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LEARNING PATH ADAPTIVITY IN SUPPORT OF FLIPPED LEARNING: A KNOWLEDGE-BASED APPROACH

Abstract:

Flipped learning inverts the two learning spaces of traditional education: the classroom group learning space and the homework individual learning space. In flipped learning, learners are exposed to direct instruction for basic knowledge acquisition before coming to the classroom for active learning with the teacher and peers. In recent years, flipped learning has received vast attention from educational practitioners and researchers. However, this study argues that existing e-learning systems mainly serve for learning management and content delivery purposes and lack support for flipped learning. As an innovative educational approach, flipped learning needs more pedagogical elements such as integrated instructional design and adaptive content delivery to achieve effective direct instruction. This study aims to create a learning adaptivity design to effectively support learning in the flipped individual learning space where the teacher is absent. Since teaching involves various pedagogical and content knowledge sources, we propose a conceptual model of teaching as the function of the knowledge triad of curriculum guidance (G), teaching activity (A), and learning object (O). To realize such conceptualization, ontological problem-solving approach is used for knowledge-based system (KBS) development to integrate the relevant knowledge sources. The knowledge model is created using the Protégé platform to develop the OWL-based domain ontology, task ontology, and the SWRL-based semantic rules to enable inference among the GAO triad for learning adaptivity. The case experiment results show that the KBS prototype is able to adaptively guide student learning in the flipped individual learning space with the knowledge sources considered.

Keywords:

Flipped learning; Individual learning space; Knowledge-based system; Ontological problem-solving

Introduction

In a traditional classroom, students learn knowledge and skills from teachers, mostly through lectures, and then try solving homework assignment problems individually to further practice the knowledge and skills they have learned. In recent years, the flipped learning model has been proposed as an alternative to the lecture-assignment model of school education. By inverting (flipping) the order of activities, students learn the basic knowledge and skills individually through videos and readings before they come to the classroom, and the classroom group learning is used for problem-solving and collaborative activities (Bishop and Verleger, 2013). In flipped learning, it is possible for teachers to shift their role from “sage on the stage” to “guide on the side” as proposed by King (1993), which allows them to use the classroom session for engaging individual or groups of students in active learning instead of simply lecturing to deliver knowledge. Flipped teaching has become viable because of the maturation of the information and communications technology infrastructure, the widespread use of online video platforms, and the promotion of recent MOOC sites, such as Khan Academy (Sparks, 2011).

To better support learners, we propose a conceptualization of direct instruction for basic knowledge acquisition in the flipped individual learning context. In the traditional classroom, teachers deliver instruction with two broad categories of knowledge: content knowledge and pedagogical knowledge (Mishra and Koehler, 2006). Content knowledge involves “what to teach” with “what material”; whereas pedagogical knowledge concerns deciding “how to teach” with “what knowledge structure.” With such conceptualization, direct instruction in the flipped individual learning space can be seen as a (*G*, *A*, *O*) triple where ‘*G’* denotes the guidance (the curricular and content knowledge structure); ‘*A’* denotes the activities (instructional design and delivery); and ‘*O’* denotes the objects (learning materials). Since the teacher is absent in the flipped individual learning space, to embed this *GAO* triple in the e-learning systems would better support student learning.

With the multiple knowledge sources involved, we propose using an ontological problem-solving to model the knowledge sources and instructional tasks in the flipped individual learning space. As a use case scenario, we take Common Core State Standards for Mathematics (CCSS Math) to represent the curricular guidance (G) concept. When teaching in the classroom, teachers are able to use multiple instructional strategies, one of them being the dynamic structuring of learning modules. We thus take learning path adaptivity to represent the teaching activity (A) concept. The video clips corresponding to the curriculum and specified by the teacher would represent the learning object (O) concept.

Literature Review

Flipped learning and learning adaptivity

Flipped learning can be simply defined as “delivering instruction online outside of class and moving ‘homework’ into the classroom” (Strayer, 2011). In a research review, Bishop and Verleger (2013) defined flipped learning from instructional viewpoint as “interactive group learning activities inside the classroom, and direct computer-based individual instruction outside the classroom.” In addition to active learning, other instructional advantages of flipped learning include teacher-student interaction, project-based learning, and differentiated teaching (Sams and Bergmann, 2013). Active learning in the group learning space, therefore, has been the focus of the flipped learning movement.

Learning adaptivity has received attention from the e-learning research community and the industry. However, many existing e-learning systems are not developed to support learning adaptivity (Bennett, 2011) and others have supported adaptivity from the instructor’s rather than the learners’ perspective (Yaghmaie and Bahreininejad, 2011). The LO-based learning management systems, for example, have adopted a modularity approach. Such an approach has greatly contributed to the development of e-learning specifications for standardization to achieve content sharability and interoperability. Yet the benefit of system adaptability has not been realized (Parrish, 2004).

Ontology for Learning Adaptivity

Ontology in philosophy studies the categories of things that exist in certain domains (Sowa, 2010). Ontology engineering as a research methodology has been widely adopted in various fields of study and ontology has been used in many disciplines as a synonym of “conceptual model” (Welty and Guarino, 2001). Following the emergence of the Semantic Web; the ontology research community has adopted the World Wide Web Consortium (W3C) recommended standards such as XML, RDF, and OWL (Web Ontology Language) for ontology representation and sharability. For ontological KBS development, Protégé[1] has become a prevalent platform for OWL-based ontology construction, problem-solving modeling, and KBS execution (Gennari et al., 2003).

Some researchers have conducted ontology-based modeling for learning adaptivity. Görgün, Türker, Ozan, & Heller (2005) constructed an OWL-based knowledge base with learner modeling for learning adaptivity. Steiner, Nussbaumer and Albert (2009) constructed a learning adaptivity system component through domain and user modeling. Karampiperis and Sampson (2006) proposed and simulated an AH system with a competence description ontology for LO sequencing. Jovanović, Gašević and Devedžić (2009) developed an adaptive learning system using Semantic Web technologies and models and developed an algorithm for LO assembly. Such ontology-based approach has used ontologies for concept modeling of learning adaptivity but has not used the inference capacity of ontologies.

Other researchers have attempted to use the strength of ontological reasoning for learning adaptivity. Yaghmaie and Bahreininejad (2011) proposed a learning adaptivity agent including a business layer with inference rules and learning content repository

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[1] Protégé ontology editor by Stanford Center for Biomedical Informatics Research, http://protege.stanford.edu/

ontology. Shen and Shen (2004) used Protégé to construct a knowledge base with a learning object ontology and used Protégé Axiom Language for rule inference to perform adaptive LO sequencing. Chi (2009) developed OWL-based ontologies and enabled content sequencing from different content sources with Semantic Web Rule Language[2] (SWRL) rules. As stated by De Bra, Aroyo and Chepegin (2004), the use of ontologies for learning adaptivity is the “next big thing.” Many ontological learning adaptivity studies, however, have used ontology-based modeling without inference. Only very few studies have constructed full OWL ontologies with ontological reasoning to take full advantage of the Semantic Web infrastructure.

A Flipped e-learning System Design

To provide learning adaptivity in the flipped individual learning space, various knowledge sources and inference mechanisms are involved in the KBS building. The conceptualized *GAO* triple represents the three knowledge sources to be integrated into the KBS to interact with the learner. The triple can be regarded as the three distinct roles of curriculum expert, teacher, and content provider. To achieve learning adaptivity, the *GAO* conceptualizations of knowledge sources need to be embedded into the e-learning systems to interact with the learner. The embedment can be done through ontological engineering to create knowledge representation and semantic rules for intelligent inference. The major components of the knowledge model include: (1) a domain ontology consisting of a common class structure and instances using *is-a* relations to express the knowledge taxonomy of the knowledge domain and to provide a standard terminology set for ontology communication; (2) a task ontology to establish an objective-oriented knowledge framework and instances using *has-a* relations to express specific problem-solving targets; and (3) a set of semantic rules to implement the problem-solving inferences.

Building CCSS Math as Domain Ontology

Domain ontology is a defined structural representation of the specified knowledge domain. The CCSS Math[3] curriculum guide is used as the knowledge domain, the curriculum guidance (G), for in this study. A snapshot of the CCSS Math sample is shown in Figure 1. Because ontology represents knowledge as a taxonomical structure, the components of CCSS Math are analyzed and reassembled into a new pattern. The formal expression is proposed as *Grade.Domain.Cluster.Standard*. For example, the expression “*CCSS.Math.Content.3.NBT.A.1*” represents course identification (*CCSS.Math.Content*) and its specific component structure:

Figure 1: A snapshot of the CCSS Math standards content

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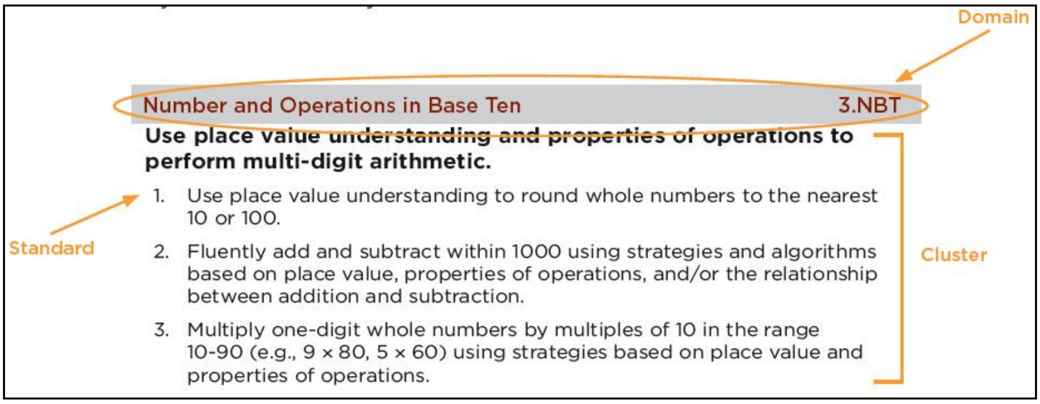
[2] Semantic Web Rule Language (SWRL), http://www.w3.org/Submission/SWRL/

[3] Common Core State Standards for Mathematics, http://www.corestandards.org/Math/



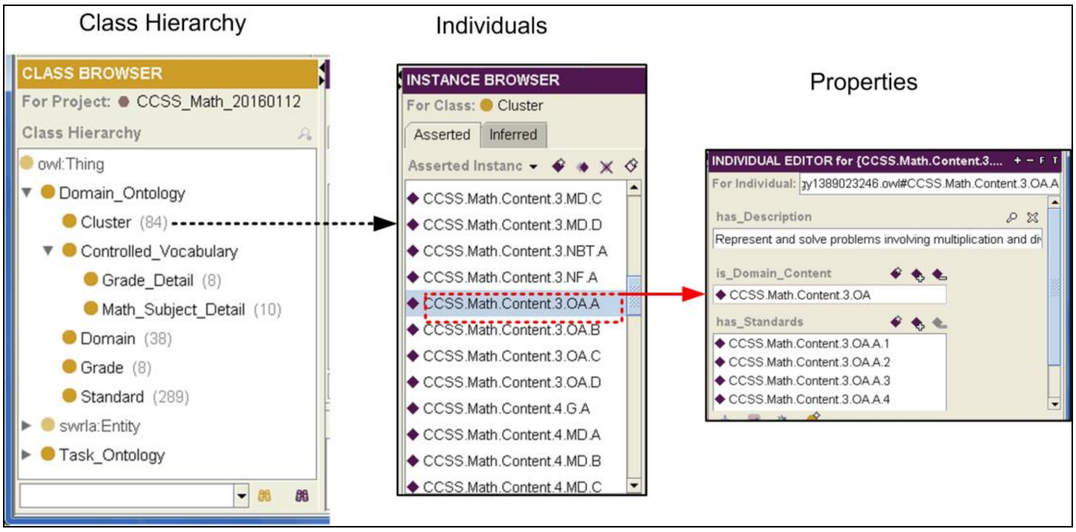
Number and Operations in Base Ten **3.NBT**

Use place value understanding and properties of operations to perform multi-digit arithmetic.

1. Use place value understanding to round whole numbers to the nearest 10 or 100.
2. Fluently add and subtract within 1000 using strategies and algorithms based on place value, properties of operations, and/or the relationship between addition and subtraction.
3. Multiply one-digit whole numbers by multiples of 10 in the range 10-90 (e.g., 9 × 80, 5 × 60) using strategies based on place value and properties of operations.

- Grade: The first part is grade level represented by a number. In this example, '*3*' means the third grade.
- Domain: The second part is the topic area (mathematical domains in CCSS usage) expressed by an abbreviation. In this example, "*NBT*" means "*Number and Operations in Base Ten.*"
- Cluster: The cluster is an overall description of what students should understand and be able to perform. In this example, the first cluster of "*3.NBT*" is marked as cluster '*A*' and has a description as "*Use place value understanding and properties of operations to perform multi-digit arithmetic.*"
- Standard: The standard part uses a number to denote a specific item of what students should understand and be able to perform (competence) after learning. For example, the first standard in "*3.NBT.A*" is marked as '*1*' and has the description of "*Use place value understanding to round whole numbers to the nearest 10 or 100.*"

Figure 2: Class structure, properties, and instances (individuals) of the Domain Ontology



For Project: ● CCSS_Math_20160112

- owl:Thing
  - Domain_Ontology
    - Cluster (84)
    - Controlled_Vocabulary
      - Grade_Detail (8)
      - Math_Subject_Detail (10)
    - Domain (38)
    - Grade (8)
    - Standard (289)
  - swrla:Entity
  - Task_Ontology

For Class: ● Cluster

- ◆ CCSS.Math.Content.3.MD.C
- ◆ CCSS.Math.Content.3.MD.D
- ◆ CCSS.Math.Content.3.NBT.A
- ◆ CCSS.Math.Content.3.NF.A
- ◆ CCSS.Math.Content.3.OA.A
- ◆ CCSS.Math.Content.3.OA.B
- ◆ CCSS.Math.Content.3.OA.C
- ◆ CCSS.Math.Content.3.OA.D
- ◆ CCSS.Math.Content.4.G.A
- ◆ CCSS.Math.Content.4.MD.A
- ◆ CCSS.Math.Content.4.MD.B
- ◆ CCSS.Math.Content.4.MD.C

For Individual: y1389023246.owl#CCSS.Math.Content.3.OA.A

has_Description: Represent and solve problems involving multiplication and di

is_Domain_Content: ◆ CCSS.Math.Content.3.OA

has_Standards:
- ◆ CCSS.Math.Content.3.OA.A.1
- ◆ CCSS.Math.Content.3.OA.A.2
- ◆ CCSS.Math.Content.3.OA.A.3
- ◆ CCSS.Math.Content.3.OA.A.4

The development result of the top class *Domain_Ontology* is shown in Figure 2 in organized screenshots from Protégé. On the left is the domain conceptual structure, showing first level classes under the top class. On the middle is an example of class *Cluster* and its contained individuals. At the right of this figure is an example of a cluster individual containing individual properties. In addition to the CCSS Math class structure, an additional class of *Controlled Vocabulary* is added to contain the common terminology for the purposes of ontology sharing and communication. This class includes sub-classes of *Grade_Detail* (holding a vocabulary of grade years) and *Math_Subject_Detail* (holding a vocabulary of 10 subject domain areas such as *Geometry*, the *Number System*, and *Number & Operation in Base Ten*).

Building Task Ontology

The purpose of designing task ontology is to represent the specific inference targets or goals unique to the knowledge system. The task ontology includes the conceptual design of the teaching activities and learning objects. Three major classes are defined including *Content_Materials, Teaching_Activity*, and *Learners*. Under each class, the necessary properties are established to describe the class details. Table 1 shows the design of the task ontology classes and the corresponding properties. Since the learning in the flipped individual learning space is in between the e-learning system and the learner, the class *Learners* is added. The design details of the properties in each class are as follows:

- *Content_Materials*: including two subclasses *Learning_Object* and *Assessment*. Under the *Assessment*, two properties are defined: the *has_Assessment_Name* indicating the assessment object title and *is_CCSS_Cluster* connecting the individual to a corresponding cluster. Under the *Learning_Object*, three properties are defined: the *has_LOName* indicating the title of the LO; the *is_CCSS_Cluster* linking the LO to a corresponding cluster; and the *has_Equivalent_LO* inferring other LOs linked to the same cluster.

- *Teaching_Activity*: This class describes an exemplar instructional design containing the sequencing of LOs. In the property design, three properties are asserted, including the corresponding cluster of the teaching activity (*is_CCSS_Cluster*), the next teaching activity (*has_FollowUp*), and the prerequisite teaching activity (*has_Prerequisite*).

- *Learners*: This class connects the learning state with learning activities. Among the 11 properties defined, the first two need to be asserted: the learner’s name property (*has_PName*) and the default teaching activity (*has_TActivity*) assigned by the teacher. Based on the selected teaching activity, three properties of curriculum guidance will be inferred: the current corresponding cluster (*is_CCSS_Cluster*), cluster description (*has_Cluster_Desc*), and standard description (*has_Standards_Desc*). Based on the known factual knowledge, the corresponding assessment (*has_Assessment*) and same level LO (*has_Available_LO*) properties will be inferred. In the learner assessment results, the property (*has_AlreadyKnow*) will be obtained as a result of assessment. If the value is “*NO*,” then the inference for the three properties *has_Pre_TActivity, has_Pre_LO*, and *has_Pre_Assessment* will continue to infer the recommended LOs for remediation.

Table 1. Design details of the Task Ontology

Class		Property			
		ID	Type	Range	Rule
Content Materials	Assessment	has_Assessment_Nam	Data	(string)	
		is_CCSS_Cluster	Object	Cluster	
	Learning Object	has_LOName	Data	(string)	
		is_CCSS_Cluster	Object	Cluster	
		has_Equivalent_LO	Object/Inferred	Learning_Object	(1)
Teaching Activity		has_Activity_Name	Data	(string)	
		is_CCSS_Cluster	Object	Cluster	
		has_Prerequisite	Object	Teaching_Activity	
		has_FollowUp	Object	Teaching_Activity	
Learners		has_PName	Data	(string)	
		has_TActivity	Object	Teaching_Activity	
		is_CCSS_Cluster	Object	Cluster	(2)
		has_Cluster_Desc	Data/Inferred	(string)	(3)
		has_Standards_Desc	Data/Inferred	(string)	(4)
		has_Available_LO	Object/Inferred	Learning_Object	(5)
		has_Assessment	Object/Inferred	Assessment	(6)
		has_AlreadyKnow	Data	(string)/YES/NO	
		has_Pre_TActivity	Object/Inferred	Teaching_Activity	(7)
		has_Pre_LO	Object/Inferred	Learning_Object	(8)
		has_Pre_Assessment	Object/Inferred	Assessment	(9)

Developing Semantic Rules

The problem-solving analysis of semantic rules usually starts with the class of the contained property and then chains to other useful individuals in a step-by-step manner until the result is achieved. To enable inference, SWRL is used. The SWRL-based rules are presented in the format of "*Premise → Consequence.*" A rule is first stated as a colloquial statement and then specified as a list of semantic statements in the format of *{Goal (Problem): Step*$_1$*; Step*$_2$*;.. .., Step*$_n$*}*. The following example describes a general process of expressing the logical cause-effect relations of whether an LO has other LOs that serve similar functions from alternative learning object sources. To locate the alternatives, the class *Cluster* plays an intermediary role to check whether the LOs are equivalent. If two LOs belong to the same cluster, then they are regarded as alternatives. In the inference process, the steps are atoms to be linked, and variables *'x', 'y', 'a'* are replaceable individuals. In rule implementation, the facts and variables are inserted into the inference engine for logical computation. The above inference steps can be written as SWRL-based rules as Rule #1:

Learning_Object (?x) ∧ is_CCSS_Cluster (?x, ?a) ∧ Learning_Object (?y) ∧
is_CCSS_Cluster (?y, ?a) ∧ differentFrom(?x, ?y) → has_Equivalent_LO(?x, ?y) (1)

The SWRL rules are edited using the Protégé SWRL tab. The following 8 rules are created from learner's perspective on obtaining CCSS Math cluster descriptions and appropriate LOs (teaching activities and assessments). Rule #2 is for identifying the CCSS cluster description of a current teaching activity. Rule #3 is for obtaining the corresponding description of a CCSS cluster. Rule #4 is for obtaining the relevant standard descriptions under a specific CCSS cluster. Rule #5 is for obtaining LOs in a specific teaching activity querying against the learner's profile. Rule #6 identifies the corresponding assessment of each obtained teaching activity for the learner. Rules #7 to #9 identify prerequisite teaching activities, LOs, and assessments, respectively, as a remedial design. When failing to pass a teaching activity assigned by the teacher, the learner will be required to learn the prerequisite activities default in the knowledge domain. The knowledge model is complete with the design of the conceptual structures of the domain ontology and the task ontology, along with the subordinate individuals and properties, and the semantic rules for learning adaptivity reasoning.

Learners(?x) ∧ has_TActivity(?x, ?y) ∧ Teaching_Activity(?y) ∧ is_CCSS_Cluster(?y, ?z)
→is_CCSS_Cluster(?x, ?z) (2)

Learners(?x) ∧ has_TActivity(?x, ?y) ∧ Teaching_Activity(?y) ∧ is_CCSS_Cluster(?y, ?z) ∧
Cluster(?z) ∧ has_Description(?z, ?ans) →has_Cluster_Desc(?x, ?ans) (3)

Learners(?x) ∧ has_TActivity(?x, ?y) ∧ Teaching_Activity(?y) ∧ is_CCSS_Cluster(?y, ?z) ∧
Cluster(?z) ∧ has_Standards(?z, ?a) ∧ has_Description(?a, ?ans) →
has_Standards_Desc(?x, ?ans) (4)

Learners(?x) ∧ has_TActivity(?x, ?y) ∧ Teaching_Activity(?y) ∧ is_CCSS_Cluster(?y, ?z) ∧
Learning_Object(?a) ∧ is_CCSS_Cluster(?a, ?z) ∧ has_Equivalent_LO(?a, ?ans) →
has_Available_LO(?x, ?ans) (5)

Learners(?x) ∧ has_TActivity(?x, ?y) ∧ Teaching_Activity(?y) ∧ is_CCSS_Cluster(?y, ?z) ∧
Assessment(?a) ∧ is_CCSS_Cluster(?a, ?z) → has_Assessment(?x, ?a) (6)

Learners(?x) ∧ has_AlreadyKnow(?x, "NO") ∧ has_TActivity(?x, ?y) ∧
Teaching_Activity(?y) ∧ has_Prerequisite(?y, ?ans) → has_Pre_TActivity(?x, ?ans) (7)

Learners(?x) ∧ has_AlreadyKnow(?x, "NO") ∧ has_Pre_TActivity(?x, ?y) ∧
Teaching_Activity(?y) ∧ is_CCSS_Cluster(?y, ?z) ∧ Learning_Object(?a) ∧
is_CCSS_Cluster(?a, ?z) ∧ has_Equivalent_LO(?a, ?ans) → has_Pre_LO(?x, ?ans) (8)

$$\begin{gathered} Learners(?x) \wedge has\_AlreadyKnow(?x, "NO") \wedge has\_Pre\_TActivity(?x, ?y) \wedge \\ Teaching\_Activity(?y) \wedge is\_CCSS\_Cluster(?y, ?z) \wedge Assessment(?a) \wedge \\ is\_CCSS\_Cluster(?a, ?z) \rightarrow has\_Pre\_Assessment(?x, ?a) \end{gathered} \tag{9}$$

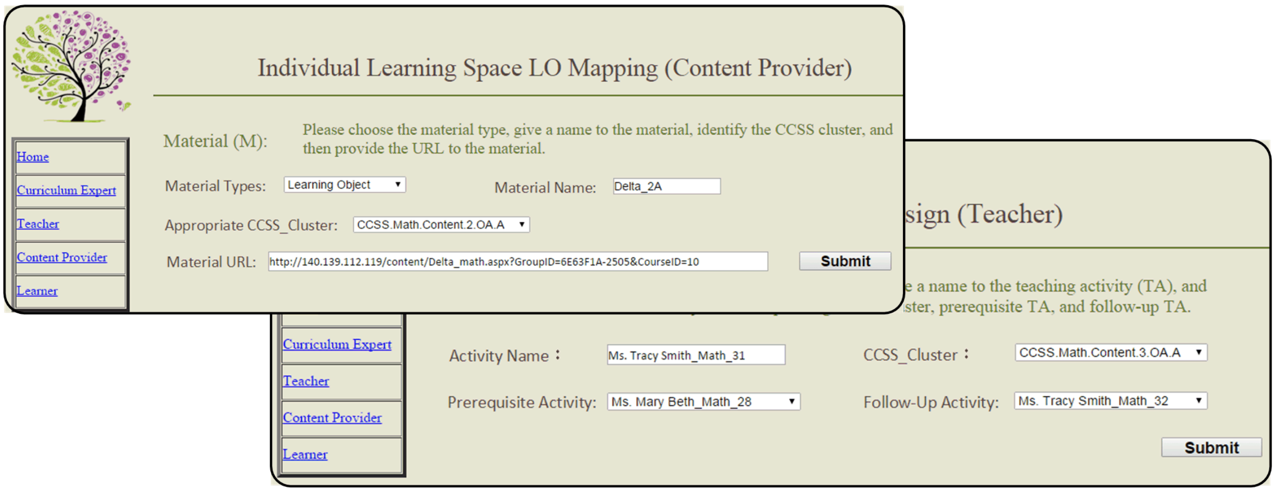
Case Experiment

The case experiment demonstrates how the designed KBS prototype can support learning adaptivity with adaptive LO sequencing. The mechanism for creating activity (*A*) is designed in the task ontology for the teacher to specify LO sequencing (learning path) according to their content knowledge, pedagogical knowledge, and understanding of the learners. To adaptively present the learning object (*O*), exemplar semantic rules are developed to infer between the task ontology and the domain ontology to achieve learning adaptivity. In this case experiment, we will build a learning path by inserting required individuals in the *Content_Materials* and *Teaching_Activity* classes, with which an individual learner will then be able to interact adaptively.

Building the individuals of corresponding classes

As designed in Table 1, the class *Content_Materials* has sub-classes *Assessment* and *Learning_Object*. The individuals of content materials need to be created with semantics (logical relations) asserted. In the designed knowledge model, the property *is_CCSS_Cluster* would link individuals under the class *Learning_Object* to the individuals under the class *Cluster*. The default basic logical relationships usually exist in the curriculum guidelines such as CCSS Math. Often, the content providers have the expertise to map the learning object (*O*) to the curriculum guidance (*G*).

Figure 3: Screen snapshot of Content_Materials and Teaching_Activity design



Individual Learning Space LO Mapping (Content Provider)

Material (M): Please choose the material type, give a name to the material, identify the CCSS cluster, and then provide the URL to the material.

Material Types: Learning Object

Material Name: Delta_2A

Appropriate CCSS_Cluster: CCSS.Math.Content.2.OA.A

Material URL: http://140.139.112.119/content/Delta_math.aspx?GroupID=6E63F1A-2505&CourseID=10

sign (Teacher)

e a name to the teaching activity (TA), and
ster, prerequisite TA, and follow-up TA.

Activity Name : Ms. Tracy Smith_Math_31

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

Prerequisite Activity: Ms. Mary Beth_Math_28

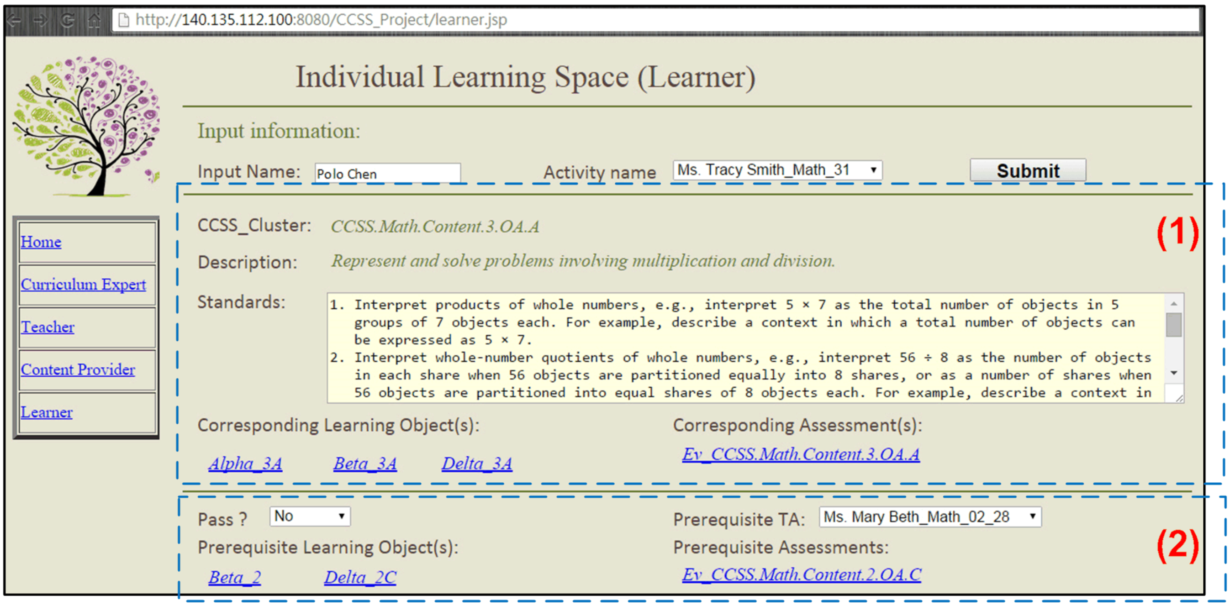
Follow-Up Activity: Ms. Tracy Smith_Math_32

This study has created Web interfaces that permit content providers to annotate specific details of learning objects and assessments. As seen in the upper left screenshot of Figure 3, for example, an individual learning object "*Delta_2A*" corresponds to an individual cluster "*CCSS.Math.Content.2.OA.A*" and it's URL. In addition to content providers, teachers, instructional designers, and e-learning system administrators are the ones with expertise to design learning paths and build teaching activities. As seen in the lower right screenshot of Figure 3, when creating the teaching activity "*Ms. Tracy Smith_Math_31*," the interface would require the teacher to identify three individuals: corresponding cluster (*CCSS.Math.Content.3.OA.A*), backward teaching activity (*Ms. Mary Beth_Math_28*), and forward teaching activity (*Ms. Tracy Smith_Math_32*).

Learner Activity

The learner interface (Figure 4) demonstrates the *GAO*-based learning activities. For example, the user Polo Chen starts "*Ms. Tracy Smith_Math_31*." The selected or assigned activity is used as input for triggering the SWRL rules to infer against the knowledge base. As seen in Figure 4, the presented results are obtained by running the JESS[4] reasoning engine. Two blocks are marked to explain the two-stage reasoning:

Figure 4: Screen snapshot of Learner activities



http://140.135.112.100:8080/CCSS_Project/learner.jsp

Individual Learning Space (Learner)

Input information:

Input Name: Polo Chen

Activity name: Ms. Tracy Smith_Math_31

CCSS_Cluster: *CCSS.Math.Content.3.OA.A*

Description: *Represent and solve problems involving multiplication and division.*

Standards:

```
1. Interpret products of whole numbers, e.g., interpret 5 × 7 as the total number of objects in 5
   groups of 7 objects each. For example, describe a context in which a total number of objects can
   be expressed as 5 × 7.
2. Interpret whole-number quotients of whole numbers, e.g., interpret 56 ÷ 8 as the number of objects
   in each share when 56 objects are partitioned equally into 8 shares, or as a number of shares when
   56 objects are partitioned into equal shares of 8 objects each. For example, describe a context in
```

Corresponding Learning Object(s): Alpha_3A Beta_3A Delta_3A

Corresponding Assessment(s): Ev_CCSS.Math.Content.3.OA.A

Pass ? No

Prerequisite TA: Ms. Mary Beth_Math_02_28

Prerequisite Learning Object(s): Beta_2 Delta_2C

Prerequisite Assessments: Ev_CCSS.Math.Content.2.OA.C

- In Block 1, Rule #2 obtains the teaching activity's corresponding cluster *CCSS.Math.Content.3.OA.A*. Rule #3 obtains a cluster's description. Rule #4 obtains the cluster's standards. Rule #5 obtains available learning objects *Alpha_3A, Delta_3A* and *Beta_3A*. Rule #6 obtains assessment *Ev_CCSS.Math.Content.3.OA.A*. Each learning object and assessment can be further linked to a specific material via hyperlink.
- In Block 2, the learner's performance in the assigned teaching activity is shown in the "*Pass?*" field. If the result is not satisfactory (shown as *"No"*), the learner will be

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[4] http://www.jessrules.com/

assigned a prerequisite teaching activity (e.g., "*Ms. Mary Beth_Math_28*") by invoking Rule #7. The remaining prerequisite learning objects and assessments are obtained by running Rule #8 and Rule #9. In this demonstration, Rule #8 obtains available learning objects "*Beta_2*" and "*Delta_2C*." Lastly, Rule #9 obtains a corresponding assessment "*Ev_CCSS.Math.Content.2.OA.C*" for the learner.

Conclusion

This study has presented how ontological problem-solving can perform knowledge modeling and inference to make learning adaptivity viable in the flipped individual learning space. This is achieved by conceptualizing classroom direct instruction as the function of the *GAO* triple and using it as the foundation to build the domain ontology, the problem-solving task ontology, and the inference rules. The case has demonstrated how the ontological KBS can adaptively guide the learner through the learning process**.**

The results of the case experiment have shown that this OWL-based ontological design is capable of connecting the content knowledge and the problem-solving task knowledge for logical inference to enable learning adaptivity. Additionally, the inclusion of teacher's pedagogical knowledge through learning path design can ensure that student's learning in the flipped individual learning space is pedagogically sound. Given that existing e-learning systems often lack the functionality of supporting learners in the flipped individual learning space, this created mechanism may be packaged to act as an external learning adaptivity service. In summary, the value of this study is threefold:

(1) Creation of ontology-driven learning adaptivity: Unlike most ontology-based learning adaptivity research, this study is ontology-driven using current Semantic Web technologies. The KBS prototyped thus would be able to take advantage of the Semantic Web for further semantic reasoning, system interoperability, and data extensibility.

(2) Pedagogical conceptualization: The conceptualization of the *GAO* triple provides an upper level modeling layer above knowledge sources. The *GAO* view of direct instruction for flipped individual learning space is an overall design guide for knowledge modeling and a pedagogical foundation for the creation of the learning adaptivity mechanisms.

(3) Ontological problem-solving design: Knowledge integration and logical inference are the core strengths of ontological methodology. We have designed and demonstrated a framework of ontological problem-solving process with full OWL-based ontologies.

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