www.cad-journal.net
Computer-Aided Design AND APPLICATIONS

Ontologies-based Knowledge Representation Method for Improving Learning Performance in the Engineering Drawing Course

Wei Liu, Meng Cong, Bing Liu, Hongning Liao and Yuanyuan Liu

Tianjin University of Commerce, lwofhebut@126.com, congmeng2002@126.com, liubing@tjcu.edu.cn, liaohongning26@163.com, liuyuanyuan@tjcu.edu.cn

Corresponding author: Yuanyuan Liu, liuyuanyuan@tjcu.edu.cn

Abstract. The engineering drawing (ED) course plays a vital role in facilitating communication across various engineering fields by employing a graphic language to overcome linguistic barriers globally. With its inclusion of geometrical principles, technical rules, drawing conventions, and visual skills, the ED course presents a challenging endeavor for the majority of engineering students to grasp essential information during their learning journey. It serves as a practical means to suggest appropriate learning methodologies to enhance the efficiency and effectiveness of teaching and learning within the ED domain. To address this, our research proposes a novel ontologies-based knowledge representation method to aid students in analyzing and utilizing information to solve complex ED problems in the accomplishment of two assembled graphs. The usability of this method is validated through a project-based learning (PBL) experiment involving two separate ED tasks. The performance of students who received training in the proposed method is compared with that of their peers without such training using statistical analysis. Results indicate that the proposed method significantly enhances the learning performance of students when tackling complex ED tasks. Furthermore, this study yields valuable insights for devising effective teaching and learning strategies for ED subjects at the university level.

Keywords: Engineering Drawing, Ontology representation, Learning Approach, Education Experiment, Project-based Learning (PBL).
DOI: https://doi.org/10.14733/cadaps.2025.285-305

1 INTRODUCTION

The engineering drawing (ED) course plays a pivotal role in facilitating effective communication within the engineering field, offering a visual language that transcends linguistic barriers. As an integral component of engineering design, this course provides a fundamental skill that forms the basis for understanding and expressing intricate design concepts, ensuring precision in engineering project execution [1-2]. The ED course empowers students to translate abstract ideas into tangible representations, establishing a crucial link between theoretical knowledge and practical application.

Proficiency in engineering drawing is essential for creating, reading, and accurately interpreting engineering documentation, blueprints, and schematics—critical skills for professional engineers [3]. Within the University Engineering Curriculum System, engineering drawing holds paramount importance as a foundational skill set. The incorporation of engineering drawing into the curriculum not only provides students with a crucial technical skill but also nurtures a mindset that values precision, innovation, and excellence in the dynamic realm of engineering [4].

Despite its paramount role in the university engineering curriculum, the engineering drawing course poses significant challenges for many undergraduate students majoring in engineering, creating obstacles in the learning process. Specifically, these challenges may arise from various factors: A primary obstacle faced by students in the ED course is the struggle to master basic concepts of geometric drawing, coupled with a lack of necessary imagination capabilities, creative thinking, observation, and inquiry skills [3]. Moreover, in most university engineering curriculum settings, the ED course follows a hierarchical design, requiring students to build understanding from one concept to another; thus, difficulties in grasping basic ED concepts make learning at subsequent levels more challenging [5]. Additionally, the meticulous attention to detail and precision required in engineering drawing demands patience and persistence, qualities that not all students may possess abundantly. Furthermore, the course often involves acquiring specific technical skills, such as understanding various projection methods and mastering intricate drafting techniques, which can be overwhelming for those not naturally inclined toward technical disciplines.

Several innovative strategies have been implemented to enhance the teaching and learning of engineering drawing, with the goal of improving students' performance in this crucial course [3-5]. One particularly noteworthy approach involves integrating the introduction and coaching of computer-aided design (CAD) tools and other three-dimensional prototyping software, such as SolidWorks and Pro-engineering. These tools not only facilitate the creation of accurate and detailed drawings but also offer a more interactive and engaging learning experience. Additionally, some virtual prototypes used in the ED course can be reconstructed using these computer-aided tools, aiding students with limited spatial abilities in better understanding and interpreting complex geometric features during the learning process. Furthermore, the adoption of project-based learning or problem-based learning (PBL) has gained popularity, providing students with opportunities to apply theoretical concepts in real-world scenarios, thereby reinforcing their understanding and skill development related to the ED course [4]. While these techniques focus on incorporating new elements, such as knowledge and practical experience with CAD software and PBL tasks, for practicing acquired theoretical knowledge about engineering drawing in lecture settings, there is still a lack of feasible methods to assist students in understanding and acquiring abstract knowledge and skills related to the theoretical unit on descriptive geometry.

To address this gap, this paper introduces a novel knowledge representation method designed to assist students in comprehending and acquiring theoretical knowledge, specifically in the realm of descriptive geometry. It accomplishes this by analyzing knowledge correlations through the application of fundamental ontological principles.

The rest of the paper is structured as follows: A concise literature review is conducted to summarize existing studies and initiatives related to proposing innovative teaching and learning methods for the engineering drawing course, as well as ontologies-based knowledge representation for fostering innovative education and other courses relevant to the engineering drawing curriculum in Section 2. The framework of the proposed method is detailed, with several cases illustrating how the ontology-based approach is applied to represent theoretical knowledge in the engineering drawing (ED) course in Section 3. Following this, the research is designed and explained in Section 4, in which the proposed method is introduced to students during the ED course lecture to aid in memorizing and understanding theoretical knowledge of descriptive geometry. Subsequently, students using the proposed method form the experimental group, which is compared with the control group consisting of students without experience with the proposed method. A comprehensive experiment in the form of PBL is organized to validate the proposed method by comparing the results of the experimental and control groups in Section 5. Finally, the paper concludes with a discussion of findings in the result analysis in Section 6.

2 LITERATURE REVIEWS

This study is built on existing research from three primary aspects: previous studies on approaches for teaching and learning the ED course to enhance its effectiveness, ontologies-based knowledge representation methods proposed to support engineering education, and methods utilized for measuring students' learning performance in the field of engineering drawing (ED). These studies collectively establish the theoretical foundations for the proposed method.

2.1 Approaches for Teaching and Learning the Engineering Drawing Course

Students encounter various difficulties and deficiencies during their learning experience in the engineering drawing (ED) course, which is particularly noticeable among first-year undergraduate students, who exhibit a relatively high failure rate in the course, as observed in numerous studies [6]. One significant reason for these challenges lies in the knowledge structure of the ED course, as the majority of students have limited capabilities in visualization and spatial abilities, both of which are fundamental skills in engineering [7-8]. Specifically, visualization plays a crucial role not only in professional engineering practice but also in teaching graphic expression [9]. Students who struggle with visualization often face difficulties in comprehending and following the content of ED courses [10]. Additionally, first-year undergraduate students typically have not fully developed their spatial abilities and encounter serious challenges in mentally manipulating figures in space [1,9].

Within the ED course, many students find it challenging to visualize objects from multiple viewpoints without adequate procedures to analyze complex geometric shapes [10]. Some studies even argue that spatial visualization ability has a significant idiosyncratic component, as it is based on the visualization process and mental imagination, making it difficult for others to acquire [11-12]. Conversely, it is commonly believed that the ability to visualize objects is a systematic process that can be taught and learned by all engineering students to support them in solving professional tasks [8,10]. However, in many cases, students lack feasible methodologies to solve ED problems, often relying on trial and error and intuition [9,13]. Moreover, the syllabi of ED courses are often organized in a manner unfriendly to first-year undergraduate students, as there are numerous concepts they must understand and master before being able to define and solve ED problems [9,14]. Failures in acquiring prior knowledge can hinder students from explaining and interpreting phenomena and ED problems accurately [15], making it more challenging for them to learn subsequent knowledge [15-16].

To alleviate these difficulties and enhance the learning performance of undergraduate students, various efforts have been made to provide students with diverse learning approaches and techniques. Among these methods, several studies have pointed out that students' struggles in ED courses reflect their difficulties in problem-solving [1,17]. Therefore, these studies emphasize the importance of cultivating problem-solving abilities to improve the learning performance of the ED course [17-18]. Another widely reported major difficulty in engineering drawing is representing an isometric solid in orthographic views, which is a frequent problem in engineering design tasks [9,19]. To assist engineering students in representing the spatial properties of objects on flat papers, studies aim to enhance both teaching and learning performance in ED by improving students' spatial perception skills [20]. Teaching techniques such as computer animation, virtual reality (VR), and augmented reality (AR) are employed to help students overcome deficiencies in spatial perception [14,20]. Evidence from previous studies has indicated that the use of visualization objects and 3D prototypes is helpful in helping students understand concepts in the subject of ED better than traditional paper-based methods [19-21].

2.2 Ontologies-based Knowledge Representations in Engineering Education

Originating from the 1960s, ontologies are commonly used as formal, explicit descriptions of concepts, enabling the formal representation of objects, their properties, and relationships within a particular domain [22]. Typically, ontologies are represented as semantic networks, where concepts are depicted as nodes interconnected with labels, making them widely utilized in the engineering domain to formalize domain knowledge in a shareable and reusable manner [22-24].

The primary benefits of using ontologies lie in their flexibility to represent concepts, properties, relationships, functions, rules, and constraints [25]. With the aid of visualization, ontologies have gained popularity across various fields, such as bioinformatics, business management, semantic networking, social networking, and education, serving as foundations for knowledge bases [26-28]. In engineering design, ontologies are crucial as formal representations to help users access understandable, shareable knowledge databases [25]. Additionally, numerous ontologies-based visualization tools such as Protégé, class browser, and Jambalaya have emerged and been implemented as knowledge representations in various domains [29-31].

The goal of using ontologies for engineering design is to provide a path towards fewer standards and analytical evidence of more challenging, complex requirements [25,30]. The main benefits of ontologies-based knowledge representations encompass three aspects: enhancing clarity and transparency of goals through graphical representations, organizing various goals around central principles or concepts in a discipline, and establishing relationships among content while supporting prerequisite learning [32]. Therefore, in engineering education, the core aspect of ontology lies in including cognitive demands that relate domain content to what learners are expected to do in coordination with that content.

From the perspectives above, there is significant potential to develop an ontology-based knowledge representation method to assist learning in the ED course, as it is built on a cross-domain knowledge foundation. However, to the best of current research domains, a feasible ontology-based knowledge representation tailored for teaching and learning in ED is still lacking.

2.3 Methods for Measuring Learning Performance of the ED Course

The learning performance of ED courses is typically assessed through examinations comprising specific tasks that students must complete within a set timeframe, typically around two hours [33]. These tasks encompass various categories, including the mental rotation test, the differential aptitude test of spatial relations, drawing complex geometry in projection view systems, basic engineering concepts of dimensions and tolerance of parts, as well as reading and comprehending assembly drawings [34]. In most cases, students' proficiency levels are evaluated through examinations based on extensive analysis studies of student performance in the ED subject [35]. Those who pass these examinations are considered qualified candidates capable of solving practical engineering drawing problems. However, there is ongoing debate about the validity of these examinations in measuring students' learning performance in the ED subject.

The ED subject is widely regarded as a critical prerequisite for educating future engineers to tackle increasingly complex engineering design problems/projects [36]. Therefore, many studies have adopted the project-based learning (PBL) strategy, as the ultimate goal of learning the ED subject is to solve practical engineering design problems [37-38]. Previous studies on teaching and learning the ED subject often utilize research instruments comprising both ED performance tests and questionnaires on problem-solving conditions [1,9,35]. Moreover, students' problem-solving skills are assessed using a 5-scale Likert questionnaire, with descriptive statistics of mean scores and standard deviation subsequently analyzed to interpret the scores obtained from research instruments [1,34]. The improvement in students' performance in the ED subject is primarily measured by their achievements in conceptual understanding and problem-solving skills. The organization of the training program typically involves various specific phases, including the preparatory phase, training phase, and transfer phase. In this context, the effectiveness of teaching and learning approaches is validated by comparing the results of participants in the experimental group with those in the control group.

2.4 Research Gap to be Filled

The review of relevant domains mentioned above has highlighted a widespread consensus regarding the difficulties observed in the learning experiences of the majority of undergraduate students, necessitating effective approaches to enhance learning performance. Among the methods developed to facilitate a smoother learning experience in the ED subject, ontologies-based methods show potential to be further developed into effective knowledge representations adapted to support learning in the ED subject. However, it is noteworthy that ontologies-based knowledge representation for learning the ED subject is still lacking. Therefore, this study aims to propose a novel ontologies-based representation to address this research gap and pave the way for learning the ED subject more effectively.

3 ONTOLOGY-BASED KNOWLEDGE REPRESENTATION APPROACH

To address this research gap, this paper aims to propose a new ontology-based knowledge representation aimed at assisting students in the ED course to improve their learning performance. Firstly, the framework of the representation approach is proposed to elucidate how the proposed approach is applied to analyze and construct the knowledge structure in the ED course. Secondly, teaching techniques will be presented to educate students on how to utilize the proposed representation approach for analyzing practical ED problems.

3.1 The Framework of the Proposed Representation Approach

The main framework of the proposed method for representing knowledge in the ED course is illustrated in Figure. 1. Based on the fundamental ideas of ontology, there are primarily three subsections that form the entire knowledge graph of the ED course. The first subsection is the concept, which plays a significant role in formulating the theoretical system of the ED course. Meanwhile, the problem subsection serves as the defined target for applying theoretical knowledge in practical drawing tasks for engineering projects. The third subsection is the procedure, which involves the main steps to divide, analyze, and then solve problems by using and synergizing concepts. It serves as a bridge between the other two subsections.

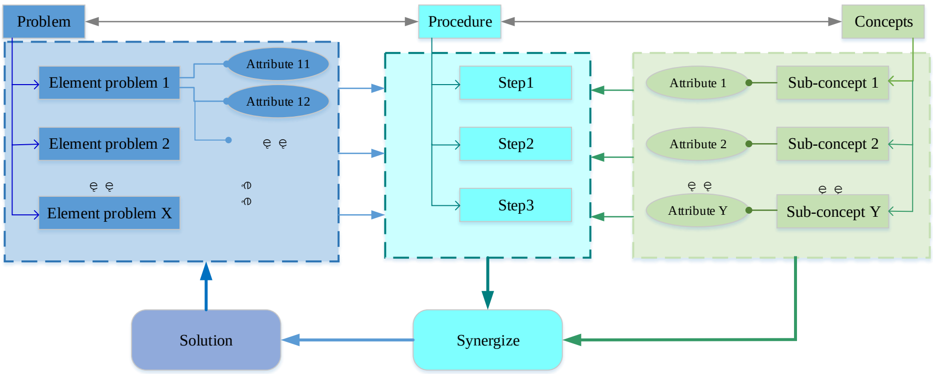


Figure 1: The framework of the proposed ontology-based representation.

In Figure 1, different subsections encompass a set of entities along with their lists of attributes. Specifically, the basic entity in the problem subsection mainly consists of typical element problems used to formulate a comprehensive problem usually through combination in the engineering practice or exercise books. In essence, a comprehensive engineering drawing problem generally can be broken down into several element problems that are usually defined by a set of attributes. For example, the drawing task for the assemble graph of certain mechanical instrument can be seen as a typical entity in the problem subsection, in this regard, the drawing for each part in the assembly can be treated as the element problem with its shape and dimensions and other attributes to be represented correctly to meet the requirements of this ED tasks. Correspondingly, the concept subsection also involves a hierarchy of sub-concepts at various abstraction levels with a set of attributes. In this lens, basic concept for drawing the assemble graph in the ED i.e., the form analysis to divide the assemble body into several basic geometries. During the application of the form analysis, the separation law and Boolean operations are used as the sub-concepts, the Boolean addition and the Boolean minus are specific attributes of the sub-concept of the Boolean operation.

The third subsection of the proposed knowledge representing approach is the procedure, which mainly comprises specific steps to resolve problems in exercises or practice. Generally, the procedure normally consists of three main steps:

Step 1: Problem analysis, in this step engineering drawing problem to be solved are decomposed into several element problems and then are defined the attribute set of each element problem;

Step 2: Iteration sequence for resolving each element problem, in this step each element problem is analyzed and solved stepwise by using the match of attribute sets from the defined element problem with the corresponding sub-concept in an iterative manner to solve all the defined element problems;

Step 3: Synergizing solutions, in this step, the overall solution to the engineering drawing problem is formulated by integrating sub-concepts in the solutions to all element problems, which is usually in forms of an assemble graph to illustrate all the information about constituting components with their correlations.

Through the aforementioned, mostly complex ED problems such as tasks of drawing assemble graphs for certain engineering instruments and can be analyzed and resolved step by step through the proposed methodology.

3.2 Teaching Technique for Educating Students of the Proposed Representation Approach

It is impractical for students to manage all three subsections within the limited time of the ED course. Students are typically more concerned about the scores they acquire in the final examination at the end of the course. Moreover, it is more beneficial to help students understand the fundamental ideas of ontology for their future studies rather than focusing solely on acquiring and remembering basic knowledge about engineering drawing. In this regard, the teaching technique primarily takes the form of exemplar typical problems; in other words, the ontology for the problem is initially taught to students to help them understand the fundamental ideas and elements of the ontology.

There are two main uses of the proposed ontology-based representation to educate students to acquire the ontological building elements outlined in Table 1. In Table 1, there are mainly two fundamental elements: the entity and the relation. Specifically, the entity can be further divided into entity and sub-entities and both the entity and the sub-entity contain a set of attributes, attributes can indicate all necessary features and characteristics of entities and sub-entities, which can be represented as a hierarchical structure as shown in Figure 2.

The second type is the relation, which indicates the correlation between attributes, sub-entities, entities, and other concepts on different hierarchical levels. The relation entity is typically formulated by attributes from different entities, such as the tolerance formed by the shape fit of both entities of a shaft with its fitted hole. Additionally, the relation entity also consists of a set of attributes, including connection types, tolerance classes, and other quality parameters.

Symbols					
Names	Entity	Sub-entity	Attribute	Connection	Subordination
Definitions and Usages	In the ED course, assemblies or complex bodies are defined as entities	Basic bodies that make up the complex bodies	Features and attributes of basic or complex bodies	Correlation between complex or basic bodies	Correlations between (Sub-)entities with their attributes
Examples	Mechanical part body (Bearing support)	Basic geometry (Cylinder)	Size (Dimensions)	Boolean operation (Boolean addition)	Belonging (connection between attribute and entity)

Table 1: Building elements of the proposed ontology-based representation.

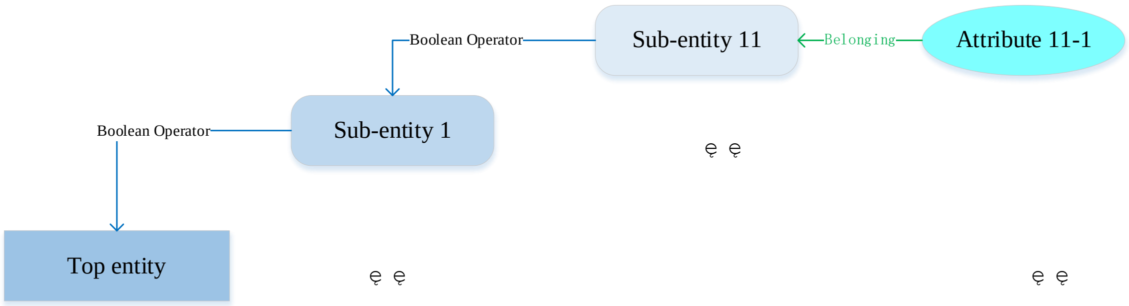


Figure 2: The entity element used for representing the concept hierarchy.

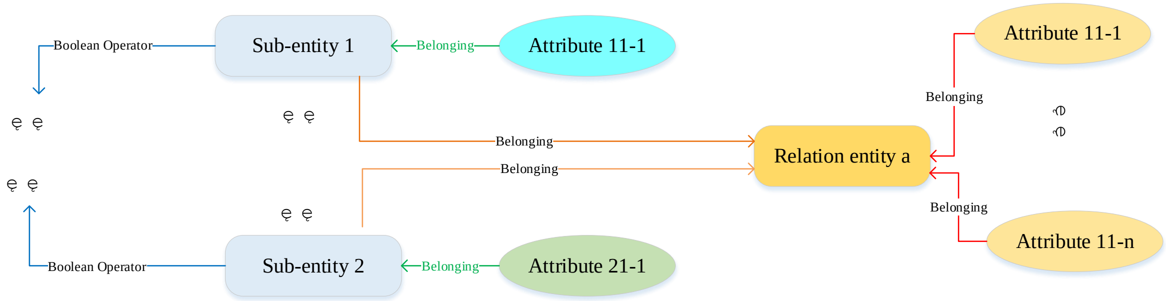


Figure 3: The entity element used for representing the relation.

In the specific example of the ontology-based representation for a bearing support part, as shown in Figure 4, with the ontological building elements outlined in Table 1, the exemplar problem is represented as a whole entity at the most abstract level. This entity involves a set of sub-entities at lower abstract levels.

The building procedure of the exemplar takes several steps that are explained with detailed information as follows.

Step1: Divide the assembly body into several basic geometry

The overall assemble body of the exemplar bearing support part pertains to the combined result of three simple basic geometries through Boolean adding operations. Additionally, basic geometries can be further divided into faces, lines, and points in space. therefore, all those basic geometries are identified.

Step 2: Figure out the main attributes of each basic geometry

Attributes especially the shape features of each geometry are analyzed and marked with their dimensions to indicating their specific shape and size. Therefore, those geometries can be represented in the engineering drawings in the three-dimensional Cartesian coordinate. These entities possess several attributes, including the dimensional annotation, dimensional/geometric tolerance, materials, and surface roughness—all of which are crucial technological specifications in the ED course.

Step 3: Interconnect entities and their attributes by fittings

therefore, entities at different abstract levels are interconnected. All these geometric elements are entities at different abstract levels. Connected through different types of fitting such the geometric and other aspects, all those basic shapes formulate the assembly body.

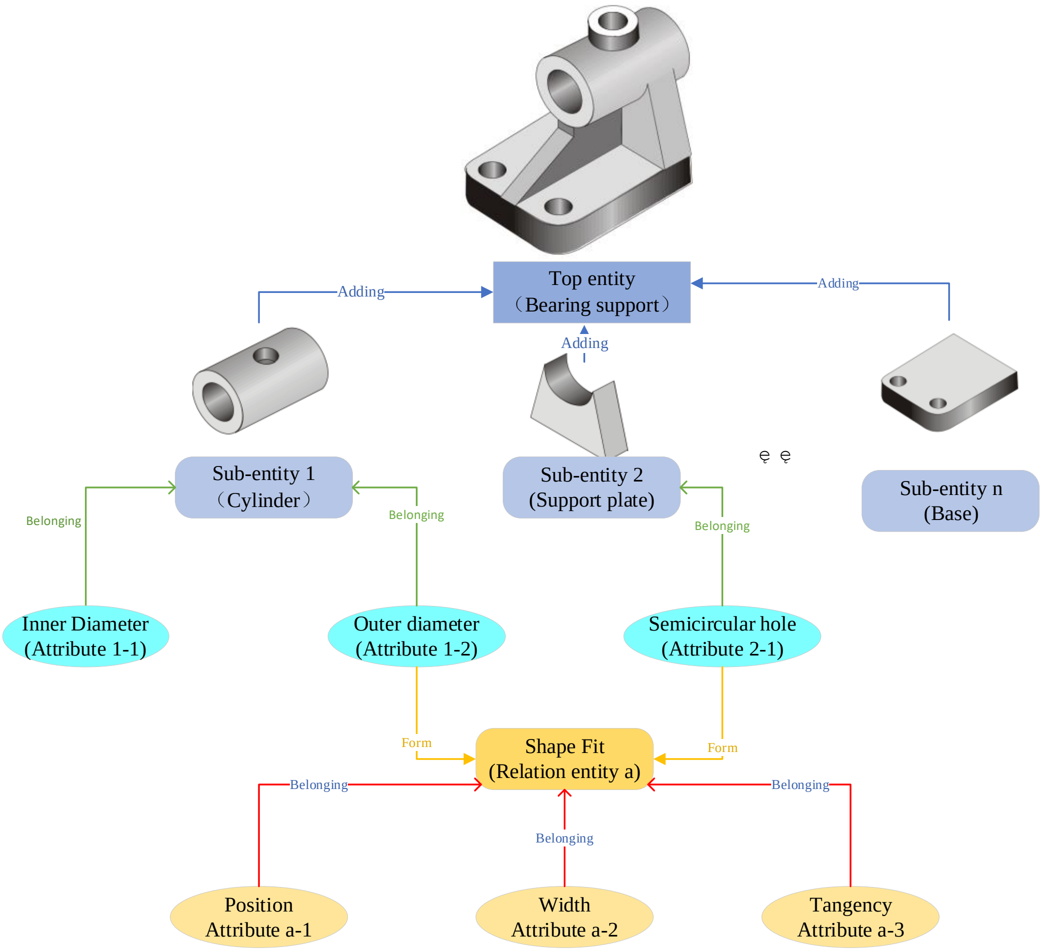


Figure 4: Exemplar case of the bearing support based on the proposed representation.

4 VALIDATION OF THE PROPOSED APPROACH

To verify the effectiveness of the proposed ontology-based representation in improving students' learning performance in the ED course, an experiment is organized to validate students' performance. This experiment involves measuring their results in two mechanical engineering drawing tasks to draw assemble graphs of two instruments that are important branches of ED course. Moreover, tasks in the section of mechanical engineering drawing are generally comprehensive since they require not only basic knowledge and skills of general engineering drawing but also the mechanical engineering knowledge.

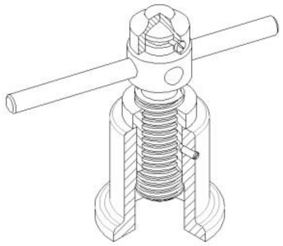
In a mechanical engineering drawing course, an assembly graph, also known as an assembly chart or assembly drawing, is a schematic representation that illustrates the relationship and sequence in which individual components or subassemblies come together to form a complete assembly or final product. Drawing an assembly graph is a comprehensive task in the ED course, due to facts that assemblies often consist of numerous parts, each with specific dimensions, shapes, and assembly requirements, moreover, it often requires knowledge of various engineering disciplines, including mechanical, electrical, and sometimes software integration, to ensure all aspects of the assembly are correctly represented. Through this project-based learning (PBL) process, students' achievements in the ED course are assessed using a set of checkpoints focusing on significant structural patterns.

4.1 Experimental Settings

This experiment is adapted from an existing practice course, which includes two separate hand-drawing tasks focused on two specific mechanical instruments: a small screw jack and a small gear oil pump. Further details about this course are outlined in Table 2 and the expected results of the assemble graphs are shown in the Appendix A and B.

Specifically, the first task is relatively simple, involving the interpretation of graphs for seven parts before drawing the assembly graph. It is recommended for students to complete this task within 8-10 hours. Subsequently, students' drawings are collected and evaluated using three checkpoints (S11 to S13) which are list in the Table 3 to measure the individual performance of participating students.

The second task entails completing the assemble graph of the gear oil pump, which comprises 12 parts and is expected to take around 16 to 20 hours. This task is evaluated using four checkpoints from S21 to S24 in Table 3 to assess students' performance.

Tasks	*Illustrators*	*Number of parts*	*Number of checkpoints*	*Recommended time*
Small screw jark		Seven	Three	8-10 Hours

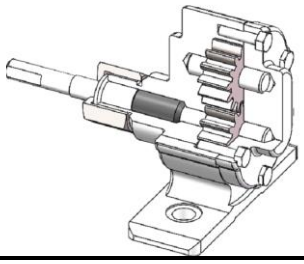
Gear oil pump		Twelve	Four	16-20Hours

Table 2: Information about tasks used for the validated experiment.

In this practical course, students are tasked with completing the assembly graphs of two instruments sequentially, with each instrument allotted 5 days for drawing. The experiment comprises six main steps, as outlined in Table 3.

Steps	*Mian Abilities*	*Instructions*
Choosing Participants	Choose participants randomly from all the students taking parts in the practical ED course.	At total 35, the half of the total students are chosen randomly according to their serial numbers
Pre-course training	Students who firstly marked as participants for the experiment are educated to learn the proposed knowledge representation.	The specific form of the proposed ontology-based representation is illustrated in Table 1 and figure 2 and 3, which is used in the pre-course training.
Test of participants	Students who firstly marked as participants for the experiment are required to finish a task to modeling the case of the small screw support.	Students who fail in providing the correct representations and those want to quit the experiment are removed from the experimental group.
First round task	In the first round of course, students from both the experimental and control groups are required to finish the first task to draw the assemble graph of the small screw support.	Students are required to draw the assessable graph all by their hands after acquire all the necessary information from the provided part graphs. In addition, students in the experimental group are suggested to use the knowledge representation to assist their drawing tasks.
Second round task	In the second round of course, students from both the experimental and control groups are required to finish the second task to draw the assemble graph of the gear oil pump.	Students are required to draw the assemble graph throughout the hand drawing based on all the provided part graphs. Meanwhile, experimental participants are suggested to apply the representation along their drawing.
Questionnaire's collection	At the end of the course, participants are required to answer a questionnaire including several questions on their comments on the proposed knowledge representation	All the students in the experimental group are required to provide their comments on the questionnaire, modeling results of engineering samples in two round tasks.

Table 3: Main activities in each step of the organized validated experiment.

Step 1: At the beginning of this course, participants are randomly selected based on their serial numbers. Initially, 33 out of 68 students are chosen as the experimental group members.

Step 2: A pre-course training session is organized to educate students in the experimental group on how to use the proposed ontology-based representation.

Step 3: Following the pre-course training, students in the experimental group are assessed based on their proficiency in using the ontology-based representation. Subsequently, only 11 out of 33 experimental participants pass the test and are deemed to have acquired the basic ability to use the ontology-based knowledge representation. The remaining students are utilized as samples in the control group.

Step 4: Students in both the experimental and control groups are tasked with completing the first-round task, which involves hand-drawing the assembly graph of the small screw jack.

Step 5: Subsequently, students in both groups are required to complete the second-round task, which involves hand-drawing the assembly graph of the gear oil pump.

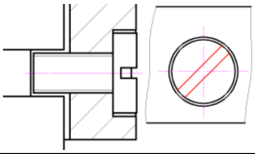
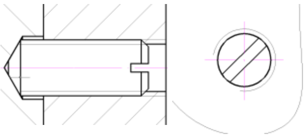
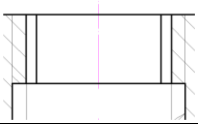
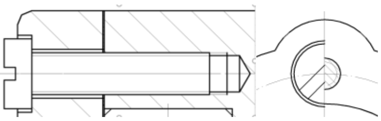
Step 6: A questionnaire comprising several questions about users' comments on the feasibility and readiness of the proposed ontology-based knowledge representation is distributed. Participants in the experimental group are required to answer all questions in the questionnaire.

4.2 Measuring Indicators of Students' Learning Performance

There are three types of evaluation indicators used to measure students' learning performance and their comments on the proposed ontology-based knowledge representation.

The first type of indicator is adapted from the original course assessment approach. This involves total assessment scores calculated by averaging the scores given by three different teachers. These scores assess the overall comprehensive performance of all students' hand-drawing results for the two assembly graphs.

The second type of indicators for students' learning performance comprises checkpoints that are anonymous to students. These checkpoints are used to evaluate students' performance by assessing their results regarding several key patterns. The list of all seven checkpoints used in this study is shown in Table 4. The quality of checkpoints is measured using a scale of 1, 3, 5, 7, and 9.

Checkpoints	*Variables*	*Sub-graphs*	*Contents*
Checkpoint 1	s11		The main and detailed drawings of the cylindrical screws in the assembled graph of the small jark support.
Checkpoint 2	s12		The main and detailed drawings of the fastening screw in the assembled graph of the small jark support.
Checkpoint 3	s13		The main drawing of the main screw structure in the assembled graph of the small jark support.
Checkpoint 4	s21		The main and detailed drawings of the cylindrical screws in the assembled graph of the gear oil pump.

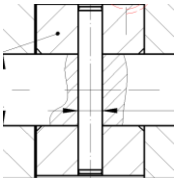
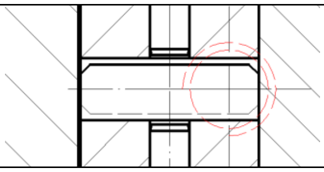
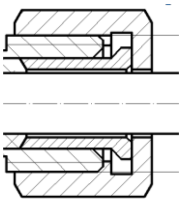
Checkpoint 5	s22		The main drawing of the characteristics of connections of the gear, the gear shaft, and the pin in the assembled graph of the gear oil pump.
Checkpoint 6	s23		The main drawing of the gear meshing characteristics in the assembled graph of the gear oil pump.
Checkpoint 7	s24		The main drawing of the fastening screw structure in the assembled graph of the gear oil pump.

Table 4: Main contents of all the measuring checkpoints.

The third type of measuring indicator involves a questionnaire administered to collect participants' comments on the proposed ontology-based knowledge representation from the experimental group. This questionnaire utilizes a five-point Likert Scale. Detailed information about each question in the questionnaire is provided in Table 5.

Questions	*Aims*	*Specific information*
Question 1	Degree of mastery of the proposed representation	To what degree of handle the proposed ontology-based knowledge representation.
Question 2	Degree of feasibility of the proposed representation	To what degree of the proposed representation in assist the ED course tasks.
Question 3	Degree of transferability of the proposed representation	To what degree of the proposed representation in assist of complex problem analyzing and solving.
Question 4	Possibility of future usage of the proposed representation	To what degree of the possibility of using the proposed representation in the future.
Question 5	Possibility of recommending the proposed representation	To what degree of the possibility of recommending the proposed representation to others for solving ED drawing tasks.

Table 5: Main contents of all the measuring checkpoints.

4.3 Analysis of Results

The effectiveness of the proposed knowledge representation on students' learning performance is measured by comparing the results of experimental participants against students in the control group using the proposed measuring indicators. The study conducts four analyses in total to reveal findings that support the validation of the proposed ontology-based knowledge representation.

4.3.1 Comparing performance between the experimental and control groups

The effectiveness of the proposed approach is primarily validated by comparing the performance of experimental participants with students in the control group. A comparison of results measured by the seven checkpoints is illustrated in Figure 5, with 95% error bars. Additionally, descriptive statistics information about the comparison is provided in Table 6.

The results indicate that there is a statistically significant improvement in performance observed in the experimental group compared to the control group, as evidenced by p-values in ANOVA tests that are lower than 0.05.

Variants	*Groups*	*Number*	*Means*	*Standard divisions*	*Significance (p-value)*
S11	0	57	3.280	2.343	0.000
	1	11	6.455	2.018	
S12	0	57	2.790	2.161	0.000
	1	11	7.546	1.573	
S13	0	57	3.456	2.172	0.000
	1	11	6.455	2.697	
S21	0	57	4.088	2.332	0.000
	1	11	7.910	1.044	
S22	0	57	4.158	2.419	0.000
	1	11	8.636	0.809	
S23	0	57	4.684	2.414	0.000
	1	11	7.546	1.293	
S24	0	57	3.491	2.010	0.000
	1	11	7.182	2.750	

Table 6: Descriptive statistic information of comparison between two groups measured by the seven checkpoints.

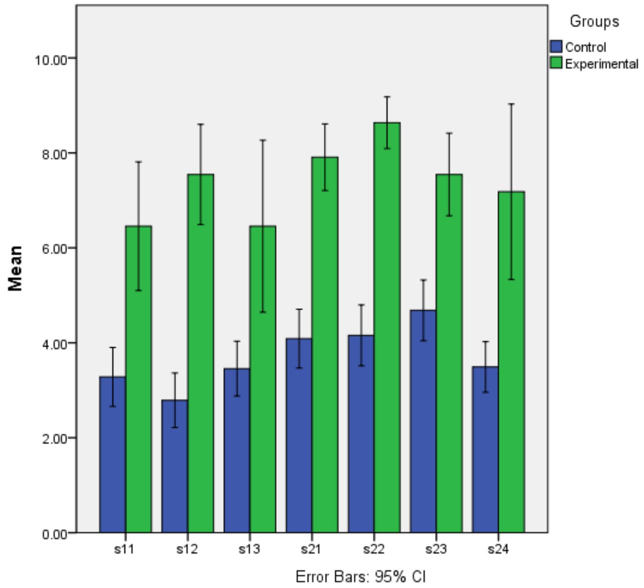


Figure 5: Comparing results of students' performance measured by seven checkpoints.

The comparison of overall scores between the experimental and control groups is depicted in Figure 6, with statistically descriptive information provided in Table 7. The results clearly indicate that students in the experimental groups have achieved better performance than their peers in the control group, as measured by the means of the overall scores and the p-value of the ANOVA test.

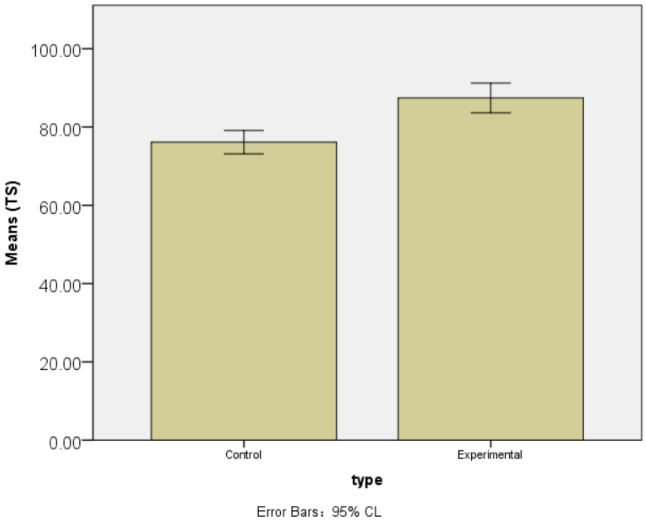


Figure 6: Comparing results of students' performance measured by overall scores.

Variants	*Groups*	*Number*	*Means*	*Standard divisions*	*Significance (p-value)*
TS (total scores)	0	57	76.13	11.26	0.002
	1	11	87.44	5.64	

Table 7: Descriptive statistic information of comparison between two groups measured by the overall scores.

4.3.2 Correlation analysis of measuring indicators

Results of correlation analysis of all the measuring indicators are analyzed by the Pearson correlation, which are shown in Table 8.

Variants	*s12*	*s13*	*s21*	*s22*	*s23*	*s24*	*TS*
s11	0.783**	0.588**	0.628**	0.540**	0.587**	0.445**	0.700**
s12	1.000	0.624**	0.744**	0.774**	0.752**	0.589**	0.751**
s13	-	1.000	0.457**	0.530**	0.455**	0.440**	0.534**
s21	-	-	1.000	0.790**	0.726**	0.597**	0.730**
s22	-	-	-	1.000	0.766**	0.604**	0.678**
s23	-	-	-	-	1.000	0.598**	0.741**
s24	-	-	-	-	-	1.000	0.603**

** at p-value =0.01 level significance

Table 8: Pearson analysis of all the measuring indicators used by the study.

Refers to table 8, all the seven checkpoints have obvious correlations with the total scores (TS), in other words, all the seven checkpoints can be used as effective indicators to measure the performance of students learning the ED courses.

4.3.3 Correlation analysis of ED tasks' performance with the modeling quality

In the experimental groups, correlations between participants' ED course performance and their performance in using the proposed modeling quality are also analyzed and shown in Table 9. However, due to the very limited sample size, the linear correlation is only measured by the Pearson parameter, which indicates that there are no obvious linear correlations between participants' ED learning performance and their modeling qualities. In other words, students who are better at handling the proposed method do not necessarily exhibit better ED learning performance.

Another observation is that the modeling quality of the two tasks shows an obvious linear correlation, indicating that students who excel at modeling the first task also model the second task with higher quality.

Variants	*m2*	*TS*
m1	0.806**	0.153
m2	1.000	0.200

** at p-value =0.01 level significance

Table 9: Pearson analysis of ED tasks' performance and the modeling quality.

4.3.4 Summary of comments on the methods

Similar to the third analysis, it only considers means of comments on the methods using the collected questionnaires, with results shown in Table 10.

Question	*Items*	*Means*	*Standard divisions*	*Degrees*
Q1	Mastery	5.000	0	Moderate
Q2	Feasibility	6.636	0.809	Relative positive
Q3	Transferability	6.455	0.934	Relative positive
Q4	Future usage	5.546	0.934	Moderate
Q5	Recommend	8.091	1.044	Positive

Table 10: Summary of participants' comments on the proposed representation.

Referring to Table 10, participants in the experimental group have provided positive comments on all the questions in the questionnaire. Students in the experimental group indicated that they could moderately handle the proposed representation. They also expressed positive views on the feasibility and transferability of the proposed ontology-based representation. Additionally, students hold positive perspectives on future usage and are willing to recommend this method based on their responses to the questionnaire.

4.3.5 Validation of the proposed method in comparison with the VR tool

Participants in the control group are encouraged to use augmented reality (AR) to assist in the drawing process. The exemplary performance of the AR assistance tool is illustrated in Figure 7. Afterward, a tracking study is organized to investigate participants in the control group and identify the users of the AR tool during their drawing tasks. However, only 9 out of 57 students remarked on the proper usage of the AR tool. Therefore, the performance of the AR users group, marked as the AR group, is compared with the experimental group, which has applied the proposed ontology-based knowledge representation method. The results of the pairwise comparison are shown in Table 11.

Variants	*Groups*	*Number*	*Means*	*Standard divisions*	*Significance (p-value)*
S11	AR	9	3.222	2.108	0.003
	1	11	6.455	2.018	
S12	AR	9	3.222	2.728	0.000
	1	11	7.546	1.573	
S13	AR	9	4.111	2.261	0.024
	1	11	6.455	2.697	
S21	AR	9	4.111	2.261	0.000
	1	11	7.910	1.044	
S22	AR	9	4.333	2.828	0.000
	1	11	8.636	0.809	
S23	AR	9	5.000	2.000	0.016
	1	11	7.546	1.293	
S24	AR	9	4.111	1.764	0.002
	1	11	7.182	2.750	
TS	AR	9	77.773	5.639	0.047
	1	11	87. 436	11.252	

Table 11: Descriptive statistic information of comparison between groups measured by the seven checkpoints and total scores.

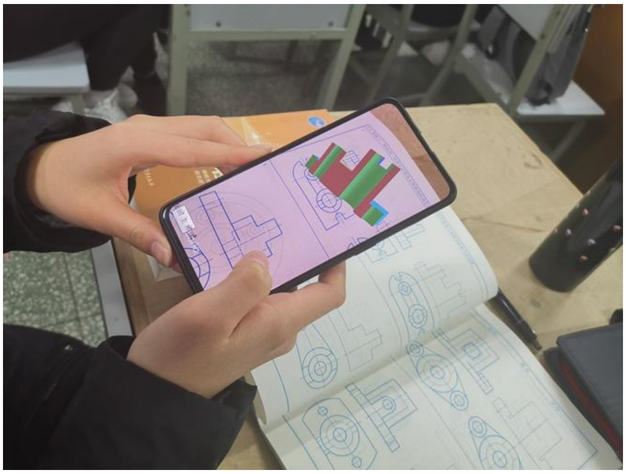


Figure 7: AR assistant learning tool for the ED course.

5 DISCUSSIONS

5.1 Main Findings

The analysis of results has revealed three main findings:

Firstly, using the proposed ontology-based knowledge representation significantly improves students' learning performance in the ED course. This is supported by the notably higher scores, both in overall scores and the seven checkpoints, observed in the experimental group compared to the control group.

Secondly, the proposed ontology-based knowledge representation is not only useful but also user-friendly for students to apply in practice. This is evidenced by the positive comments collected from participants in the experimental groups through questionnaires. Moreover, the tracking study results have indicated that the proposed approach is more effective than the AR assistance tools though the using of AR or VR tools can help improve students' understanding about mechanical assemblies mainly on the intuitive and sensory perception. Relatively, performance of ED mainly depends on students' rational thinking and logical deduction are based on the relationships between the components within an assembly.

Thirdly, there is no apparent correlation between the mastery of the proposed representation and the learning performance in the ED course. In other words, students who are more proficient in using the proposed representation may not demonstrate better performance than those who are less proficient in using the proposed modeling methods.

5.2 Implementations for Teaching ED Courses

Based on the main findings of this study, there are two important implementations for improving the teaching of the ED course for undergraduate students:

Firstly, it is advisable to recommend the proposed ontology-based knowledge representation for undergraduate students to use in learning the ED course. Additionally, the proposed knowledge representation can be utilized as a pre-test module before tackling complex ED tasks, such as drawing assembly graphs.

Secondly, there is no need to extensively train students to acquire sophisticated mastery of the proposed knowledge representation. Training programs should be kept simple and concise. Moreover, it is unnecessary to require students to build ontology-based models of tasks before drawing assembly graphs.

5.3 Limitations and Opportunities for Future Study

The limitations of this study are evident, as there is only one teaching technique utilized for the education of the proposed ontology-based knowledge representation, without further comparisons with other teaching approaches except for the use of AR/VR for the visualization of assembly samples.

To address these research gaps, there are two insights for initiating further studies in the future:

Firstly, there is a need to focus more on improving teaching techniques or approaches for the proposed representation. There is significant potential to enhance the accessibility and feasibility of the representation by integrating computer-aided approaches, which necessitates in-depth investigation in the future.

Secondly, studies should aim to compare the practical effectiveness of the proposed representation with other teaching and learning techniques for coping with complex tasks in ED courses. Future research can formulate more promising teaching and learning approaches for undergraduate students in ED courses by integrating existing methods and techniques.

6 CONCLUSIONS

To enhance the learning performance of undergraduate students in ED courses, this study introduces a novel ontology-based knowledge representation approach aimed at analyzing complex ED course samples to alleviate major difficulties. The effectiveness of the proposed representation is validated through a reorganized PBL-based ED practical course comprising two separate hand-drawing tasks. Analysis of course results indicates that the proposed representation significantly improves students' learning performance in ED courses. Subsequently, implementations for teaching ED courses are summarized, recommending the use of the proposed representation in pre-course activities. Additionally, limitations of this study are highlighted, pointing out several opportunities for future in-depth studies.

ACKNOWLEDGEMENT

The paper is sponsored by the Tianjin Municipality General Higher Education Undergraduate Teaching Quality and Teaching Reform Research Project (B231006905) and the Undergraduate Education and Teaching Reform Project of Tianjin University of Commerce (24JGXM02090).

Wei Liu, https://orcid.org/ 0000-0001-6111-4149
Meng Cong, https://orcid.org/0009-0006-2609-1483
Bing Liu, https://orcid.org/0000-0001-5120-137X
Hongning Liao, https://orcid.org/0009-0007-11651-8622
Yuanyuan Liu, https://orcid.org/0009-0002-1795-2596

REFERENCES

[1] Yasin, R-M.; Halim, L.; Ishar, A.: Effects of problem-solving strategies in the teaching and learning of engineering drawing subject, Asian Social Science, 8(16), 2012, 65-79. http://dx.doi.org/10.5539/ass.v8n16p65

[2] Kosse, V.; Senadeera, W.: Innovative approaches to teaching engineering drawing at tertiary institutions, International Journal of Mechanical Engineering Education, 39(4), 2011, 323-33 https://doi.org/10.7227/IJMEE.39.4.53

[3] Walther, J.; Kellam, N.; Sochacka, N.; et al.: Engineering competence? An interpretive investigation of engineering students' professional formation, Journal of Engineering Education, 100(4), 2011, 703-740. https://doi.org/10.1002/j.2168-9830.2011.tb00033.x

[4] Foss, M.; Liu, Y.: Project-based learning (PBL) center to bridge students with technology, 2020 Intermountain Engineering, Technology and Computing (IETC). IEEE, 2020,1-5. https://doi.org/10.1109/IETC47856.2020.9249156

[5] Wang, Y.; Ma, J.; Kremer, G E.; et al.: An investigation of effectiveness differences between in-class and online learning: an engineering drawing case study, International Journal on Interactive Design and Manufacturing (IJIDeM), 13, 2019, 89-98. https://doi.org/10.1007/s12008-018-0510-8

[6] Moreno, R.; Ludmila, O.L.: Do classroom exemplars promote the application of principles in teacher education? A comparison of videos, animations, and narratives, Educational Technology Research and Development 56, 2008, 449-465. https://doi.org/10.1007/s11423-006-9027-0

[7] Olkun, S.: Making connections: Improving spatial abilities with engineering drawing activities. International journal of mathematics teaching and learning, 3(1), 2003, 1-10.

[8] Rafi, A.; Samsudin, K. A.; and Ismail, A.: On improving spatial ability through computer-mediated engineering drawing instruction, Journal of Educational Technology & Society, 9(3), 2006, 149-159.

[9] Garmendia, M.; Guisasola, J.; and Sierra, E.: First-year engineering students' difficulties in visualization and drawing tasks, European Journal of Engineering Education, 32(3), 2007, 315-323. https://doi.org/10.1080/03043790701276874

[10] Kuhar, S.; and Podgorelec, V.: Ontology visualization for domain experts: A new solution, In 2012 16th International Conference on Information Visualisation, 2012, 363-369, IEEE. https://doi.org/10.1109/IV.2012.67

[11] Potter, C.; and Van der Merwe, E.: Perception, imagery, visualization and engineering graphics, European Journal of Engineering Education, 28(1), 2003, 117-133. https://doi.org/10.1080/0304379031000065216

[12] Kadam, K.; Mishra, S.; Deep, A.; Iyer, S.: Enhancing engineering drawing skills via fostering mental rotation processes, European Journal of Engineering Education, 46(5), 2021, 796-812. https://doi.org/10.1080/03043797.2021.1920891

[13] Islamoglu, O. S.; and Deger, K. O.: The location of computer-aided drawing and hand drawing on design and presentation in the interior design education, Procedia-Social and Behavioral Sciences, 182, 2015, 607-612. https://doi.org/10.1016/j.sbspro.2015.04.792

[14] Ismail, M. E.; Othman, H.; Amiruddin, M. H.; and Ariffin, A.: The use of animation video in teaching to enhance the imagination and visualization of student in engineering drawing. In IOP conference series: materials science and engineering, IOP Publishing, 203, 2017, 012023. https://doi.org/10.1088/1757-899X/203/1/012023

[15] Halim, L.; Yasin, R. M.; and Ishar, A.: Camed: An innovative communication tool in teaching engineering drawing, WSEAS Transactions on Information Science and Applications, 9(2), 2012,58-67.

[16] Lagenbach, J.; Wächter, M.; Lohrengel, A.; and Müller, N.: Teaching Engineering Drawing in a Technology Changing Environment, In DS 82: Proceedings of the 17th International Conference on Engineering and Product Design Education (E&PDE15), Great Expectations: Design Teaching, Research & Enterprise, Loughborough, UK, 03-04.09, 2015, 162-167.

[17] Kadam, K.; Mishra, S.; Iyer, S.; and Deep, A.: Unfolding learning difficulties in engineering drawing problem-solving, Australasian Journal of Engineering Education, 2024,1-13. https://doi.org/10.1080/22054952.2024.2309703

[18] Wu, S. P.; Van, V. B.; and Rau, M. A.: How drawing prompts can increase cognitive engagement in an active learning engineering course, Journal of Engineering Education, 109(4), 2020, 723-742. https://doi.org/10.1002/jee.20354

[19] Ali, D. F.; Omar, M.; Mokhtar, M.; Suhairom, N.; Abdullah, A. H.; and Halim, N. D. A.: A review on augmented reality application in engineering drawing classrooms, Man India, 97(19), 2017, 195-204.

[20] Chen, Y. C.; Chi, H. L.; Hung, W. H.; and Kang, S. C.: Use of tangible and augmented reality models in engineering graphics courses, Journal of Professional Issues in Engineering Education & Practice, 137(4), 2011, 267-276. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000078

[21] Tiwari, A. S.; Bhagat, K. K.; and Lampropoulos, G.: Designing and evaluating an augmented reality system for an engineering drawing course, Smart Learning Environments, 11(1), 2024,1-19. https://doi.org/10.1186/s40561-023-00289-z

[22] Collins, A. M.; and Quillian, M. R.: Retrieval time from semantic memory, Journal of verbal learning and verbal behavior, 8(2), 1969, 240-247. https://doi.org/10.1016/S0022-5371(69)80069-1

[23] Baker, E.; Chung, G.; and Herman, J.: Ontology-based educational design: Seeing is believing, 13,2009,1-32, National Center for Research on Evaluation, Standards, & Student Testing, Los Angeles, CA: CRESST.

[24] Altan, Z.: The importance of ontology in software engineering education programs, The Online Journal of Science and Technology, 7(1),2017, 119.

[25] Lee, J.; and Jeong, Y.: User-centric knowledge representations based on ontology for AEC design collaboration, Computer-Aided Design, 44(8), 2012, 735-748. https://doi.org/10.1016/j.cad.2012.03.011

[26] Stevens, R.; Goble, C. A.; and Bechhofer, S.: Ontology-based knowledge representation for bioinformatics, Briefings in Bioinformatics, 1(4), 2000, 398-414. https://doi.org/10.1093/bib/1.4.398

[27] Mikroyannidis, A.; Theodoulidis, B.: Ontology management and evolution for business intelligence, International Journal of Information Management, 30(6), 2010, 559-566. https://doi.org/10.1016/j.ijinfomgt.2009.10.002

[28] Mika, P.: Ontologies are us: A unified model of social networks and semantics, Journal of web semantics, 5(1), 2007, 5-15. https://doi.org/10.1016/j.websem.2006.11.002

[29] Dudáš, M.; Lohmann, S.; Svátek, V.; and Pavlov, D.: Ontology visualization methods and tools: a survey of the state of the art, The Knowledge Engineering Review, 33, e10, 2018. https://doi.org/10.1017/S0269888918000073
[30] Annamalai, M.; and Mohseni, H. R.: Jambalaya: the closest visualisation fit for the protégé ontology conceptual-relationship tracer, In 2010 International Conference on Science and Social Research (CSSR 2010),2010, 201-206. https://doi.org/10.1109/CSSR.2010.5773767
[31] Li, Z.; Liu, X.; Wang, X.; Liu, P.; and Shen, Y.: Transo: a knowledge-driven representation learning method with ontology information constraints, World Wide Web, 26(1), 2023, 297-319. https://doi.org/10.1007/s11280-022-01016-3
[32] Chen, Y. J.: Development of a method for ontology-based empirical knowledge representation and reasoning, Decision Support Systems, 50(1), 2010, 1-20. https://doi.org/10.1016/j.dss.2010.02.010
[33] Violante, M. G.; Moos, S.; and Vezzetti, E.: A methodology for supporting the design of a learning outcomes-based formative assessment: the engineering drawing case study, European Journal of Engineering Education, 45(2), 2020, 305-327. https://doi.org/10.1080/03043797.2019.1622653
[34] Silva, I. B. D.; Agostinho, O. L.: A strategy for teaching and learning technical drawing, International Journal of Engineering Education, 34(6), 2018, 1939-1950.
[35] Chae, J.; Hwang, S.; Seo, W.; and Kang, Y.: Relationship between rework of engineering drawing tasks and stress level measured from physiological signals, Automation in Construction, 124, 2021, No.103560. https://doi.org/10.1016/j.autcon.2021.103560
[36] Adams, R.; Evangelou, D.; English, L.; De Figueiredo, A. D.; Mousoulides, N.; Pawley, A. L.; and Wilson, D. M.: Multiple perspectives on engaging future engineers, Journal of Engineering Education, 100(1),2011, 48-88. https://doi.org/10.1002/j.2168-9830.2011.tb00004.x
[37] Dos Santos, E. F.; Gonçalves, B. C. M.; De Oliveira, K. B.; and Silva, M. B.: Project Based Learning applied to technical drawing, Creative Education, 9(03),2018, No. 83333. https://doi.org/10.4236/ce.2018.93034
[38] Mursid, R.; Saragih, A. H.; and Hartono, R.: The effect of the blended project-based learning model and creative thinking ability on engineering students' learning outcomes, International Journal of Education in Mathematics, Science and Technology, 10(1), 2022, 218-235. https://doi.org/10.46328/ijemst.2244

APPENDIX A: ASSEMBLE DRAWING OF THE FIRST AND SECOND TASKS IN THE EXPERIMENT