z) ∧ has_Description(?z, ?a) → has_Standards_Desc (?x, ?a)
Rule-6: Find available LO for learners	Learners(?x) ∧ has_TActivity(?x, ?y) ∧ Teaching_Activity(?y) ∧ has_Available_LO (?y, ?a) → has_Available_LO(?x, ?a)
Rule-7: Find assessment for learners	Learners(?x) ∧ has_TActivity(?x, ?y) ∧ Teaching_Activity(?y) ∧ has_Assessment(?y, ?a) → has_Assessment(?x, ?a)
Rule-8: Find pre-Teaching activity	has_AlreadyKnow(?x, "NO") ∧ has_TActivity(?x, ?y) ∧ has_Prerequisite (?y, ?z) ∧ Teaching_Activity(?a) ∧ is_CCSS_Cluster (?a, ?z) → has_Pre_TActivity(?x, ?a)
Rule-9: Find pre- learning object	has_AlreadyKnow(?x, "NO") ∧ has_Pre_TActivity (?x, ?y) ∧ Teaching_Activity(?y) ∧ has_Available_LO(?y, ?z) → has_Pre_LO(?x, ?z)
Rule-10: Find pre-assessment	has_AlreadyKnow(?x, "NO") ∧ has_Pre_TActivity (?x, ?y) ∧ Teaching_Activity(?y) ∧ has_Assessment(?y, ?z) → has_Pre_Assessment(?x, ?z)

4 Experiment

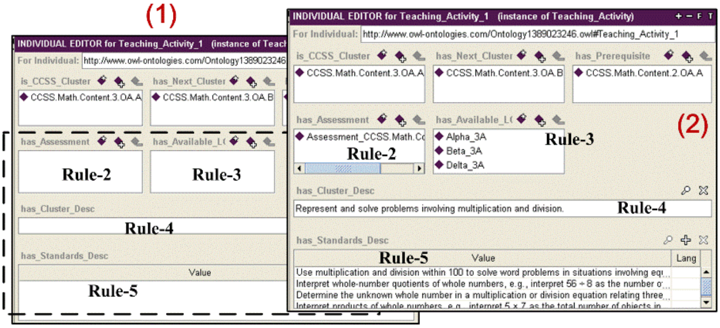
The aforementioned knowledge model development has completed the conceptual structure of the domain ontology and related instances. The conceptual structure and semantic rules design are also completed. This section is to demonstrate the mechanism of learning path personalization through learning object sequencing. The task is done by applying the concepts of Teaching activity and Learners with the use of inference engine for rule inference to obtain implicit knowledge.

4.1 Teaching Activity

The instructor, instructional designer, or the LMS administrator, with their expertise in instructional activity management, may announce the current curriculum activity as shown in Fig. 2. This show case use "Teaching_Activity1" as an example.

The 3 properties are the corresponding current cluster, the next activity cluster, and the pre-requisite cluster. These annotations are known factual knowledge. As shown in screenshot (1) of Fig. 2, the three property values at individual editor pane are "CCSS.Math.Content.3.OA.A","CCSS.Math.Content.3.OA.B", and "CCSS.Math.Content.2.OA.A", respectively. Other properties of the individual are blank and are marked as corresponding rules Rule-2 through Rule-5 (see Table 2).

Screenshot (2) of Fig. 2 shows the results of running the inference engine. The blank properties in screenshot (1) have obtained property values. For example, the `has_Available_LO` has obtained *"Alphla_3A, Beta_3A, and Delta_3A"*, which are three learning objects of same level. The inference engine used in this study is JESS (Java Expert System Shell), a third party inference tool embedded in Protege platform as a plugin.



INDIVIDUAL EDITOR for Teaching_Activity_1 (instance of Teach

For Individual: http://www.owl-ontologies.com/Ontology1389023246

is_CCSS_Cluster: CCSS.Math.Content.3.OA.A

has_Next_Cluster: CCSS.Math.Content.3.OA.B

has_Assessment

has_Available_L(

has_Cluster_Desc

has_Standards_Desc

INDIVIDUAL EDITOR for Teaching_Activity_1 (instance of Teaching_Activity)

For Individual: http://www.owl-ontologies.com/Ontology1389023246.owl#Teaching_Activity_1

is_CCSS_Cluster: CCSS.Math.Content.3.OA.A

has_Next_Cluster: CCSS.Math.Content.3.OA.B

has_Prerequisite: CCSS.Math.Content.2.OA.A

has_Assessment: Assessment_CCSS.Math.C(

has_Available_L(: Alpha_3A, Beta_3A, Delta_3A

has_Cluster_Desc: Represent and solve problems involving multiplication and division.

has_Standards_Desc:

Value	Lang
Use multiplication and division within 100 to solve word problems in situations involving eq...	
Interpret whole-number quotients of whole numbers, e.g., interpret 56 ÷ 8 as the number o...	
Determine the unknown whole number in a multiplication or division equation relating three...	
Interpret products of whole numbers, e.g., interpret 5 x 7 as the total number of objects in	

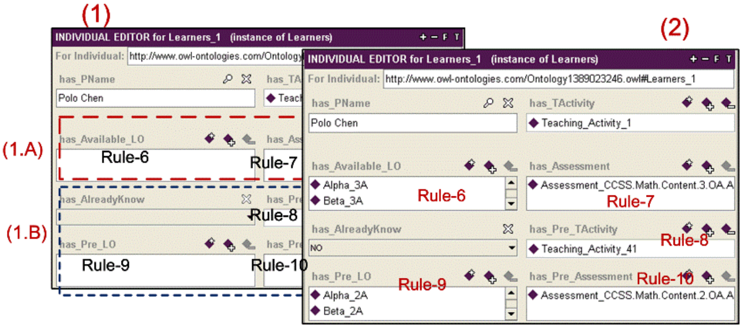
Fig. 2. Results of Teaching Activity after running the inference engine

4.2 Learners

This study is intended to design the self-regulated learning in a flipped learning context. The learner would start the instructor-assigned activity. For example, screenshot (1) of Fig. 3 has Learners_1 as the starting point. The learner and the current learning activity are to be asserted (two properties in the upper part of the individual editor are shown as asserted property values respectively: "Polo Chen" and "Teaching_Activity1"). The other 6 properties are shown blank. For the purpose of elaboration, in Screenshot (1) of Fig. 3, block (1.A) and block (1.B) are marked to explain the two-stage inference:

- In block (1.A), two rules (Rule-6 and Rule-7, see Table 2 for details) are applied to obtain the corresponding learning objects and assessments. After running JESS, the results are shown in Screenshot (2) of Fig. 3.
- In block (1.B), the learner's performance in this teaching activity needs to be shown in `has_AlreadyKnow`. If the results is not satisfactory (shown as *"NO"* in this property), the learner will be routed to the pre-requisite teaching activity. The remained three properties in block (1.B) use the rules Rule-8 to Rule-10 (see Table 2for details). After running JESS, the results are shown in Screenshot (2) of

Fig. 3. In this demonstration, the learner is assigned *"Teaching_Activity_41"* (Rule-8), learning objects "*Alpha_2A*, *Beta_2A*, and *Delta_2A"* (Rule-9), and "*Assessment_CCSS.Math.Content.OA.A"* (Rule-10)for remedial learning.



INDIVIDUAL EDITOR for Learners_1 (instance of Learners)

For Individual: http://www.owl-ontologies.com/Ontology1389023246.owl#Learners_1

has_PName: Polo Chen

has_TActivity: Teaching_Activity_1

has_Available_LO: Alpha_3A, Beta_3A

has_Assessment: Assessment_CCSS.Math.Content.3.OA.A

has_AlreadyKnow: NO

has_Pre_TActivity: Teaching_Activity_41

has_Pre_LO: Alpha_2A, Beta_2A

has_Pre_Assessment: Assessment_CCSS.Math.Content.2.OA.A

Fig. 3. Results of Learners after running the inference engine

5 Conclusion

This study created a learning path adaptivity mechanism through the ontology-driven knowledge base approach: The modeling of the CCSS Mathematics knowledge domain, a learning path adaptation task ontology, and a set of semantic rules to enable the learning path adaptivity. As the experiment has shown, the ontology-driven knowledge base adaptivity mechanism is able to facilitate learning remediation by specifying a learning path for the learner to return to the needed pre-requisite learning objects and assessment. This mechanism is most suitable for learner's remedial learning in flipped learning context. The value of this study is threefold:

5. The use of ontology-driven approach: Instead of an ontology-supported approach, the ontology-driven design has not only retained the strengths of ontology information systems in terms of concept consistency, classified taxonomy, and computing inference, but also given the advantage of elasticity to knowledge modeling.
6. The teaching-learning reconceptualization: The learning path adaptivity mechanism is enabled through the sematic rules to create causal inferences between the domain ontology and the task ontology, which is based on the conceptualization of education (G, M, T) triplet and the reality that learning could happen in between LMS and learner.
7. Pedagogical embedment: The ontological implementation of learning path adaptivity is practically meaningful for flipped learning. In a time when learning can be the interaction between the LMS and the learner, sound pedagogical considerations are important for further development of learning path research.

Based on the conceptualizations and implementation of this study, future studies in learning path adaptivity may extend from remediation to incorporate more comprehensive pedagogical principles such as the possibility of concurrent learning paths and user profile modeling for better learning path adaptivity.

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