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Using a linked data-based knowledge navigation system to improve teaching effectiveness

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ABSTRACT

A linked data approach provides new opportunities for annotating, interlinking, sharing and enriching massive open online educational resources. However, it can be difficult for non-expert users to build and utilize the educational linked data in educational settings. Thus, flexible and user-friendly ways to represent, interlink, visualize and utilize the educational linked data become increasingly important. This paper proposes a linked data-based knowledge navigation system (LDKNS) for improving the teaching effectiveness. In the system, learning resource ontology was implemented to represent learning contents, and linked data visualization technologies were used in a formal curriculum structure. It presents a use case of building the educational linked data and creating interactive knowledge visualizations to support teachers and students in art design education. A contrast experiment was conducted to evaluate the effectiveness of the proposed system. The experiment involved 115 second year undergraduate students divided into experimental and control groups. It was found that there was a significant increase in the motivation of students who used the LDKNS. It was also found that students' achievement in the experimental group performs better. Furthermore, the results of a survey on cognitive load revealed that using the system can decrease their cognitive load. Thus, we believe that art design education supplemented with the LDKNS yields a significant learning advantage for students by improving learning performance.

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KEYWORDS
Learning resource ontology; linked data visualization; learning cell; knowledge network; interactive learning environments

1. Introduction

Open educational resources provide open access to high-quality digital educational resources (Piedra et al., 2015). With the rapid development of the massive open online courses (MOOCs), online learning becomes more and more popular. MOOCs with an amount of open learning objects are becoming an essential source of information for learners. Most MOOC learning systems, such as Udacity, Coursera, Udemy, xuetangX and edX, use content management platforms where learning contents are organized in a hierarchical standalone structure (Zhuhadar, Kruk, & Daday, 2015), and more semantic relationships between learning materials are lack. Meanwhile, the user interface is more similar to the traditional digital library in the above open learning environments, and learners were probably struggling with learning tasks for lack of some related knowledge (Zhuhadar, Kruk, & Daday, 2015).

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Semantic Web technologies, such as ontology, RDF and OWL, can give information on the web well-defined meaning (Berners-Lee, Hendler, & Lassila, 2001) and provide good opportunities for learning and teaching in the Web 2.0 era (Tiropanis, Davis, Millard, & Weal, 2009). The Semantic Web has been widely used to support teaching and learning in various educational settings (Jensen & Jesper, 2019). A linked data (Berners-Lee et al. 2009) approach is the revolutionary technology in the Semantic Web, which provides new opportunities for annotating, interlinking, sharing and enriching educational contents (Zarzour & Sellami, 2017; Pereira, Siqueira, Nunes, & Dietze, 2018). However, it can be difficult for non-expert users to build and utilize the linked data (Dadzie & Rowe, 2011) in educational settings. Thus, flexible and user-friendly ways to represent, interlink, visualize and utilize the educational linked data become increasingly important. The design of user interfaces in eLearning, and more specifically interfaces (Dietze, Liu, Yu, & Pedrinaci, 2011) that organize and represent the learning resources visually, plays a central role in the generation and consumption of educational linked data (Mazumdar, Petrelli, & Ciravegna, 2014). Well-designed visualizations harness the powerful capabilities of the human perceptual system, providing users with rich and various representations of the data (Zablith, Fernandez, & Rowe, 2015). Proper organization and management of massive open online learning resources is beneficial to teachers' instructional design and students' learning.

In this study, we developed a linked data-based knowledge navigation system (LDKNS) for providing formal semantic course information to students in online interactive learning environments, along with an experimental evaluation of teaching a "3D Constitution" course in art design education. The proposed LDKNS enables the integration of linked data technologies into open online learning environments to improve educational information delivery and provides a flexible and user-friendly visualized learning support for each student. In other words, this novel system provides an approach for the generation and utilization of the educational linked data by the building of open learning resource semantic relationships embedding in the teacher's instructional process and student's learning.

2. Literature review

2.1 Knowledge navigation

Knowledge navigation is an appropriate method for instructors to demonstrate subject knowledge, visualize explicit knowledge and interlink learning resources in open online learning environments. Kayama and Okamoto (2001) developed a knowledge-based navigation system with a semantic map to generate the navigation information for the exploratory activity. Topic maps is one method for knowledge navigation, which could describe the relativeness between concepts and even link concepts to online information resources easily (Pepper, 2010). Kemény, Erdős and Váncza (2008) used topic maps to enable the usability and accessibility of knowledge resources of a research community to members of the group. Zhai, Wang and Lv (2008) applied topic maps to develop an urban traffic information portal for knowledge navigation. Huang and Chen (2013) developed a blogging system with knowledge navigation demand for both formal and informal learning in civic education.

The knowledge navigation approach not only provides new opportunities for teachers to organize and display explicit knowledge in subject educational settings but also offers students with knowledge network structure and learning path.

2.2 Linked data visualization system

Linked data is a key component of the Semantic Web vision, which provides good opportunities for the semantic organization and management of open learning resources in web environments (Yu, Pedrinaci, Dietze, & Domingue, 2012; Ruiz-Calleja, et al., 2012). Semantic Web technology-based knowledge navigation connects users and resources more effectively by presenting information resources for users within a specific knowledge structure and providing users with more diverse, qualitative and complete information (Huang & Chen, 2013).

Exploring and visualizing linked data is a core task for a variety of users in numerous scenarios (Desimoni & Po, 2020). Linked data visualization systems such as linked data-specific browsers offer data visualization options to support the consumption of linked data (Dadzie & Rowe, 2011; Pereira, Siqueira, Nunes, & Dietze, 2018). RelFinder[1] is one of the linked data visualization systems which extracts and visualizes relationships between given objects in RDF data and makes these relationships interactively explorable. It provides standardized SPARQL access for browsing the linked data. RDF Gravity[2] is a tool for visualizing ontologies which provides graph visualization, generating views from RDQL queries and visualizing multiple RDF files. Sgvizler[3] is a visualizer which renders the result of SPARQL select queries into charts or HTML elements. It parses the results into the JSON format and displays the chart using the Google Visualization API or a custom-made visualization or formatting function.

Based on the Sgvizler, Tilahun, Kauppinen, Keler and Fritz (2014) designed and developed a Linked Open Health Data (LOHD) system for integrating spatial and statistical health data from various sources. By using the visualization interface of the LOHD system, users can query HIV-related information about African countries, facilitating flexible queries and different kinds of linked data visualizations. Kozaki, Yamagata, Mizoguchi, Imai and Ohe (2017) applied ontology and linked data techniques to develop a navigation system (Disease Compass) for the visualization of disease chains and other information. The results showed that the linked data visualization system can provide the exploration of disease knowledge and related information for users without experience with ontologies or linked data. The design of user interfaces for linked data, and more specifically interfaces that represent the data visually, plays a central role in the interaction with the linked data (Dadzie & Pietriga, 2016).

This literature review shows the application of linked data visualization system in various domains. Although the above-linked data visualization systems provide diverse linked data visualization functions, there are some challenges in educational settings. Current linked data visualization systems are not typically customized for educational purposes for user interface and function features. On the one hand, they are designed and developed for the common domain, not taking into consideration educational settings and learning process requirements. On the other hand, the user is expected to write SPARQL queries, which is challenging for non-technical and non-expert users. Visualizations enable non-technical users to use the linked data (Brunetti, Auer, & García, 2012) and increase the usability and accessibility of linked data-based systems (Kopanitsa, Hildebrand, Stausberg, & Englmeier, 2013). To overcome those challenges, it is necessary to design and develop a flexible and user-friendly linked data-based visualization learning system to support teacher's teaching and student's learning process. This study pays emphasis on a linked data visualization learning system for teachers and students in online interactive learning environments.

3. Linked data-based knowledge navigation system

Having analysed the state of the art in domains of knowledge navigation and linked data visualization systems, as well as the challenges of the linked data visualization system applications in educational settings, we propose a linked data-based knowledge navigation system called LDKNS. LDKNS is designed and developed based on the previous work including the Learning Cell resource organization model (Yu, Yang, Cheng, & Wang, 2015) and the extended relation metadata model (Wu, et al., 2018). LDKNS is a sub-system of the Learning Cell Knowledge Community (LCKC). LCKC provides users with the two main learning resource organization forms: Learning Cell (LCell) and Knowledge Group (KGroup). LCKC can be accessed online at http://lcell.bnu.edu.cn. In the LCKC, 26,957 users have registered, 91,844 learning cells have been created and 7104 knowledge groups have been formed (as of 14 July 2020).

3.1 System architecture

LDKNS allows teachers to visually annotate semantic relationships between learning resources in the process of their instructional design. Meanwhile, LDKNS provides a visual dynamic knowledge network graph for students to support their self-learning. In addition, LDKNS also offers management of the educational linked data for system administrators. To carry out the above tasks, LDKNS is based on a number of components depicted in Figure 1, relying on existing linked data standards and open-source technologies.

LDKNS implements a set of user interfaces giving access to its functionalities through online learning services. KGroup Management Interface and LCell Management Interface allow teachers to manage the knowledge groups and the learning cells, respectively. Visual Annotating Interface provides teachers with a set of visualization and annotation tools offering semantic and related information about learning resources. Knowledge Network Interface is deployed that provides functionalities to show a visual and interactive knowledge network graph with various semantic relationships between learning resources for students. Resource Management Interface allows administrators to manage the learning resources. Ontology Management Interface allows system administrators to manage the resource ontologies. Linked Data Management Interface allows administrators to manage the RDF semantic data. RDF generator is used to build the educational linked data.

For the implementation of the system, we have used Semantic Web technologies, including ontology editor protégé, RDF storage Jena TDB and Jena Fuseki. Fuseki is used as a server to expose the RDF triples as a SPARQL endpoint accessible over HTTP for parsing, manipulating, querying, serving and serializing educational linked data stored in TDB.

3.2 Learning resource ontology

The use of ontologies allows us to enhance the semantic representation of knowledge, to associate formal descriptions for learning resources and to compose new resources from existing resources (Halimi, Seridibouchelaghem, & Faron-zucker, 2014). In LDKNS, the learning resource ontology is developed to describe the semantic relationships between learning resources.

The learning resource ontology is a generic model that formalizes the domain knowledge of the learning resources' relations. It mainly describes two types of knowledge: *LCell* (Learning Cell) and *KGroup* (Knowledge Group). The *LResource* class represents the root concept. The *LCell* class and the *KGroup* class are sub-concepts of the *LResource* concept, which represent two types of learning resources (Figure 2).

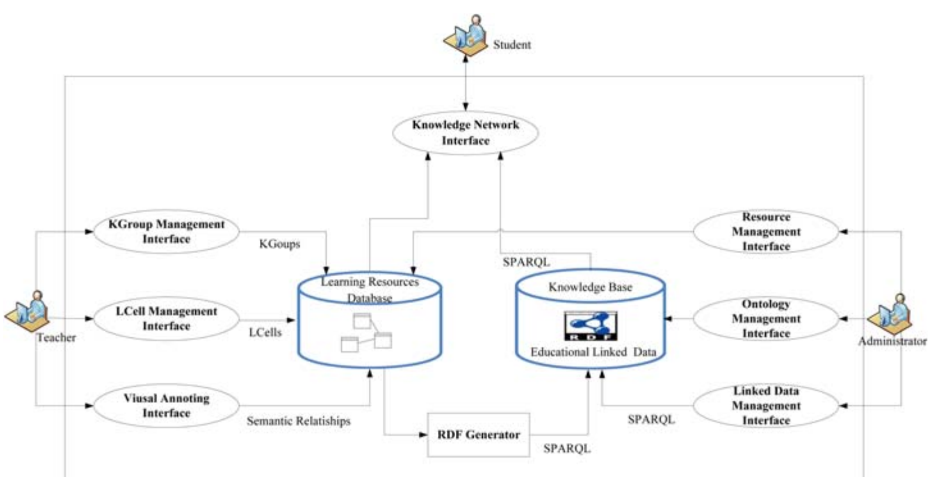

Figure 1. LDKNS architecture.

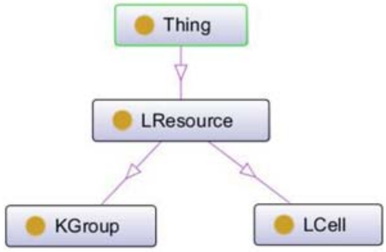

Figure 2. Representation of the learning resource ontology concepts.

Properties, such as *isPriorOf*, *isNextOf*, *hasPart isPartOf*, *isA*, *isSameAs*, *isRelatedTo*, *isSimilarTo*, *reference*, *isIntroductionOf*, *isFactOf*, *isDefinitionOf*, *isLawOf*, *isProcessOf* and *isExampleOf*, are sub-properties of the root property *R2R* (Figure 3). These properties are used to describe properties related to the Learning Cells and Knowledge Groups.

3.3 Educational linked data generation

RDF generator is utilized to consolidate the educational relation data in a linked data schema for the purpose of reasoning new semantic relationships and simplifying students' future learning processing. To achieve the educational linked data generation, the RDB2RDF tool was used to implement the semantic mapping based on the above learning resource ontology from the relation table data to RDF triples, and the generated RDF triples were loaded into the Jena TDB triple store. Educational linked data conform to linked data specifications and standards.

4. Methodology

To evaluate the performance of the proposed LDKNS-based learning approach, an experiment was conducted for the "3D Constitution" course of a university art design education. We aimed to investigate the effects of the proposed approach on the students' learning motivation, learning achievement and cognitive load.

4.1 Participants

Two intact classes at the university were selected to participate in this study. A total of 115 undergraduate students in their second year at the Environmental Art and Design Department taking the course of "3D Constitution" were the participants of this study. These students were majoring in Art Design. Each class received the same teaching progress provided by the same teacher. The control group consisted of 36 female and 23 male students, whereas the experimental group consisted of 35 female and 21 male students. The experimental group took the course of "3D Constitution" using the LDKNS, while the control group followed the same lessons using the traditional lecture-based learning method. Both groups underwent a pre-test and a design works post-test. The experimental group was also given pre-questionnaire and post-questionnaire of learning motivation and cognitive load. All of the two group students were taught by the same teacher who had more than eight years' experience of teaching art design courses.

4.2 Experimental procedure

The duration of this study was seven weeks. Two weeks before the intervention, unit 1 and unit 2 were taught to both groups of students. The teacher selected two learning units based on the

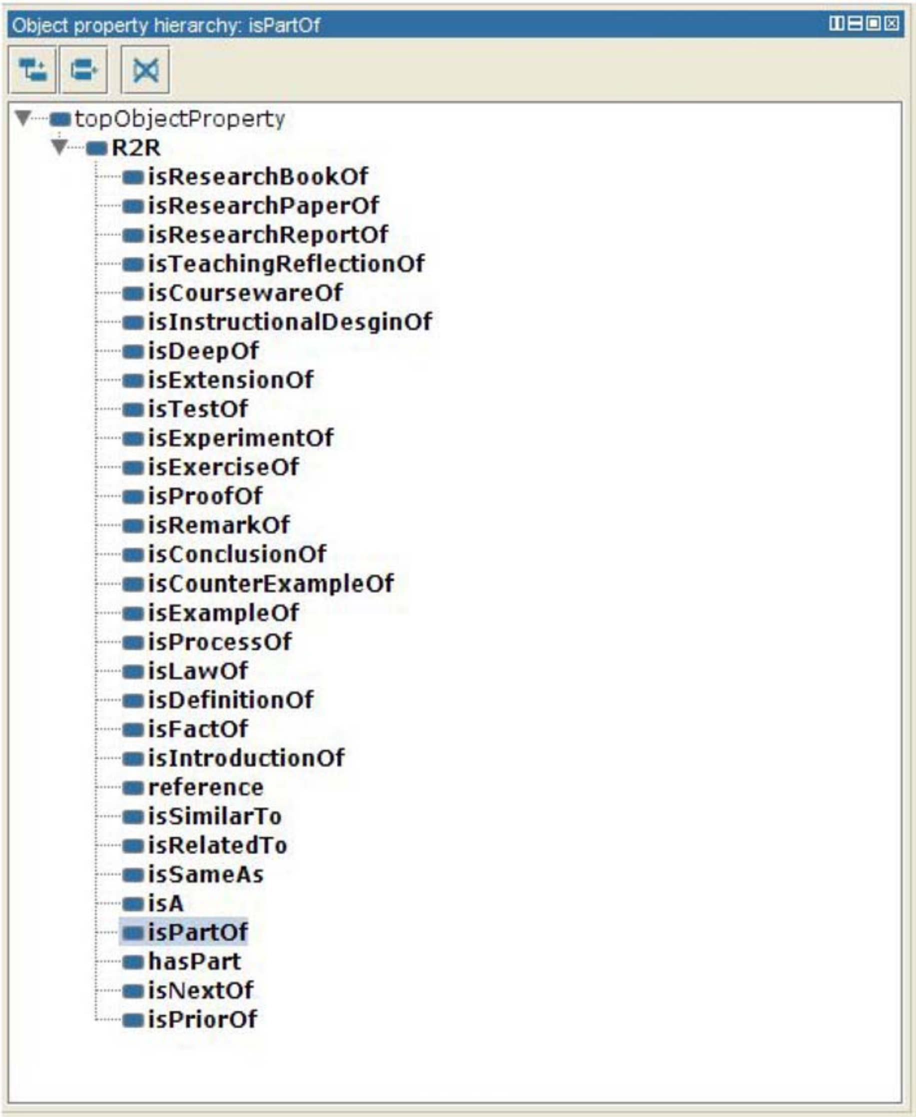

Figure 3. Representation of the learning resource ontology properties.

textbook of 3D Constitution for this study: "Introduction to 3D Constitution" and "Development of 3D Constitution". At the end of this process, both the experimental and control groups underwent a pre-test.

After the pre-test, the students in the control group were taught the learning content units 3–7 of the "3D Constitution" course using a lecture-based approach focused on traditional teaching activities such as lecturing, PowerPoint presentations and design instance analysis. Students in the control group received the traditional lecture in the face-to-face classroom and were asked to complete their homework before the next class on their own. In-class activities included lecture, design instances analysis, students' art design works analysis and evaluation.

After the pre-test, the students in the experimental group were taught using the LDKNS-based approach. It took into consideration pre-class learning material organization and in-class learning activities. The design of learning materials and learning activities before class and within class

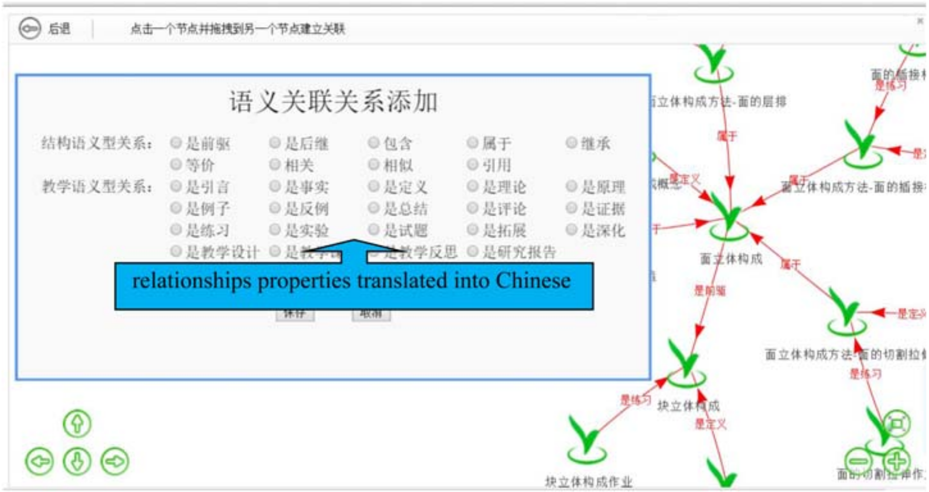

Figure 4. Visual relationships annotating of learning resources.

were carried out with the aid of the LDKNS (Figure 4). Pre-recorded micro-lessons exposed students to key concepts before classes in an interactive and visual demonstration supporting self-directed learning. Students can review confusing concepts and break them into more understandable portions and proceed at their own pace. While students were watching micro-lessons, they participated in related activities. They used a visually interactive display form to organize and display the learning materials in order to attract the attention of students. The knowledge network of micro-lessons in LDKNS can be seen in Figure 5. Using the visual knowledge network to organize and demonstrate the related concepts aimed to attract the attention of students, assist students in building relevance of knowledge by associating art design concepts with prior knowledge of students. Teaching activities consisted of design instance analysis, students' art design work analysis and evaluation by the aid of the system.

At the end of the intervention, the experimental group was given the CAT test and questionnaire to collect scores and data for their learning achievement, cognitive load and motivation, while the control group was only given the CAT test. We used SPSS software to analyse the collected quantitative data in the experimental process.

4.3 Research tools

The tools for assessment in this study included a pre-test, a post-test and the questionnaire for measuring the students' learning motivation and cognitive load. The Consensus Assessment Technique (CAT) originally developed by Amabile (1982) is one of the most widely used evaluation techniques in identifying and assessing creative products (Lu & Luh, 2012). The CAT was employed for this study to evaluate the students' design works. The pre-test aimed to evaluate the students' prior knowledge and skills of learning the "3D Constitution" course unit. Teachers were asked to give a composite score to determine the overall creative quality of each student's design work in the "3D Constitution" course. The perfect scores of the pre-test and post-test were 100. The Course Interest Survey (CIS) was to measure students' motivational reactions to the classroom instruction based on the ARCS motivation model (Keller, 1987). The CIS is considered a valid and reliable instrument with a documented reliability coefficient of 0.95 and four factors reliability (Cronbach's $\alpha = 0.80, 0.82, 0.79$ and 0.84 for attention, relevance, confidence and satisfaction, respectively) (Bhagat, Chang, & Chang, 2016). The questionnaire of learning motivation was modified based on the measure of CIS and also translated to Chinese by two language experts before experiment.

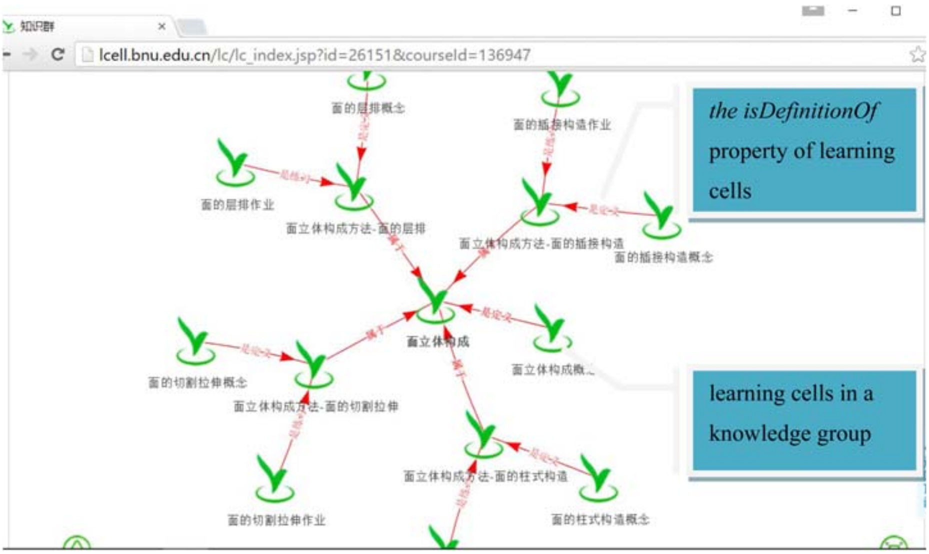

Figure 5. Knowledge network of micro-lessons in LDKNS.

The questionnaire of cognitive load (Pass, Tuovinen, Tabbers, & van Gerven, 2003) was modified based on the measure of Hwang, Yang and Wang (2013). It consisted of two factors: mental load and mental effort

5. Results

In this study, the collected data were examined by descriptive statistics to explore the group numbers, means and standard deviations. The paired-sample t-test, analysis of variance and analysis of covariance were conducted on the learning motivation, cognitive load, CAT pre-test scores and post-test scores. In addition, learning motivation, learning achievement and cognitive load were analysed.

5.1 Analysis of learning motivation

Table 1 shows the results of the CIS motivational questionnaires conducted before the intervention and after the intervention of the course. Means and standard deviation are provided for dependent variable attention, relevance, confidence and satisfaction.

A paired-sample *t*-test was conducted to compare motivation to determine the effect of the LDKNS-based learning approach on the motivation of students. The results of a paired-sample *t*-test of CIS motivational questionnaires carried out afterwards are presented in Table 1. As shown

Table 1. *T*-test results of the motivation of the experimental group.

Variable	Test	*N*	Mean	*SD*	*t*
Attention	Pre-questionnaire	56	3.21	.61	−7.01*
	Post-questionnaire	56	3.85	.48	
Relevance	Pre-questionnaire	56	3.78	.59	−3.99*
	Post-questionnaire	56	4.03	.50	
Confidence	Pre-questionnaire	56	3.73	.51	−5.90*
	Post-questionnaire	56	4.07	.52	
Satisfaction	Pre-questionnaire	56	3.42	.66	−6.15*
	Post-questionnaire	56	4.05	.69	

*$p < .05$.

Table 2. Analysis of variance results of pre-test scores.

Groups	*N*	Mean	*SD*	*F*	*p*
Experimental group	56	76.43	6.63	2.81	.097
Control group	59	74.24	7.38		

Note. *$p < .05$.

Table 3. Analysis of covariance results of post-test scores

Source	SS	*df*	*MS*	*F*	*p*	Partial η^2
Pre-test	52.626	1	52.626	1.405	.238	.012
Groups	856.268	1	856.268	22.862	.00*	.170
Error	4194.785	112	37.453			

*$p < .05$.

in Table 1, the results of the paired-sample *t*-test indicated a significant difference between the pre-questionnaire and post-questionnaire for attention ($p < .05$, $t = -7.01$), relevance ($p < .05$, $t = -3.99$), confidence ($p < .05$, $t = -5.90$) and satisfaction ($p < .05$, $t = -6.15$).

The results of the paired-sample *t*-test revealed that there was a statistically significant increase in the motivation of students. Results indicated that students' motivations had increased, maybe because the art design course was made engaging.

5.2 Analysis of learning achievement

The CAT pre-test was applied before the intervention of the "3D Constitution" course to identify the prior levels of students' design works in the experimental group and the control group. Before intervention, the analysis of variance was conducted on pre-test scores collected from the experimental group and the control group. Table 2 shows the analysis of variance results regarding pre-test scores of the experimental and control groups. We observed that the distributions in respect to learning achievement between experimental and control groups were almost similar. As can be seen in Table 2, there was a non-significant ($F = 2.81$, $p = .097$) difference between the experimental and control groups. This showed that the experimental group and the control group were similar before the intervention was conducted.

The CAT post-test was also used after the "3D Constitution" course to identify the levels of experimental and control groups. The analysis of covariance was conducted on post-test scores collected from the experimental group and the control group. To exclude the impact of the CAT pre-test scores on their "3D Constitution" learning, students' CAT pre-test scores were used as the covariate. Table 3 shows the analysis of covariance results regarding post-test scores of the experimental and control groups. As can be seen in Table 3, there was a significant ($F = 22.862$, $p < .05$, $\eta^2 = .170$) difference between the experimental and control groups. Results revealed that students in the experimental group performed better than students in the control group. The CAT test scores provided sufficient evidence that students' learning achievements were similar for pre-test scores but different for post-test scores. The students' achievement was improved.

Table 4. *T*-test results of the cognitive load dimensions of the experimental group.

Variable	Test	*N*	Mean	SD	*t*
Mental load	Pre-questionnaire	56	3.46	.84	−5.34*
	Post-questionnaire	56	2.71	.77	
Mental effort	Pre-questionnaire	56	3.54	.81	−7.31*
	Post-questionnaire	56	2.61	.78	

*$p < .05$.

5.3 Analysis of cognitive load

The study also compares the two aspects of cognitive load: mental load and mental effort, as shown in Table 4. For the mental load dimension, the means and standard deviations were 3.46 and .84 for the pre-questionnaire of the experimental group, and 2.71 and .77 for the post-questionnaire. The paired-sample *t*-test result shows that the mental load of the experimental group before intervention is significantly higher than after that of the experimental group ($t = -5.34$, $p < .05$). On the other hand, for mental effort, the means and standard deviations were 3.54 and .81 for the pre-questionnaire of the experimental group, and 2.61 and .78 for the post-questionnaire. The paired-sample *t*-test result shows a significant difference between the mental effort ratings of the two groups ($t = -7.31$, $p < .05$).

The way of structuring and presenting the learning resource or the strategy adopted for guiding the students to learn have a positive impact on the reduction of cognitive load (Pass, Tuovinen, Tabbers, & van Gerven, 2003). Knowledge Network reduces the cognitive load by providing a visualized way of helping students to organize their knowledge. The knowledge navigation approach provides an interactive and visual demonstration for supporting student's self-directed learning.

6. Discussion and conclusions

In this paper, we presented the LDKNS, a visual and interactive learning system that enables to generate and utilize the educational linked data in the open online education domain. LDKNS provides a visual and knowledgeable way to build and utilize the educational linked data in the process of teacher's teaching and student's learning. The evaluation of the LDKNS leads us to believe that as an educational application of the linked data visualization, it is usable and useful as well as provides new learning services for teachers and students. It provides a flexible and user-friendly way to represent, interlink, visualize and utilize the educational linked data. Through the above inferential statistical analyses, this study determined that the proposed LDKNS could generate more effective outcomes in the promotion of students' learning performance compared with traditional teaching modes. Linked data provide new opportunities for annotating, interlinking, sharing and enriching massive open online educational resources. The production and consumption of the linked data play important roles in web knowledge services. Linked data offers an exciting opportunity to support the evolution of exposing knowledge, sharing content and engaging with learners (Piedra et al., 2015; Zablith, Fernandez, & Rowe, 2015). In future work, we wish to integrate the LDKNS into linked data cloud to connect with other linked data so as to offer other expanding teaching and learning services for teachers and students. By these means, we will enable teachers and learners to easily and effectively discover and utilize more educational datasets in the linked open data cloud.

On the other hand, there are some limitations to the LDKNS. One limitation of the present study is that the LDKNS-based learning approach was evaluated within a "3D Constitution" course of art design discipline at university. As for higher education in other disciplines, the results may not be generalizable. Therefore, further research is needed in other disciplines and educational contexts to confirm the findings of this study. Another limitation of the present study is that it examined the role of the LDKNS-based learning approach in the promotion of students' motivation, achievement and cognitive load. Other aspects such as students' self-efficacy and self-sufficiency will be needed to assess.

Notes

1. http://www.visualdataweb.org/relfinder.php.
2. https://rdf-gravity.software.informer.com/1.0/.
3. https://www.findbestopensource.com/product/sgvizler.

Disclosure statement

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