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Development of an Online Engineering Drawing System to Enhance Junior High School Students' Learning in an Engineering Graphics Course

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The purposes of this study were to develop the HappyCAD online engineering drawing system and to examine its effects on students' learning. The HappyCAD system includes instructional management and engineering drawing modules. The engineering drawing module provides three-dimensional (3D) models and interactive 3D solids. Learners can interact with the system and use various tools for drawing. Students can also receive feedback from teachers and redesign their engineering drawings. The HappyCAD system was implemented as an e-learning tool in an engineering graphics course for junior high school students. Students' perceptions of online learning with HappyCAD in engineering drawing were reported along with learning outcomes that resulted from their use of the e-learning tool. This study demonstrated the positive effects of an online engineering drawing system on students' engineering drawing literacy. The finding suggests that students generated positive attitudes towards learning engineering graphics in an online environment. Students' error patterns in drawings were also analyzed in this study.

Keywords: online engineering drawing system; junior high students; engineering graphics; e-learning

1. Introduction

1.1 Online Engineering drawing systems

With the development of Information and Communication Technologies (ICT), e-learning has emerged as an increasingly widespread paradigm in Education. The utilization of ICT tools and delivery mechanisms in the engineering education environment is becoming a more effective instructional strategy [1, 2]. E-learning is defined as the use of virtual, web-based learning environments with digital content to support learning. It encompasses various combinations of classroom and web-based learning practices, from the use of some ICT tools to support classroom teaching to predominantly online learning. Teachers can use such interactive systems to explain complex concepts more easily than with a textbook. Previous studies have shown that the use of ICT tools effectively enhances students' motivation and learning capabilities [3].

Engineering drawing is a basic competence required of engineers to solve engineering design problems [4]. This skill is an essential component of all technological engineering and design curricula. The potential of computers to enhance students' engineering drawing capabilities has been recognized. Practical experience has shown that Computer-Aided Drafting (CAD) programs are valuable aids in engineering education [5]. Lin and Pan [6] indicated that the advantages of CAD use include the simplification of drawing processes; ease of image modification, storage, copying, and management; enhancement of image effects; and compatibility with computer-aided manufacturing. CAD systems provide a visual environment for the design and delivery of images, from the conceptual design stage to the drafting and detailed layout phases. Students can use CAD programs to produce acceptable models and drawings and enhance their understanding of the graphic concepts introduced in a course. However, commercial CAD programs are complex and characterized by a certain rigidity of use in educational settings, especially for novice learners. Connelly and Maicher [7] noted that the inability to visualize in three-dimensional (3D) space remains a challenge for many introductory computer graphics students. Web-based environments with CAD tools have been developed as interactive laboratories for engineering students [7, 8], and the adoption of online CAD systems has shown promise in helping such students' learning in engineering drawings.

Many CAD systems developed to improve students' engineering drawing skills are limited, as they primarily provide visual assistance to help students understand engineering lectures [9]. Connelly and Maicher [7] developed an interactive web-based tutorial system to assist students in mastering the principles of multiview projections. This system provides input tools allowing students to draw on

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the screen and feedback through array coordinate comparisons. Students felt that this product was helpful in understanding multiview drawing. However, the vague nature of feedback provided by this system was the limitation of this study [7]. Cerra et al. [8] developed a similar web-based interactive CAD program for students in an introductory engineering drawing course. In this system, students are prompted to complete exercises using available tools in a self-correction module wherein successes and errors are displayed. Information provided during the correction phase is stored in the database for future processing. The authors found that students who used these interactive web-based tools significantly outperformed those who did not [8]. As Nicol and Macfarlane-Dick [10] have stated, however, feedback from teachers can help students to develop an understanding of expectations, correct misunderstandings, and obtain immediate responses to difficulties. Thus, the features of a web-based system may be improved by providing teachers' feedback tools to enhance students' learning.

1.2 Online feedback

Online learning systems serve as virtual advisors that provide students and teachers with appropriate feedback [11]. Teachers should act as facilitators who guide students' learning and offer help tailored to the needs of individuals [12]. Most e-learning course management systems can store, track, and monitor students' online activities, including visits to course material, results of online quizzes, and participation in online discussions. These data can be valuable for teachers seeking to understand students' online activities, but they are very limited. The simple statistics that they provide contain insufficient detail, are difficult to comprehend, and are rarely used by instructors as a basis for giving learning-related suggestions to students [13].

Interest in the analysis of data on learners' interactions with e-learning systems is growing [14]. Gaudioso et al. [15] developed a learning management system that provided teachers with indicators of students' learning activities, including students' (interest in) performance, eagerness, and level of interest in improving their submissions. They also developed an adaptive web-based educational hypermedia system that identified common patterns of student behavior. These systems reduced the dropout rate and increased the number of students who passed a physics course [15]. Similarly, Kosba et al. [11] developed a web-based learning system with adaptive feedback that incorporated individual student models representing their preferences, communication status, and domain knowledge. It generated feedback and suggestions for students and teachers based on the identification of potential individual-, group-, and class-level learning and communication problems. This system improved students' learning in web-based distance learning settings. However, the application of such support systems for teachers is limited to courses involving online discussion or small group projects. Moreover, most studies have focused on adult college students, with limited attention to junior high education. The results of applying web-based engineering drawing to junior high education are still inconclusive. For younger students, such as those in junior high school, instant feedback from teachers to correct misconceptions is valuable.

In sum, the use of web-based learning environments for the management and distribution of educational materials, progress tracking, and reporting has increased significantly [16], and recent studies have documented a link between personalized feedback and methods for improving students' motivation and meta-cognition [11]. Thus, instructional tools that help teachers explain complex concepts and provide individualized feedback to students should be included in web-based CAD learning systems, and the effectiveness of such approaches must be examined. In this study, the HappyCAD system, which provides an interactive learning environment for junior high school students and an instructional management system for teachers in the context of an engineering graphics course, was developed. The following research questions were examined using a quasi-experimental approach for adopting the HappyCAD on junior high school students' engineering drawings:

1. What are the effects of the HappyCAD system on junior high school students' learning in engineering drawings?
2. What are the error patterns of junior high school students in engineering drawings?
3. What are students' attitudes toward the use of the HappyCAD system in an engineering graphics course?

2. HappyCAD system

The HappyCAD online engineering drawing system proposed in this study includes an engineering drawing module for students and an instructional management module for teachers.

2.1 Engineering drawing module

This module provides various tools enabling students to draw engineering graphics. To enhance students' understanding of 3D projection concepts, we developed 3D solids using AutoDesk 3D Max

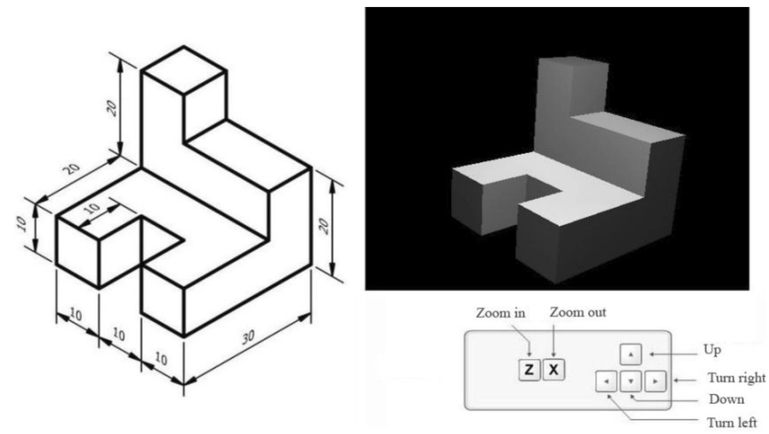

Fig. 1. Interactive 3D views of solids in the engineering drawing module of the HappyCAD system.

and Virtools software. Students could manipulate the 3D solids from different viewpoints (Fig. 1).

The HappyCAD system also provides a drawing area with four categories of interactive tools for isometric drawing: general editing tools (undo, show/hide grid background, delete object, save, erase), drawing tools (line, line on the grid, ellipse, arc, dotted line), dimensioning tools (dimension in millimeters, diameter/radius, linear dimension with arrow, border-line dimension, radius dimension), and arc tools (Fig. 2). After completing an assignment, students could submit it online.

2.2 Instructional management module

This module provides an interface for teachers to assign and grade exercises (Fig. 3). They could give comments and feedback on students' assignments using various grading tools, including all interactive drawing tools available to students (used to make corrections on students' drawings) and feedback tools (scoring text, indication of excellent work, and comments field) (Fig. 4). Immediately after grading, students could check their scores on assignments and get teachers' feedback online.

3. Methodology

3.1 Participants

We included all seventh-grade students in one junior high school in Taipei. A total of 190 seventh graders from six classes participated in this study for eight weeks. We used the simple cluster randomization method to allocate the participants. Three classes each were randomly assigned to the experimental (98 students) and control (92 students) groups. Students in the experimental group used the HappyCAD online engineering drawing system in an engineering graphics course, and those in the control group received traditional instruction. The traditional instruction was the teacher-centered

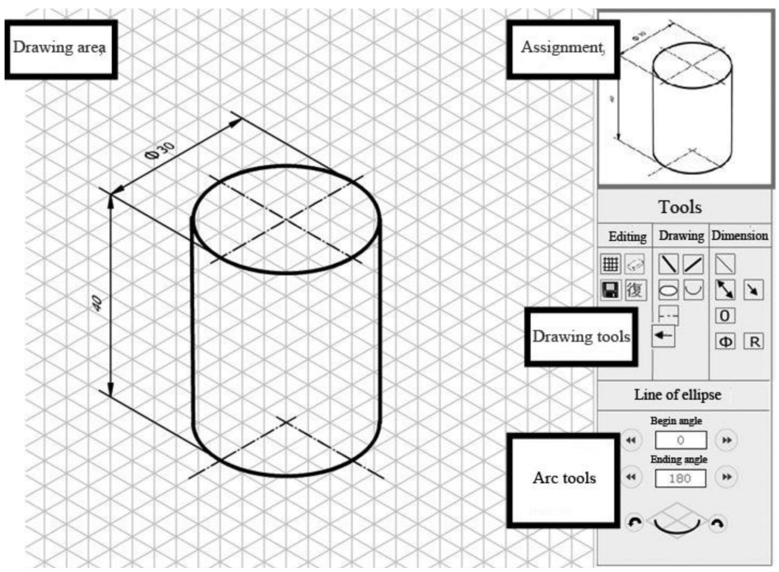

Fig. 2. The engineering drawing area in the HappyCAD system.

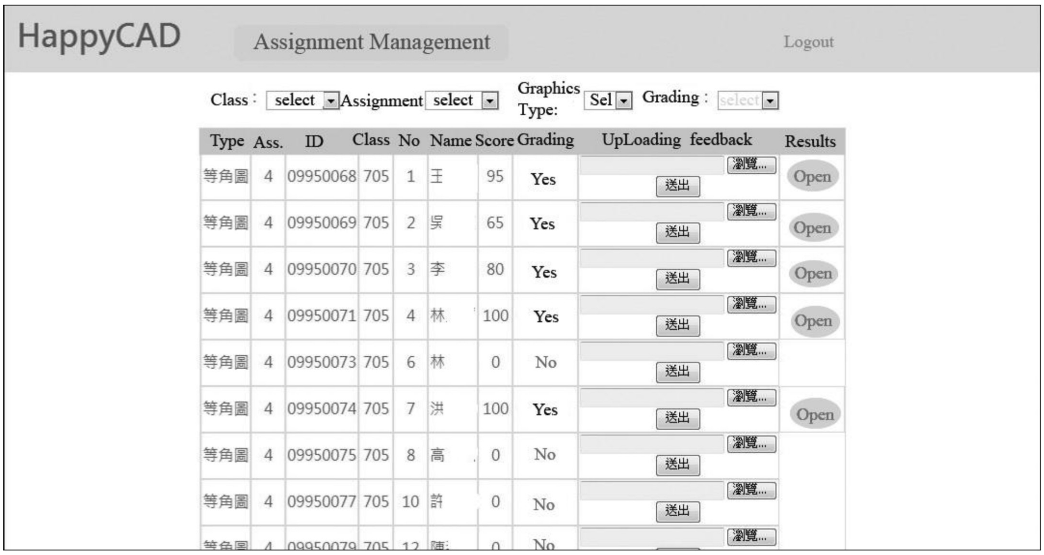

Fig. 3. The assignment interface of the HappyCAD system.

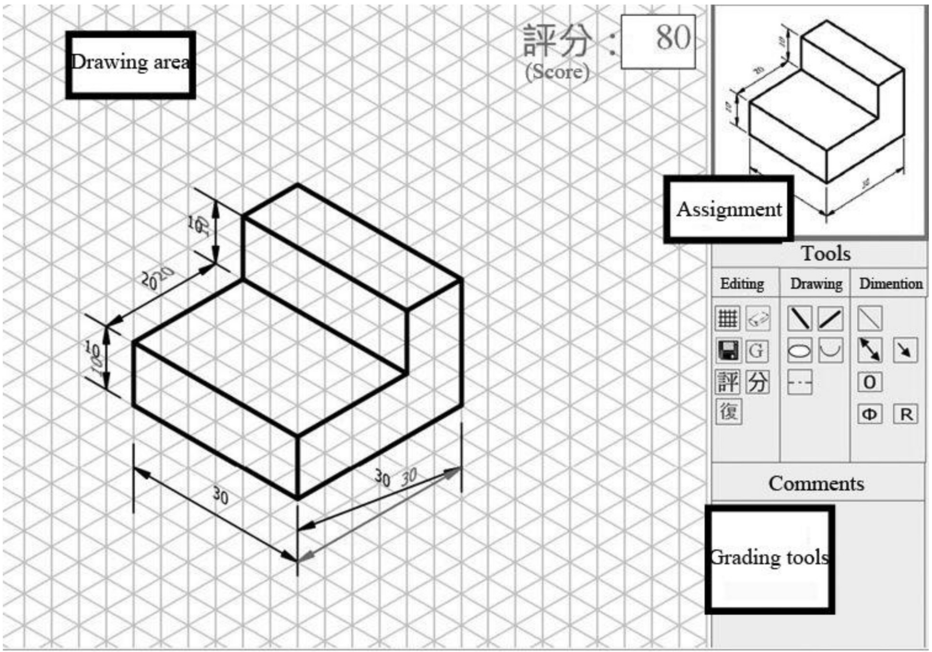

Fig. 4. Example of grading tool use in the instructional management module of the HappyCAD system.

approach. Students in the control group used the paper-and-pencil engineering drawing on the assignments. Each engineering graphics course was one 50-min session per week.

3.2 Measures

The Engineering Drafting Achievement Test (EDAT) was developed by the researchers. EDAT, designed to assess junior high school students' engineering drawing comprehension, was administered to students before and after participation in the eight-week study. The EDAT comprises two subtests evaluating engineering drawing literacy and engineering drawing ability. Its 29 problems include tasks such as the conversion of isometric drawings to three-dimensional views (top, front, and side) and vice versa, correction of diminution errors, and graphics creation. Therefore, we used the same problems on EDAT as the pre-test and post-test in this study. The analysis of EDAT items indicated that the level of difficulty and discrimination index were 0.65 and 0.43, respectively. The coefficient of internal consistency reliability of the EDAT was 0.92.

Table 1. Students' pre- and post-test scores on the Engineering Drafting Achievement Test

	Experimental group (n = 98)					**Control group (n = 92)**					
	Pre-test		**Post-test**			**Pre-test**		**Post-test**			
Test	***M***	***SD***	***M***	***SD***	M^a	***M***	***SD***	***M***	***SD***	M^a	***F***
Overall	47.78	17.22	62.43	16.82	62.84	49.00	16.78	59.00	18.07	58.56	5.17*
Engineering drawing literacy	31.04	9.13	39.58	10.69	39.82	31.82	9.58	37.04	11.11	36.79	5.28*
Engineering drawing ability	16.73	10.27	22.85	8.30	22.94	17.18	10.38	21.96	8.77	21.85	1.08

M = mean, SD = standard deviation, M^a = adjusted mean.

Analysis of the covariance was used to compare EDAT scores from the experimental and control groups.

A questionnaire was also administered to the experimental group after the completion of the study to explore students' attitudes toward engineering drawing. There were four factors included in the questionnaire: six items assessed interface usability, five items assessed students' perception about integrated HappyCAD into the curriculum, five items accessed the learning efficacy and seven items accessed the motivation. The ratings followed a 5-point Likert scale, from 1 = 'strongly disagree' to 5 = 'strongly agree'. Cronbach's alpha coefficient of the questionnaire was 0.84. We also interviewed randomly selected students about their perceptions of using the HappyCAD system in the engineering graphics course.

Content analysis was performed to examine students' error patterns in engineering graphics assignments using a coding scheme based on that applied in a previous study [17]. Error patterns in graphic drawing, line drawing, and dimensioning were classified using 25 categories (Appendix). Two coders were trained to analyze error patterns in 90 sample assignments before the experiment. The inter-rater reliability coefficient was 0.92.

4. Results

4.1 Students' achievement scores

Before implementing analysis of covariance analysis (ANCOVA), the homogeneity of variance assumption was tested. The results of Levene's test of EDAT scores indicated there is no significant (F = 1.24, p = 0.24), representation that the variances were homogeneous and the homogeneity assumption had been met. The ANCOVA analysis showed that there was significant differences between the experimental group and the control group on EDAT scores (F = 5.17, $p < 0.05$), especially for the subtest of engineering drawing literacy (F = 5.28, $p < 0.05$). Table 1 indicated that students in the experimental group showed greater improvements than the control group in overall and engineering drawing literacy scores on EDAT (${M_{EG}}^a$ = 62.84 and 39.82, respectively; ${M_{CG}}^a$ = 58.56 and 36.79, respectively). Scores on the engineering drawing ability subtest did not differ significantly between groups (F = 1.08).

4.2 Students' error patterns in engineering drawings

Students in the experimental and control groups made comparable numbers of errors in graphics drawing and dimensioning on the six engineering graphics assignments analyzed (Fig. 5). However, students in the experimental group made fewer errors than those in the control group on line drawings (Fig. 5) (experimental group: n_{error} = 4, M = 0.04; control group: n_{error} = 59, M = 0.64). The results also demonstrated a gradual reduction in errors made by students in the experimental group with respect to those in the control group during the study period (Fig. 6).

Among all the students, the greatest number of errors (n_{error} = 513) was made in dimensioning. The three most frequent errors were missing dimensions (Fig. 7) (D9; n_{error} = 92), misplacement of lengths (D6; n_{error} = 78), and misrepresentation of the length of scaled lines (D5; n_{error} = 60).

4.3 Students' attitudes toward using the HappyCAD system in an engineering graphics course

Overall, the survey results indicated that students had a positive attitude toward learning with the

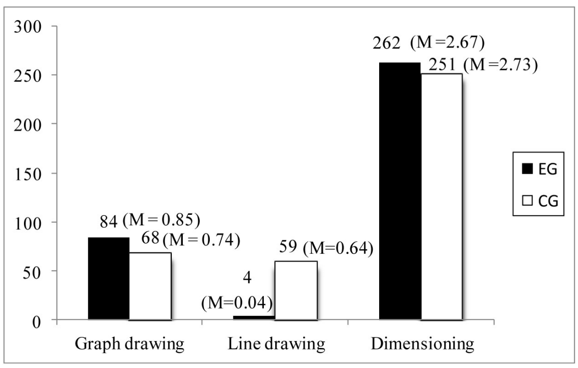

Fig. 5. Results of error pattern analysis in the experimental group (EG) and the control group (CG).

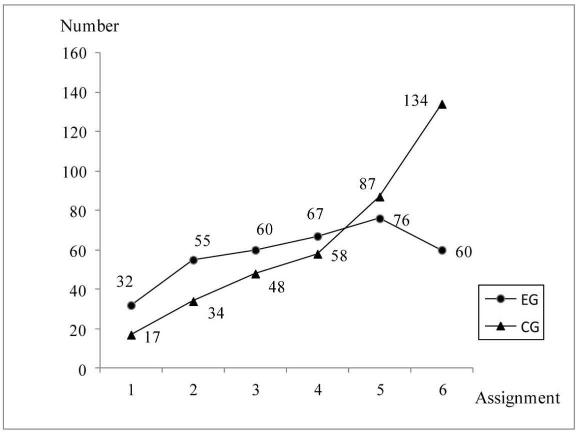

Fig. 6. Results of error pattern analysis by assignment: EG = experimental group, CG = control group.

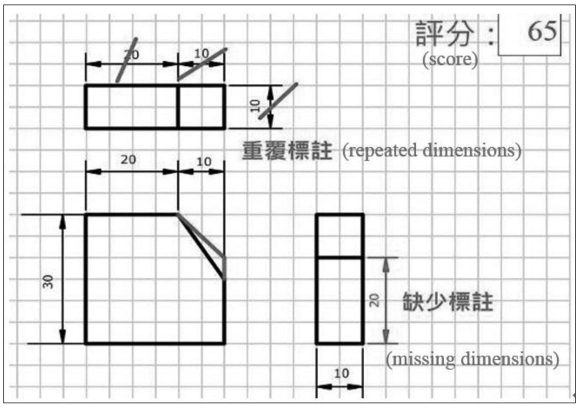

Fig. 7. Examples of missing and repeated dimensions (teacher's corrections in grey).

HappyCAD system (Table 2) (M = 4.23, SD = 0.82). Students were satisfied with the system's interface (*M* = 4.3, *SD* = 0.79), had a positive attitude toward the incorporation of HappyCAD into the curriculum (*M* = 4.41, *SD* = 0.78). They showed the highly learning efficacy (*M* = 4.39, *SD* = 0.75) and motivation (*M* = 3.96, *SD* = 0.89) about using HappyCAD in the engineering graphics course.

In interviews with students, frequently cited reasons for the enhancement of their attitudes toward learning engineering graphics were: (1) teachers' feedback on engineering drawings effectively helped them to correct misconceptions, (2) the manipulation of 3D solids within the system helped them to draw graphics projections, and (3) they enjoyed using the system in the engineering graphics course.

Table 2. Students' attitudes toward using the HappyCAD system

Category	*M*	*SD*
Overall	4.23	0.82
Interface usability	4.30	0.79
HappyCAD integration into curriculum	4.41	0.78
Learning efficacy	4.39	0.75
Motivation	3.96	0.89

M = mean, *SD* = standard deviation.

5. Discussion

This paper describes the design and implementation of an online engineering drawing system for junior high school students in an engineering graphics course. The results of this study indicate that the HappyCAD e-learning system facilitated students' learning and motivation. These results are consistent with previous research suggesting that interactive CAD programs are positively influence students' motivation [8]. Features of the HappyCAD system that facilitated students' engineering drawing literacy were hidden line removal, isometric views, and other 3D functions.

Moreover, the results of this study support the utility of this online system for teachers, as it provided grading tools that effectively facilitated the provision of feedback to correct students' errors and the monitoring of students' progress. Such tools can aid real-time learning, especially for novice students in engineering drawing. An 'ideal online learning environment' is one that scaffolds and supports maximal intellectual development in learners [18]. The instructional management module facilitates teachers to provide feedback to student work and helps the teacher monitor student progress [19]. Teachers' correction of engineering drawing errors within the HappyCAD system benefited students. The results were in line with the previous study indicating the positive links between corrective feedbacks and achievement outcomes [20].

Our study indicated that the HappyCAD facilitated students' engineering drawing literacy. The present study results were in accordance with those of previous studies indicating that the online learning in engineering drawing could enable students to interact with 3D views of solids when needed to solve problems [7, 8]. Students who used the HappyCAD system were motivated to learn the material and were more cognitively engaged. They believed that learning engineering graphics was interesting and important. Moreover, these positive attitudes were associated with engineering drafting achievements. The results of this study also indicated that the HappyCAD system was easy to use for junior high school students. More research is needed to explore whether greater exposure to integrated computer applications in engineering graphics education benefits students' attitudes and self-efficacy.

The analysis of error patterns of this study indicated that students who used the system showed improvement in line drawing abilities. Among engineering graphics concepts and skills, dimensioning was most difficult for these junior high school students. Therefore, additional computer exercises may be needed to provide students with increased opportunities to practice dimensioning skills. Future systems should be developed to help students' dimensioning skills, and that their effectiveness should be examined. In addition, researching how to prevent robust and persistent misconceptions of difficult engineering graphics concepts that maybe reinforced during formal instruction would be fruitful.

6. Conclusions

The present study demonstrates that an online drawing system is an effective practice for promoting novice learners' engineering drawing literacy and attitude toward learning engineering graphics. The HappyCAD provided a model of integrating interactive tools and ongoing feedbacks. With the use of online interactive tools, we made a step beyond traditional lecture-based learning. This application offers important features that facilitate students to explore the solutions. Therefore, in the online engineering drawing environment, knowledge acquisition occurs through interacting with tools. Moreover, using HappyCAD in the classroom increased the amount of feedbacks given by the teachers and students. This study provided the evidence that an online teaching and learning process is essential for the beginning learners in engineering drawing courses.

Moreover, this study highlights the importance of analyzing error patterns of junior high students' engineering graphics. The results of this study indicated that dimensioning was the most difficult task for junior high school students, especially on missing or misplaced dimensions. With this information, teachers can adopt an effective instructional method and provide directions for future lesson plans. Therefore, integrating the analytic module of students' errors in online learning can provide useful pedagogical information for engineering educators.

Based on this study, there are several directions that are worth pursuing. First, the same achievement test was used for the pre-test and post-test, which may threaten the internal validity of the study. Future studies should develop different achievement instruments to re-examine the present findings. Second, the feedback tools provided by the HappyCAD system were designed for junior high students, which may limit the ability to generalize the present findings. Additional feedback tools for promoting junior high students' engineering drawing in the online learning environment should be carefully considered in the future study. Third, the engineering graphics assignments presented in the HappyCAD system were from textbooks and were according to the grade levels of the participants. The advanced engineering graphics assignments were excluded from the study. Future studies should therefore compare the impact of advanced problems for students with different abilities. More, future developments may include the design and implementation of a unique application system incorporating a personalized learning approach through automatic recommendations.

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Appendix

Coding scheme of error patterns in engineering drawings

Category	Code	Item
Graphics drawing	G1	Too short
	G2	Too long
	G3	Angular error
	G4	Extra line
	G5	Missing line
	G6	Misplacement of circle center
	G7	Incorrect circle size
	G8	Incorrect circle shape
Line drawing	L1	Missing line
	L2	Incorrect line type
	L3	Line misplacement
	L4	Missing dotted line
	L5	Incorrect dotted line type
	L6	Misplacement of dotted line
Dimensioning	D1	Misplacement of extended dimension
	D2	Angular error in extended dimension
	D3	Incorrect length of scaled line
	D4	Angular error in scaled line
	D5	Incorrect labeling of scaled line length
	D6	Misplacement of dimension length label
	D7	Incorrect labeling of angle
	D8	Repeated dimension
	D9	Missing dimension
	D10	Incorrect diameter symbol
	D11	Incorrect radius symbol

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