Capturing and Disseminating the Principles of Self-Regulated Learning in an Ontological Framework

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ABSTRACT
Self-regulated learning, a seminal theory in education psychology, concerns how learners' regulate their cognitive tactics and strategies. However, research indicates that learners rarely use the optimal learning tactics and strategies. Our system, MI-EDNA formally captures the SRL principles in the ontological framework and we use the Description Logic reasoning mechanism and the inference engine based on the production rules to disseminate SRL principles to the learners, providing the opportunities to reflect on and regulate their learning process.

Categories and Subject Descriptors
I.2.4 Knowledge Representation Formalisms and Methods – *representation languages, semantic networks.*

Keywords
Ontology, Semantic Web, Ontology Web Language, Knowledge Representation, Description Logic, Production rules, Self-Regulated Learning, Learning Tactics and Strategies, Model Tracing, e-learning

INTRODUCTION
In our research, learning is viewed as an activity that students do for themselves in a *proactive* way rather than as a covert event that happens to them in reaction to teaching [41]. Such proactive students are called self-regulated learners and the theory that models and predicts such cognitive and metacognitive traits is called the theory of Self-Regulated Learning. There has been much research in educational psychology [41][39][32][24] that conceptually articulate how people regulate their learning, particularly how they create structural knowledge and process that underlie their abilities. Recently, there has been a surge of interest among educators and computer scientists to inject and maximize the experience of self-regulation in e-learning, especially in intelligent learning environments.

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Many systems in Intelligent Tutoring (ITS) were built without foundations in educational theories or in social theories of human interaction processes. These systems employed a variety of knowledge representation schemes such as symbolic rules, fuzzy logic [21], Bayesian networks [19], neural networks, case-based reasoning [1], and even some hybrid approaches [33], without explicit theoretical connectivity between the knowledge that is represented and the interactions of the students. Many researchers have advocated knowledge representation schemes for ITS systems that hinted on the need for a theoretical basis to model student interactions [40][18][31][36]. Of late, ITS has employed machine learning, dialogue based communication, and planning systems with explicitly represented theories of mixed-initiative interactions [1][3][8][7][9][11] that add a sense of *naturalness* [18] to the represented knowledge.

Instructional design methodologies have been used to build ontology-aware educational systems [25][27][6][20][28]. These methodologies explicitly connect students' task ontologies with their goals, their cognitive states, their interaction with the system, and with the pedagogical knowledge. Other researchers [4][10][29] have developed instructionally well-designed task ontologies as part of an overall framework for web-based information systems, where the learner activities, the domain model, and the educational strategies/goals are independently represented and semantically connected.

Instructors continuously adapt their teaching strategies and techniques to address specific conditions within their teaching environment. Although significant progress has been made in ITS and LMS, key challenges still remain in devising effective approaches to capture human teaching strategies, learner strategies, and a mapping between the two. A much bigger challenge lies in disseminating theory-oriented teaching strategies in a context that is not only appropriate for the learners but also offers explanations to the participants as to why the system advocates a particular strategy. This is the motivation behind our research. Our focus is to capture and disseminate the principles of self-regulated learning in an ontological framework for a distributed community of learners and teachers. One of the key design goals of our system is the ability of the system to explain why a particular teaching or learning strategy is appropriate or not appropriate in a given learning context.

In this paper, we discuss the designs of a computational mechanism based on the principles of self-regulated learning [39][41] that formally recognizes opportunities for system-initiated interactions. These interactions are aimed at both the learners and the teachers engaged in a blended online learning environment. We will present a brief introduction to ontology and our vision of how ontologies relate to Semantic Web. We will then introduce the theory of Self-Regulated Learning (SRL) and identify some of the principles of SRL that we intend to formally capture and systematically disseminate in our system. Next, we will present the architecture of our system named MI-EDNA, highlight the salient features of our ontology, discuss how we semi-automatically instantiate the ontology, and outline how we recognize SRL-oriented tactics and strategies. We will follow it up with a discussion on how to recognize opportunities for system-initiated interactions using a rule-based approach, how to develop interfaces for user-initiated[1] interactions using logic-based reasoning, and highlight our plan for an evaluation of the system.

BACKGROUND

MI-EDNA is a learning environment that employs ontological representations to capture the semantics of the models of SRL. This section highlights our views on Ontology and SRL, how we capture SRL in an ontological formalism, and how ontologies relate to Semantic Web.

Ontology and Semantic Web

Ontology is a formal specification of knowledge in a domain. It formalizes conceptualizations [14] [35]. Ontology captures not only the commonalities among different conceptualizations in the domain but also formally establishes differences among those conceptualizations. In general, ontology is used as a mechanism to promote common conceptualizations. However, it can also formally capture the differences among conceptualizations. In this sense, we contend that one should focus on the *process* of capturing conceptualizations in the ontology rather than just the commonalities. In a simplified sense, ontology provides an extendable and shareable framework to capture the common vocabulary in a domain. It includes machine-interpretable definitions of basic concepts in the domain and the relations that exist among them [30]. Presently, ontology is one of the popular knowledge representation techniques in AI.

Formally, ontology consists of *entities, relationships, properties, instances, functions, constraints, rules, and other inference procedures.* The power of ontologies rests with its ability to represent knowledge explicitly (as concepts, properties, and constraints); it's the ability to encode semantics (as meta-data, rules, and other inference procedures); and it's the ability to allow for a shared understanding of the represented formal knowledge within and in-between humans and the machines.

[1] The phrase user-initiated implies that the interface is meant for both the student and the instructor

In our research, we employ ontological approach to represent the knowledge structure, interactions and SRL strategies for the following reasons.

- Share common understanding of the structure of the knowledge among people or software agents (assumptions are explicit)
- Enable reuse of domain knowledge across different applications and experiments
- Analyze domain knowledge and interaction data independent of each other, as well as in conjunction with each other
- Provide formal representation through Ontology Web Languages (OWL), facilitating the use of constraints and reasoning based on Description Logic (DL)

Representing and reasoning with SRL tactics and strategies, encoding and sharing learner and content knowledge, and developing and using the cognitive model of the learner require ontological representation and reasoning at different levels of granularity. Assuming that ontologies promote the use and the extension of a common formal conceptualization in each domain one may assume that simply employing ontologies in web-based systems would realize the goals of Semantic Web. Unfortunately, the world of Semantic Web is much more complicated than to be solved by such a simplistic notion. As we mentioned earlier the centrality of ontology is in the *process* of capturing conceptualizations in the ontology. In a community of users interacting in a semantic web application that revolves around a common ontology, it is inevitable that inconsistencies arise in the ontology among multiple users over a period of time. Maintaining such inconsistencies in the ontology is quite intractable and remains the foremost challenge in Semantic Web. In this paper we identify a possible solution to overcome this challenge in terms of the evolution of cognitive models of users that revise the ontology from time to time.

Recent surge in semantic web research has resulted in the evolution of a W3C standard - Ontology Web Language (OWL)[2]. OWL enables the definition of domain ontologies, sharing of domain vocabularies, and the representation of the same at different levels of granularity. From a formal perspective, axioms and constructors in OWL capture the DL reasoning in terms of class consistency and consumption, in addition to other ontological reasoning.

There are different types of ontologies.

- *Domain ontologies* capture the knowledge related to a particular type of domain. E.g. Wine ontology[3],
- *Upper Ontologies* are related to several domains and not referred to the particular one. E.g. SUMO[4]

[2] http://www.w3.org/TR/owl-features/

[3] http://ontolingua.stanford.edu/doc/chimaera/ontologies/wines.daml

[4] http://reliant.teknowledge.com/DAML/SUMO.owl

- *Application Ontologies* are the type of ontologies which contain all the necessary knowledge to model a particular application in a domain or across domains. E.g. Airfare[5]
- *Structural Ontologies* refer to any particular domain. They provide representational entities without stating what should be represented. E.g. SUO-IFF[6]

In this paper we will present *application ontologies* and *domain ontologies* to show how we capture SRL knowledge in the ontologies and how we disseminate SRL-specific inferred knowledge.

Self-Regulated Learning

SRL is a theory that concerns how learners develop learning skills and how they develop expertise in using learning skills effectively [38]. SRL comprises a set of strategies and tactics employed by learners to regulate their own learning processes. It arises from two key observations. First, learners' goals for learning take precedence over goals set by teachers, authors of curricula, and developers of learning objects. Second, learners are in charge of how they learn. They choose which study tactics and learning/problem-solving strategies to use as they strive to achieve their goals.

In the realm of SRL, a collection of specific features that characterize a process (or an artifact) is called a **schema**. Many schemas are formatted as a set of rules for carrying out tasks. For instance, experienced programmers have schemas that not only help them recognize strategic formations of program pieces; their schemas also include sophisticated tactics for handling the interrelations among program pieces. Moreover, an automated schema is what is typically known as skill. A **tactic** is a particular part of a schema that is represented as a rule in IF-THEN form, sometimes called a condition-action rule. IF a set of conditions is the case, THEN a particular action carried out. IF not, a learner's ongoing behaviour or qualities of interacting with the task proceed unchanged. A **strategy** is a design or a plan for approaching a high-level goal, such as mastering a new software system. A strategy coordinates a set of tactics. Each tactic is a potential tool to use in carrying out a strategy, but not all tactics that make up the strategy are necessarily enacted.

The self-regulated learning model, as described by Winne [39] consists of various tactics and strategies that students use to reach their goals. Hadwin, et al [16] reports some of the generic tactics and strategies students use in the domain of Reading. McCombs and Marzano [22] identify some of the means to recognize strategies and tactics employed in computer programming. We are currently designing an experiment to identify strategies and tactics used by students when engaged in learning activities in the domain of java programming.

Research shows that learners often set unsuitable goals, have a limited repertoire of learning skills, often do not use learning skills they have, and frequently need extensive help to manage learning and collaborative tasks [38]. In our work, we capture and disseminate SRL knowledge by observing the sequences of strategies and tactics used by the learners and responding to the same. Capturing the principles of SRL in our ontology involves classifying the principles into strategies and tactics involved in the learning process. Kumar et. al [22][12] present a sample ontological mechanism to capture human teaching tactics and strategies. In our work, we have developed a core ontology of learner interactions that serve as a basis to pattern-match various tactics and strategies enacted by the learners.

Presently, our work focuses only in recognizing tactics enacted by the learners, envisage the underlying strategy that spawned the tactics, and recognize opportunities for the delivery of SRL-based feedback. In summary, MI-EDNA observes the fine-grained interactions of the learner with the online material, populates these interactions in an ontology, automatically translates these interactions into fine-grained tactics, predicts the coarse-grained strategies, matches these observed tactics and strategies against the optimal tactics and strategies prescribed by SRL, triggers system-initiated interactions to prompt and guide the learner who has strayed away from optimal SRL tactics and strategies, enables a logic-based query interface for learner-initiated interactions, develops a cognitive model of skills of the learner, and attempts to revise the ontology based on the model.

SYSTEM ARCHITECTURE

The architecture of MI-EDNA is presented in Figure 1.

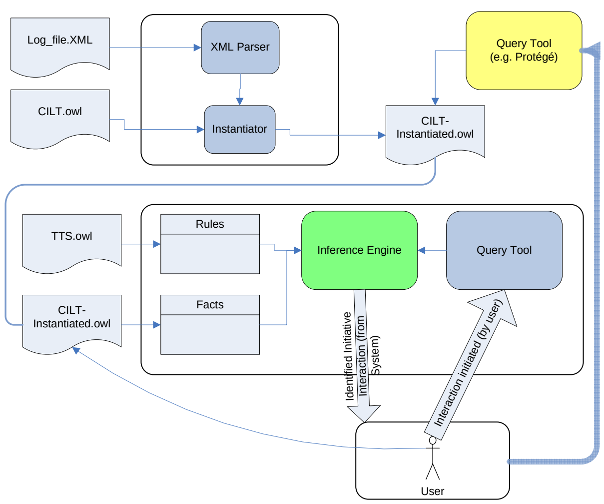

Figure 1 - Architecture of MI-EDNA

The architecture promotes modularity and adaptability since the rules and facts can be fed into the system in OWL format and reasoned with, *at run time*. The architecture is

[5] http://interchange.mit.edu:8080/gcms_v4/Global/ontology.htm

[6] http://suo.ieee.org/IFF/

geared towards addressing our goals of capturing the interactions by the learner and disseminating the principles of SRL to the learners.

The architecture is implemented from within the scope of the LearningKit Project[7] as part of a generic study tool named gStudy[8]. Learner interactions with gStudy are automatically captured in an XML log file and are simultaneously mapped onto an extensive ontology named CITL. The interactions that we currently target in gStudy include browsing, highlighting, compiling code, text chatting, indexing, concept mapping, note taking, reviewing, and collaborating. Using the log as the source one can record various tactics and strategies when students are engaged in performing tasks related to reading, composition, or problem-solving.

The observed interactions are automatically instantiated in our ontology. A query interface has been built using which learners themselves review, recognize, and relate strategies and tactics that they used as part of their learning activities. Further, the system also attempts to recognize learner strategies and tactics as observed in their interaction with gStudy. The system can initiate interactions with the learner to promote specific strategies and tactics. It can also initiate interactions with the learner when it finds gaps in learner strategies and tactics. Further, it can initiate interactions with the learner with respect to the strategies and tactics employed by other students. Using these three recognizable opportunities, we provide contextualized feedback to learners, on the fly, as they study or solve problems in specific learning activities. Our research collects data on how such explainable and theory-oriented prompting and feedback promote significant, transferable, and enduring changes to learner study skills and problem solving abilities. The rest of the section discusses the components of the architecture.

Ontological Underpinnings

The use of ontology as knowledge representation and knowledge sharing mechanism is a century-old notion in Philosophy. Over the past decade, ontological knowledge representation has been extensively employed in online learning environments. In educational environment, the use of ontology for authoring [4] [20], knowledge engineering [28], and automated instantiation [1] have been areas of recent interest.

The ontological representation of the domain knowledge and the interaction knowledge allows for a formal representation of concepts and the relationships between them in Description Logic as formulated in OWL-DL. OWL-DL allows us to represent concepts and relations with restrictions. In the following section, we will describe the CILT and the TTS ontologies in detail.

Content-Interaction-Learner-Time Ontology

Content, learner, interactions, and time are computational entities that are fundamental in representing the learner interactions within the gStudy tool. The objective in building this upper level application ontology is twofold –first, it provides a sharable and interoperable framework; second, it provides flexibility in terms of plug-and-play components. That is CILT as a whole can be applied across different domains in interoperable manner. Also, the four major components (Content, Learner, Interaction, and Time) of the ontology can be used interchangeably across different applications/domains.

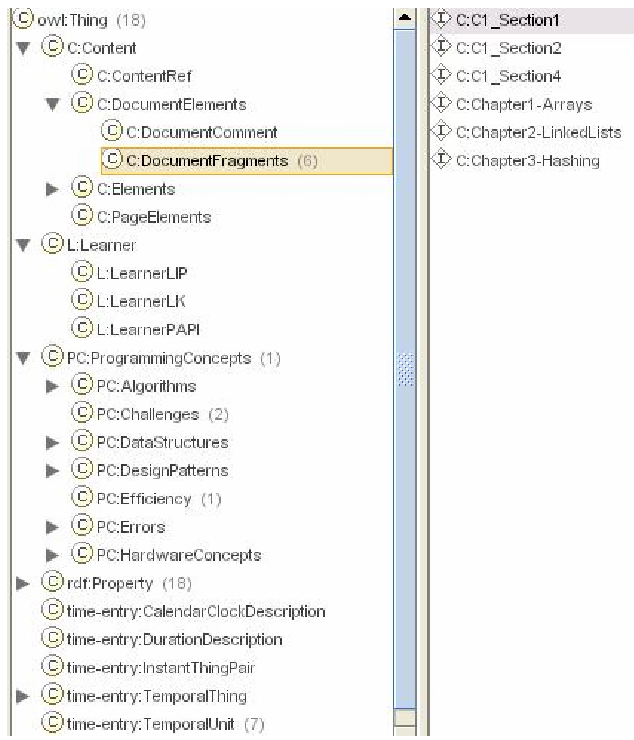

Figure 2 - Excerpt from the CILT ontology

Specific domain ontologies are a collection of ontology set which define the details of general concepts and their features in each sub-domain. The CILT ontology[9] relies on four specific domain ontologies listed below:

- Content - This ontology holds references to all the content related to the application in a domain.
- Interaction - This ontology defines the interactions a learner can enact within an application.
- Learner - This ontology identifies the concepts and relations associated with the learner's subject knowledge, their social skills in terms of online communication, and process/normative/knowledge feedback that

[7] http://www.learningkit.sfu.ca/index.html

[8] gStudy – The online learning tool developed for LearningKit project.

[9] http://www.sfu.ca/~shakya/ontology_lib

they received from the instructors or from the system. This ontology can be easily extended to allow for other learner ontologies such as LIP, PAPI, and so on.

- Time - The time ontology is imported from DAML-Time[10].

The CILT ontology is represented in OWL-DL format. CILT ontology is enhanced by the *restrictions* on concepts and relations based DL constructs. For example, for every *note* taken by a learner, the *note* has to be linked to atleast one *documentFragment.* Thus, with the use of *Cardinality* synopsis as such featured in OWL-DL enriches the representation of CILT. It captures the essence of the learners' interactions in the application at any given timeframe. An excerpt of the ontology is presented in Figure 2. Interaction ontology consists only of object properties that glue the other three ontologies together.

Teaching Tactics and Strategies Ontology

The TTS ontology formally captures SRL-specific teaching tactics and strategies in addition to other human-oriented teaching tactics and strategies. An excerpt of the TTS ontology is presented in Figure 3.

```
</owl:Class>
<owl:Class rdf:about="#SRLSelfReflectionPhase">
  <owl:disjointWith>|
    <owl:Class rdf:about="#SRLPerformancePhase"/>
  </owl:disjointWith>
  <rdfs:subClassOf>
    <owl:Class rdf:about="#SelfRegulatedLearningET"/>
  </rdfs:subClassOf>
  <owl:disjointWith rdf:resource="#SRLForeThoughtPhase"/>
</owl:Class>
<owl:Class rdf:about="#EvaluationTT">
  <owl:disjointWith rdf:resource="#IndependdentSeatWorkTT"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#SummarizingTT"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#IdentifyingNewConceptsTT"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#FeedbackShowingGrowthTT"/>
  </owl:disjointWith>
  <owl:disjointWith rdf:resource="#QuestionsTT"/>
  <owl:disjointWith>
    <owl:Class rdf:about="#ClusteringTT"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#OutliningTT"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#TransitionTT"/>
  </owl:disjointWith>
  <owl:disjointWith>
    <owl:Class rdf:about="#MakingDecisionTT"/>
  </owl:disjointWith>
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
  >evaluates self by reflecting, reviewing or attempting the quizes</rdfs:comment>
  <owl:disjointWith>
    <owl:Class rdf:about="#PerformanceImprovementTT"/>
  </owl:disjointWith>
  <owl:disjointWith>
```

Figure 3 - Excerpt of SRL principles in TTS

Educational Psychologists have identified and advocated a number of models of learning corresponding to SRL. One such model promotes that SRL consists of the phases of forethought, performance, and self-reflection [41]. The forethought phrase corresponds with the preplanning a learner would undergo prior to engaging in the learning activity. The self-reflection phase corresponds with the post-leaning process. The performance phase reflects the processes that occur during learning. Learners' engage themselves in learning tactics to achieve self-control and self-reflection during this phase.

Student learning activities, their interactions with MI-EDNA, and typical SRL tactics and strategies are represented in the TTS ontology. The necessary and sufficient conditions of SRL tactics and strategies are also represented in the ontology. The tactics and strategies are feed into the JESS inference engine as production rules. The system relies on SRL rules and the learners' interactions to recognize initiative opportunities and prompt feedback to learners during the learning process.

The TTS ontology can represent different SRL models, independent of each other. OWL-DL axioms synopsis such as *disjointWith*, *oneOf* and OWL-DL boolean combinations of class expressions synopsis such as *unionOf*, *intersectionOf* provides the expressive power of representing the SRL models in the TTS ontology. Presently, MI-EDNA represents and reasons with two SRL models – Zimmerman's three phase model [41] and Winne and Hadwin's model [16].

Different types of constraints have been built corresponding to '*owl:DataTypeProperty*' and '*owl:ObjectProperty*' in Protégé with respect to the phases of the SRL models. For example, the *SelfRegulatedLearningET* in Zimmerman's SRL model consists of '*DataTypeProperties'* such as *'hasGoal'*, *'hasExpectedOutcome'*, *'hasSelfEfficiency'*, *'hasStrategicPlan'* and so on. The concept constructs for *SelfRegulatedLearningET* define the uniqueness of the three phases of the model. As an extension of the concept, the concept constructs further define the concept *OptimalSelfRegulatedLearningET* by imposing restrictions on the *DataTypeProperties*.

Learner transitions across phases are enabled based on values of certain *DataTypeProperties.* For example, in order to reach optimality, the *SRLForeThoughtPhase* enforces the restriction on *DataTypeProperties* such as *hasGoal*, *hasPlannedStrategy* to be set to *True*. This indicates that the learner has defined his/her goal prior to starting the learning process.

Recognizing interactions at finer levels, such as highlighting, linking, creating summary note, creating concept notes, browsing and matching these interactions to tactics and strategies at the coarser levels [16] enables the system to identify the SRL principles and phases that the learners are engaged in.

Ontology Instantiation

Ontology of any domain or application serves as the blueprints for knowledge sharing and representation in that domain or application. This very basis of the framework that underlies ontology supports the key capabilities needed to realize the vision of Semantic Web, namely representing, acquiring, sharing, and utilizing knowledge on the web. However, knowledge representation and sharing capabili-

[10] http://www.isi.edu/~pan/damltime/time-entry.owl

ties need to be transparently interwoven between the web application and services at the user interaction level and the ontological representation, recognition, and reasoning at the meta level. Automated instantiation of the ontology still remains as one of the crucial aspects of ontological knowledge engineering for the web. The strength of semantic web relies heavily on the automatic or semi-automatic instantiation of knowledge in the ontology.

Manual knowledge instantiation is tedious, cumbersome, and error prone. Ideally, ontologies should be instantiated in an automated fashion. This is particularly vital in a web environment. However, not many systems have been designed to fully automate instantiation of the underlying ontologies. Given the importance and complexity involved in instantiating ontologies, it remains an ongoing research in our laboratory.

We are successful in accomplishing automatic and semi-automatic instantiation of ontologies in MI-EDNA. The content is meta-tagged and instantiated in the ontology in a semi-automatic manner. For instance, the online contents for Java Programming have been developed and tagged using DocBook[11] platform. We then used a script to convert the tagged content into the corresponding OWL format. Later, we invited content authors to verify and validate the associations between the content and the tags. Since the content mainly consists of static information[12], the verification and validation process involves minimal interaction from the content author. Nevertheless, manual interaction, mostly from the content author, is still required to identify, verify, and validate the concepts, the relations, and the constraints associated with the content.

The learner interactions, however, are fully automated. While learner interactions are logged in a file, in parallel, the real time interaction data is also fed into the ontology instantiating concepts and relations.

Reasoning and Inference

The formal representation of the SRL principles in the TTS and the CILT ontologies enables knowledge to be processed with logical reasoning mechanism as well as with rule-based reasoning. The ontologies are represented in the OWL-DL sublanguage and thus, permits the use of reasoners based on Description Logic (DL) [5]. DL reasoners[13] help build and maintain sharable ontologies by revealing inconsistencies, hidden dependencies, redundancies, and misclassifications [34]. Some of the basic DL reasoning techniques are: class consistency, concept subsumption, instance checking, and concept satisfiability [5].

[11] www.docbook.org

[12] Dynamic content creation and tagging is yet another ongoing research in our lab

[13] http://www.racer-systems.com/

In the content ontology that is within CILT, the relation '*hasElement*' has been established between '*Document-Fragment*' and '*Image*' as an '*owl:TransitiveProperty*', and the relation '*isPartOf*' has been established as the '*inverse property*' of '*hasElement*'. Instantiating the ontology, the '*Chapter1_section1*' has a relation '*hasElement*' of type '*Image*', which in turn is a part of the '*Media*'. As a result of this, DL can be used to conclude that '*Chapter1_section1*' has an element '*Media*'.

Aside from OWL reasoners for inferencing knowledge from the ontology, we are also using the JESS inference engine to infer SRL specific strategies and tactics. The system uses the JESS inference engine with the rules built to cater to the requirements of the TTS ontology. The instantiated CILT ontology with OWL-DL formalisms are parsed into the JESS inference engine as JESS facts. Thus, we have used rule-based mechanism in MI-EDNA. JESS rules play a major role in the analysis and dissemination of SRL specific knowledge. The TTS ontology defines the rules for JESS and the interactions of the learner act as facts. This production rule mechanism permits the system to detect the SRL principles that the learners are engaged in and provides the logical point of information dissemination to the learners.

Disseminating SRL principles

We have explained how the SRL principles are captured in the ontological representation and how the learner interactions are automatically instantiated into the CILT ontology. This section explains the reason *why* and *how* we plan to disseminate the SRL principles that have been captured.

Research in educational psychology has successfully shown that self-regulatory processes induce positive, significant, transferable, long-term behavioural changes in learners' study patterns. When learners study or solve problems, research indicates they can benefit by having access to feedback about

- Methods they use to study/solve problems (process feedback),
- How much they have learned (knowledge of results), and
- How learner's peers study and what they score on tests (normative feedback).

Because gStudy logs fine-grained data about the interactions pertaining to these types of feedback, we can mine these data to generate these feedbacks.

Table 1 presents the mapping of interactions, tactics and strategies. In each row, the first column indicates the set of interactions enacted by the learner; the second column indicates SRL tactics corresponding to these interactions; and the third column indicates the SRL strategy corresponding to the tactic. For instance, the learner interaction recognized as *summaryNoteTaking* is mapped onto the SRL tactic named *summarizing* which in turn mapped onto the SRL strategy named *ElaborationStrategy*.

Table 1 – Sample mappings of Interactions, Tactics and Strategies

Interactions	**SRL Tactics**	**SRL Strategies**
Concept Highlight	IdentifyingNewConceptsTT	CriticalThinkingTS
Summary NoteTaking	SummarizingTT	ElaborationTS
Linking Note to Concept	ClusteringTT	OrganizationTS

Zimmerman's SRL model defines that during the Performance phase learners engage in self-control through the use of SRL strategies such as *elaboration, organization* and engage in self-reflection through the *critical thinking strategies.* In the example shown in the table, the learner has demonstrated the performance of the *elaboration strategy*, the *organization strategy* and a partial performance of the *critical thinking strategy*. Thus, MI-EDNA is able to track higher level SRL strategies from lower level interactions and tactics.

Table 2 – SRL Rules

Feedback categories	**System initiation opportunity**	**Rules example**
Process feedback	• Based on the student's interaction, the system can guide the student in using some more of the SRL tactics in their online learning	If student is only **highlighting**, then the system can recommend the use of **taking notes** to the highlighted text for material relevance and ease of search on topics.
	• If the student is taking notes on specific topic then the system can initiate some other reference material the student may want to review.	If the student is taking **notes only on certain topic**, then system can recommend **other document location**s that is linked to the same topic, that the learner may not be aware of.
Knowledge of results feedback	• Based on learners' accomplishment with the online course and the interactions accomplished, the system can initiate information on the learner's current knowledge status.	The system can show the **learners' knowledge status** based on the interactions and content learner had interacted.
Normative feedback	• Based on all peer interactions and accomplishments, the system can initiate comparative knowledge status and comparative accomplishment statistics	The system can show the learners' their standings in regards to the score or the learning style with respect to their peers.

MI-EDNA has two distinguishing features. First, system-initiated queries and responses are based on data that gStudy gathers on the fly. For instance, a student can inquire about the number of times she has reviewed a glossary term in a session. Second, the topic of queries can be about the content studied and about the study tactics as traced by gStudy. For example, a learner will have tools to build complex queries, such as what percent of students in his/her class highlight text then immediately make a note and link that note to relevant glossary items and score more than 85% on the test covering the assignment.

Thus, our system disseminates SRL principles to induce positive, significant, transferable, long-term behavioural changes in learners' study patterns by scaffolding the learning process with appropriate feedback and guidance.

PLANS FOR EVALUATION

An experiment was conducted to access the utility of gStudy in disseminating SRL behaviour. 230 Students participated in the experiment and log files were collected that contained the interactions of the learners with the gStudy software. The results of the experiment have been reported in Hadwin et.al. [17]. As part of the evaluation of MI-EDNA, we plan to conduct a test to calculate the percentage of tactics and strategies that MI-EDNA is able to automatically recognize with reference to the number of tactics and strategies manually recognized by Hadwin et. al [17].

In addition, we also plan to conduct a full-cross over empirical evaluation to access the change in the self-regulatory abilities of learners.

CONCLUSIONS

Our research explores the effectiveness of the formal representation of the SRL principles. Ontological Representation creates a feasible, sharable and an easily expandable knowledge base. Through MI-EDNA we are able to successfully capture and disseminate the SRL tactics and strategies. Using the same underlying instantiated ontology, we enable reasoning based on Description Logic and production rules. We contend that using MI-EDNA the learners will have more opportunities to reflect on and regulate their learning processes.

Some of the research directions we plan to pursue in the future include a) knowledge engineering of applied educational psychology domains such as reading, composition and problem-solving, b) a model of the self-regulatory capabilities of learners, c) an evaluation of the influence of mixed-initiative interactions and interfaces, d) the development of a cognitive model of the self-regulatory skills of the learner, e) employing MI-EDNA for co-regulated learning, f) the verification and validation of the underlying SRL model based on the cognitive model, g) providing a common ontological SRL framework for geographically distributed learners and instructors in a blended online learning environment, and g) explanation-aware SRL modelling and scaffolding.

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