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The effect of 3D-stereogram mobile AR on engineering drawing course outcomes among first-year vocational high schoolers with different spatial abilities: a Bloom's taxonomy perspective

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ABSTRACT
Engineering drawing is valuable in capturing geometric features, conveying engineering ideas, and creating a blueprint of the intended product. Engineering students usually perform orthographic projections, imagining a 3D situation and sketching its 2D representation. That requires imagination and mental visualization, determined by the learner's spatial ability. This study proposes the infusion of an AR stereogram mobile application into an engineering drawing course to establish how it influences learning outcomes among students with different spatial abilities. The quantitative experimental study involved two mechanical engineering classes in northern Taiwan, $N = 69$ first-year vocational high schoolers. Statistical analysis revealed that the experimental group with high spatial ability recorded better results and excellent drawing skills. Bloom's taxonomy categorization reported that spatial ability influenced "understanding" and "applying" levels, with the strongest effect on "understanding." Although no significant interaction existed, learning outcomes were highly affected by spatial ability in "understanding" and "applying" levels and AR in the overall performance. The findings and discussions show AR holds great potential to enhance students' spatial ability for real-time visualization and enables better concept comprehension by improving their understanding of engineering topics. Future studies should consider these implications in creating effective and immersive learning environments for different courses in engineering education.

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Spatial ability; learning outcome; augmented reality; orthographic projection

Introduction

There is a debate about whether drawing is a skill that comes with a natural ability or a nurtured talent. Students with innate drawing ability usually enjoy the drawing aesthetic and artsy graphics. However, in engineering, there is an applicable rule in the drawing principle (Chang, 2012). Mechanical drawing requires complex and precise regulation; a survey reported that rework on engineering drawing could be a stressor in the workplace (Chae et al., 2021). It is because errors are most likely to occur in a complex drawing (Rica et al., 2020). Realizing the pivotal role of drawing in engineering, this study aims to provide an alternative method of teaching how to draw in vocational high school.

Engineering drawing is a compulsory unit in the first-year vocational high school program. It enhances the ability to visualize objects from different angles and boosts engineering concept mastery (Ali et al., 2017). Over the past few decades, this skill has primarily been taught through

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teacher-centered traditional approaches where students sit passively, copying from the board, drawing, reading, or daydreaming (Rugarcia et al., 2000). However, in recent years, technologies such as the semantic web, gamification, cloud computing, multimedia, and augmented or virtual reality (VR) in education have been embedded in the learning process to improve students' experiences (Ali et al., 2017). Augmented reality (AR) is likely to reach a high penetration level because it no longer requires expensive hardware and sophisticated equipment (Mystakidis et al., 2022). Moreover, when delivered through mobile interaction, it creates superior pervasive experiences that are continuous in space, making the users aware of and responsive to both the context and pose compared to desktop-based AR or the head-mounted display virtual reality (Madeira et al., 2022). Hence, this study seizes the opportunity to offer such an experience to first-year students to complement their visual-spatial abilities through a mobile-based AR in the engineering drawing exercise.

AR offers an immersive interface that enables participants to interact with digital information embedded within the physical setting (Wang et al., 2018). By displaying virtual elements alongside real objects, AR facilitates observation of events that cannot be observed with the naked eye, thus increasing students' motivation and helping them to acquire better investigative skills (Akçayır & Akçayır, 2017). It also develops students' critical thinking and problem-solving, reduces cognitive load, engages learners, and makes them active participants (Papanastasiou et al., 2019; Wei et al., 2015). In addition, AR could also assist in developing spatial ability (Carbonell Carrera & Bermejo Asensio, 2017).

In this study, an AR-based mobile phone app. is embedded into the drawing class for vocational school. It aimed at offering an alternative teaching strategy to the upcoming engineers to nurture this critical skill for their future careers. The researchers considered spatial ability as a variable for an in-depth investigation. Spatial ability comprises spatial relations and visualizations, which are the mental manipulation of visual images and their parts in 2D and 3D (Cho & Suh, 2019). However, students' ability to visualize mental manipulation of graphical images is still a challenge because of poor training-age timing or inadequate teaching content (Olkun, 2003). Embedding AR in engineering courses assists learners in acquiring a better understanding and immersive experience, thus boosting their intellectual endeavors in visualizing and manipulating various engineering designs and geometric activities (İbili et al., 2020). AR's ubiquity and immersive nature makes it suitable for more accessibility and deeper engagement with the learning content, thus lowering or eliminating the need for physical 3D models to undertake the numerous tasks and exercises in each drawing unit. While VR can offer some of the listed merits, Hoe et al. (2019, p. 329) reported some distinguishing features of AR, as detailed in Table 1.

Many recent studies have explored spatial ability in AR for varied reasons, including teaching spatial skills (Lee et al., 2019), spatial cognition in engineering designs (Kwiatek et al., 2019), and improvement of spatial thinking (Johnson, 2019), to mention a few. From these studies, AR is an effective aid in acquiring or applying spatial skills. However, there are minimal efforts to leverage this technology and its relevant interventions to explore cognitive abilities and outcomes of learning in a skill-based course. Therefore, this research aims to narrow the constraints of poor teaching strategy, limited learning on the student's side, and boring class interactions by embedding AR in a first-year vocational high school orthographic projection course.

Table 1. Comparison of AR and VR (Hoe et al., 2019, p. 329).

AR	VR
1. User can see a mix of real and virtual environments	1. User is completely immersed in the virtual environment
2. Gives extra real spatial information as a reference	2. User cannot obtain additional spatial information from their surrounding environment
3. User has real motor perception and visual feedback from the 3D spatial visualization display	3. No real motor perception; all motor and visual feedback is computer – or machine-generated
4. User is not required to wear any equipment	4. User is required to wear equipment such as HMD
5. Affected by external light sources	5. Rarely affected by external light

The study applied Bloom's taxonomy in assessing learning outcomes since many educators across different fields have widely used this framework to state their learning intentions (Köksal & Ulum, 2018; Tíjaro-Rojas et al., 2016). It provides a ready-made structure of appropriate illustrative verbs which educationists consider very effective in evaluating the right graduate attributes (Meda & Swart, 2018). The researchers examined the students' visualization skills and learning outcomes regarding final course assessment test scores and actual drawing skills from worksheets. The instructional procedures and guidelines conformed to the taxonomy by outrightly indicating verbs consistent with the theory to ensure that learning outcomes were clear, observable, and measurable. This study anticipated that students would become active participants by interacting with AR objects and improving their engineering communication and knowledge construction.

Based on this study's aim, the researchers attempted to answer this question: Are there statistically significant differences in learning outcomes of experimental and control groups in an AR-embedded engineering drawing course at different levels of spatial ability among first-year vocational high school students?

Literature

Augmented reality on handheld devices

Through the years, new technologies have often enabled new education opportunities. For instance, computers in the classroom can enrich teaching or learning and boost student achievement more than teaching without such aids (Ebadi & Ashrafabadi, 2022). AR has already shown the potential to help students learn more effectively and increase knowledge retention than traditional 2D interfaces (Gargrish et al., 2021). Through AR, students understand complex phenomena, enhance their creative design, and strengthen their memory by providing unique visual and interactive experiences that combine real and virtual information to communicate abstract problems (Ebadi & Ashrafabadi, 2022; Wei et al., 2015).

Books and mobile games are the most popular AR applications for knowledge acquisition (Wei et al., 2015). AR print books extend the educational experience because their pages provide ideal images for AR visual tracking (Ebadi & Ashrafabadi, 2022). Examples of the implementation of ideal images of AR include engineering graphics education (Arulanand et al., 2020), civil engineering, architecture or building engineering (Alsafouri & Ayer, 2019), and engineering drawing courses in recent years (Ali et al., 2017). They have highlighted that learning processes that involve the latest technology positively affect students learning experiences. Thus, engineering students can use AR to improve visualization skills and mastery of engineering courses besides communicating engineering concepts and graphics (Zaid et al., 2022). A recent study has shown that AR is the best alternative to cover these issues (Ali et al., 2017).

The use of handheld devices such as smartphones and tablets has dramatically increased over the past few years, leading to a growing interest in mobile AR applications (Alsafouri & Ayer, 2019; Arulanand et al., 2020). Mobile AR is an appropriate teaching aid for engineering drawing courses because most students own smartphones (Ali et al., 2017). Moreover, learners can access a wide range of information and opportunities from various sources for more authentic learning through mobile AR (Arulanand et al., 2020). A study by Omar et al. (2019) showed that most students preferred using smartphones or tablets rather than desktops for engineering education visualizations. Similarly, Alzahrani (2020) pointed out that providing AR experiences on mobile devices can have unique benefits over offering non-AR content on the same topic. Arulanand et al. (2020) reported that it was hard to explain 3D geometry by drawing on paper or a whiteboard. Thus, using 2D images to teach spatial skills does not allow students to optimize their spatial ability skills because it only focuses on developing memory skills (Ali et al., 2017).

The inclusion of AR in this course was grounded on animate vision theory, which regards vision as a vital tool for a sensory exploration of the environment through a cycle of fragmentary perception

(Clark, 1998). In other words, "physical vision enables mental visualization." AR, therefore, provided a stimulating environment for learners to engage in spatial phenomena in many ways, as previously elucidated by Shelton and Hedley (2004). First, AR users retain their proprioception of self even while immersed in a virtual environment. Total virtual environments often neglect users' physical space in the real world (Smink et al., 2019), hindering their capacity to match virtual experience to the real world as required for external representation of the mental image in a drawing course. Secondly, the retention of sensorimotor function in AR allows the user to combine 3D objects in the virtual or physical environment without losing the advantage of either object or individual movement. Consequently, it triggers behaviors that help learners move or rotate the object, a core activity in this course. Thus, AR could significantly impact the teaching process because virtual objects and the real world co-exist while allowing students to manipulate and manage these materials (Wang, 2017). This study utilized virtual 3D images created in the AR mobile app interface to enable students to experience the mental rotation of real objects, which seems a better way to teach engineering drawing visualization and creative imagination skills.

Engineering drawing in vocational high school

Vocational education refers to a process with a curriculum in it that is tailored to the fields and expertise of students (Rosina et al., 2021). It equips the learners with practical skills, attitudes, understanding, and knowledge relating to occupations in aspects of economic or social life (Hassan & Maizam, 2017), whether in business or the industrial world. Thus, it is critical for the graduates of vocational schools to demonstrate and communicate the acquired skill sets to prospective employers or their colleagues in the field. For those specializing in engineering or technical courses, one way to achieve this is through technical drawing. Moses (2019) defines technical drawing as a universal language consisting of graphical symbols that lead to a pictorial representation of a designer's or engineer's vision in a physical form. Hence, engineering drawing plays a vital role in every sphere of engineering and technology.

Despite this, over the years, technical drawing has been taught by conventional methods that utilize drawing instruments like T-square, ruler, compass, and protractor to draw on the blackboard and paper. Hassan and Maizam (2017) listed the traditional teaching methods and lack of modern teaching aids as the major challenges to effective teaching of technical drawing in vocational schools. To explain this, Djohar and Komaro (2018) held that improper teaching material or inappropriate learning models in a mechanical engineering drawing could lead to dismal attainment of the learning goals, hence low achievement. Further, they noted that vocational trainers employ more teacher-centered approaches that are not innovative, leaving the facilities owned by students not fully optimized to support the learning process.

Two elements of the learning process are essential for its success: teaching methods and instructional media (Mujiarto et al., 2022). No single teaching style can work best or effectively for all teachers. However, vocational instructors should note that twenty-first-century learners are exposed to many advancements in digital technology that affect every aspect of their lives. Therefore, teachers should strive to adopt student-centered techniques that use these technologies in the learning process (Mostmans et al., 2012). Resultantly, students' motivation, competencies, and learning outcomes will be greatly enhanced. In technical drawing, cutting-edge multimedia helps to improve the learners' imagination and visualization (Mujiarto et al., 2019). Spatial visualization enables engineers and other technical specialists to manipulate mentally, rotate, twist, or invert pictorially-presented stimulus objects (Akasah & Alias, 2010). Thus, it is vital to enhance such skills among the upcoming engineers in vocational high school. AR is one way of strengthening spatial skills since it provides real-time 3D visual support by offering a complete blend of real and virtual environments (Hoe et al., 2019). Accordingly, this study leverages the AR technology on devices already owned by the students for interactivity and enhancement of spatial skills. It aims to mitigate the existing poor teaching methods and inappropriate media.

Spatial ability in engineering drawing

Spatial ability is a vital component of human intelligence that relates to the use of space. Basically, it refers to a collection of cognitive, perceptual, and visualization skills (Pujawan et al., 2020). Even though a disparity exists among researchers on conventional classification, most propose three main subfactors of spatial skills: spatial relations, spatial visualization, and spatial orientation (Murthy et al., 2015). Spatial ability, thus, instills in the learner (1) the ability to visualize the mental rotation of objects, (2) the ability to understand how objects appear in different positions, (3) the skill to conceptualize how objects relate to each other in space, and (4) 3D understanding.

Descriptive geometry, engineering concepts, and their applications require a higher level of visualization and imagination. Samsudin et al. (2011) posit that spatial visualization and mental rotation are essential for success in engineering, scientific and technical fields. This ability enables engineers to conceptualize the relations between reality and its abstract model (Tomc & Kočevar, 2020). Presently, engineering and visual communication has increasingly evolved with the emergence of cutting-edge digital technologies like computer graphics and other multimedia applications. Therefore, the spatial ability has become necessary in engineering-related subjects such as calculus, mathematics, computer-aided design, engineering drawing, and geometry. That means a better understanding of spatial ability and its influence would be potentially beneficial in shaping engineering education and profession.

This study recognizes that engineering drawing demands plenty of imagination skills and comprehension of the relationship between 3D objects and their 2D projections, which sum up to spatial abilities. The researchers grouped students into two levels of spatial ability (high and low) and compared the learning outcomes in the two clusters.

Augmented reality in 3D spatial visualization

Augmented reality has often been used as a visualization tool to enhance the learning experience (Schiavone, 2020). In engineering education, Dorribo-Camba and Contero (2013) found that AR significantly improved spatial visualization skills among learners. Engineering fields demand strong visualization skills to develop creativity and design capabilities (Ali et al., 2017). First-year engineering students may find drawing orthographic views and perspectives challenging when they cannot mentally construct 3D shapes from 2D views (Papakostas et al., 2021). Hence, it is vital to adopt an instructional approach and tools that enable them to see all the views perfectly and clearly to boost their understanding of engineering drawing concepts. AR, a complete blend of real and virtual environments, can provide real-time 3D visual support with the surrounding information, thus promoting spatial visualization and mental rotation (Hoe et al., 2019). That way, a link is created between perceptual-motor skills and visual cognition to enhance the students' perception awareness during spatial visualization. The orthographic projection topic covers visualization and mental rotation of objects from the front, side, and top views. Accordingly, this study applied a stereogram mobile AR technology, which reportedly motivates students during the learning process and enhances their visualizing skills (Omar et al., 2019).

Cognitive abilities in orthographic projection

Engineering drawing comprises views and dimensions, where "views" describe the shape while "dimensions" represent the size and relative distance of the object. To fully delineate the size and shapes of objects, it is requisite for all engineers, both in training and practice, to acquire a prior understanding of geometrical concepts of point, line, surface, and solid object. An orthographic projection is often helpful in instilling mastery of these basic concepts of geometrical space, especially in novice engineering trainees (Samsudin et al., 2011). In orthographic projection, views are drawn directly from the top, front, or sides to represent 3D objects as 2D drawings in a standardized manner. This process requires spatial visualization and mental rotation (Zaid et al., 2022). By examining and controlling instructional procedures in the orthographic projection unit, this study focused on cognitive processes associated with mental rotation and spatial visualization, which are core to its success.

The present study is guided by the cognitive information processing theory, which outlines processes, sequences, and structures through which an individual receives and stores information, emphasizing cognitive processes during learning. That entails processing instructional input to develop, test, and refine mental models until they are sufficiently elaborate and effective to cause relatively permanent changes in a problem-solving situation (Zhang et al., 2006). This exercise presumed that spatial visualization and mental rotation in orthographic projection drawing comprehensively applied cognitive information processing theory. Learners indulged in the construction of 3D mental representation in a sequence of multi-stage processes, including (1) manipulating given spatial information, (2) retrieving previously constructed mental image and modifying it, (3) constructing completely new representation, and (4) encoding external representation into an internal representation (Kok, 2018). These processes were executed repeatedly till the desired mental image was fully visualized and decoded through drawing on the worksheets. Recalling the assertion that learners' attention is limited and selective (Oberauer, 2019), this study postulated that a rich and interactive instructional environment occasioned by the AR would offer more flexibility to students who prefer self-directed and interactive learning styles to attain individual goals. By presenting this course to learners of varying spatial ability levels, the study also hypothesized differential performance among students regarding scores on worksheets and acquisition of actual drawing skills. That would manifest different cognitive abilities and accurately measure learning outcomes in an AR-integrated orthographic projection unit.

Learning outcomes are action verbs that enable instructors to document the skill sets they expect students to achieve at the end of the program (Nevid & McClelland, 2013). They include such words as analyze, apply, compare, define, describe, identify, demonstrate, and formulate. Learning outcome measurement requires a framework for classifying the intention or expectation from students due to instruction. One such framework is Bloom's taxonomy, which provides carefully developed definitions for each of the six major categories in the cognitive domain: knowledge, comprehension, application, analysis, synthesis, and evaluation. The taxonomy is hierarchical in that each level is subsumed by higher levels (Forehand, 2010). Later Bloom's six major categories were changed from noun to verb form; remembering, understanding, applying, analyzing, evaluating, and creating with the following meanings (Forehand, 2010):

- *Remembering:* Retrieving, recognizing, and recalling relevant knowledge from long-term memory,
- *Understanding:* Constructing meaning from written, and graphic messages through interpreting,
- *Applying:* Use procedure through executing or implementing,
- *Analyzing:* Breaking materials into constituent parts and how parts relate to each other,
- *Evaluating:* Making judgments based on standards through critiquing, and
- *Creating:* Putting elements together to form a functional whole (Forehand, 2010).

Memorization and recall are lower-order cognitive skills (LOCS) because they only require a minimum level of understanding. In contrast, the application of knowledge and critical thinking are high-order cognitive skills (HOCS) that need deep conceptual understanding (Su, 2021). Bloom's taxonomy has been widely used across disciplines to align course objectives and classify educational goals to the level of skills achieved (Nevid & McClelland, 2013). For instance, to measure the impact of flipped anatomy classroom (Morton & Colbert-Getz, 2017), instructional objectives in introductory psychology (Nevid & McClelland, 2013), and to evaluate the usability of AR-based educational application (Weng et al., 2021).

This paper used three lower levels of Bloom's taxonomy, including remembering, understanding, and applying, as a framework for exploring learning outcomes in an AR-embedded engineering drawing course. LOCS was most suitable for assessing outcomes because the participants were first-year students taking an introductory course that only required a quick grasp, recall, and understanding of basic facts and concepts before applying them later in the course. This study compared the experimental and control groups among first-year vocational high schoolers with varying spatial abilities.

Proposed augmented reality (AR) learning system

The AR content originated from the engineering drawing textbook's orthographic projection unit. The objective was to let students compare the rotation of the 3D model and visualize the three views of the 3D model; front view, side view, and top view, as illustrated in Figure 1, and lastly, draw the correct model in three views on their own.

AR content development utilized a Unity3D (game editor) and Qualcomm's Vuforia (augmented reality kit) with JavaScript as the interaction environment. The final 3D AR could be rotated, switch modes; front view, top view, and side view, and finally zoomed in and out.

Each student in the experimental group used AR to augment the real-world learning system, rotate the 3D object, switch viewing modes, and learn how to map and zoom, enhancing their visual-spatial processing ability. During the whole exercise, students worked individually using their smartphones. By the end of the lesson, the learner should have drawn a 3D model showing a vertical plane and single and complex slopes in an orthographic view. Figure 2 shows a student in the experimental group interacting with AR content.

After the final course assessment test, the control group also tried out the AR stereogram in their engineering drawing to learn, experience, share their feeling with the rest, and eliminate the impression that they were discriminated against or left out.

Methodology

Participants

A total of 69 first-year mechanical engineering students at a vocational high school in northern Taiwan participated in this experimental study. The topic was "orthographic projection," a drawing unit requiring students to visualize and draw 3D objects. The participants were randomly assigned into two classes, experimental (33) and control (36). They were further stratified into two

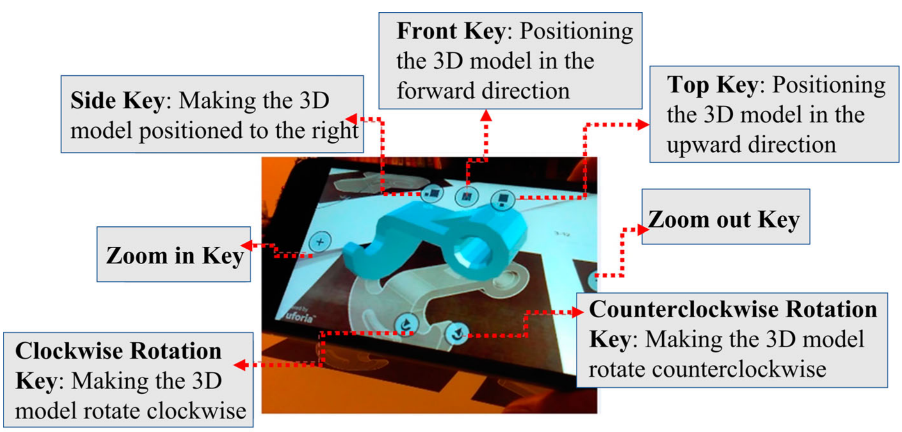

Figure 1. Augmented Reality of 3 view angles with a stereo rotation.

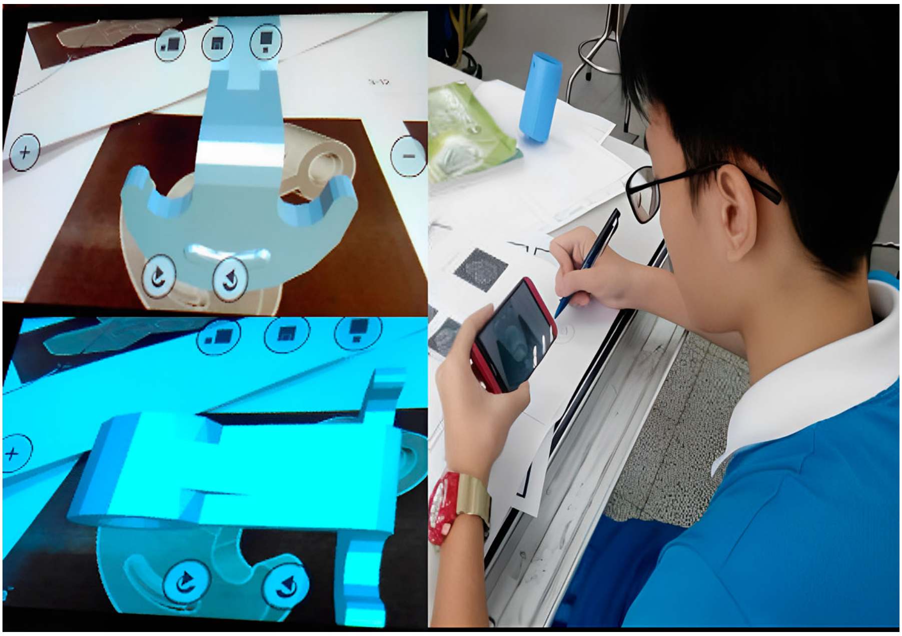

Figure 2. A Participant interacting and drawing using AR stereogram.

levels of spatial ability, high and low, with 17 students each, totaling 34 students for analysis. That was achieved by taking 25% of top students in both classes as high spatial ability and 25% of low students as low spatial ability after a spatial test (*See the study design section for details*). Before commencing the study, all participants received a consent form and were advised on the voluntary nature of the research. All of them were encouraged to work alone till the end of the six lessons.

Study design

This experimental research involved two already existing classes, each divided into groups, A and B. Group A from both classes jointly formed the experimental class/ group, while B was the control group. The teacher in the experimental group taught orthographic projection using the integrated AR stereogram and drawing worksheets. Conversely, the control group used the conventional lecture method and drawing worksheets. The task in both worksheets was identical, except that the textbook and models used by the experimental group had an artificial label to enable rotation and interactivity with the stereogram mobile AR. The two classes ran concurrently. At the end of each lesson, teachers in respective classes gave feedback to the students by reinforcing weaker concepts, clearing misunderstandings, and providing positive comments to encourage them to learn. The students took a spatial ability test in the first week for categorization and a course assessment test in the last week to gauge learning outcomes. For analysis of spatial ability, 25% of top students in the experimental group had 8 participants with high spatial ability. Otherwise, 25% of low students had 8 participants with low spatial ability, totaling 16 participants. Similarly, 25% of top students in the control group had 9 participants with high spatial ability, and 25% of low students had 9 participants with low spatial ability, totaling 18 participants. The objective of the tests was to explore the influence of different teaching methods and spatial ability on learning outcomes, both overall and at the first three levels of Bloom's taxonomy hierarchy of cognitive skills. The research framework is shown in Figure 3.

Experimental procedure

Before the experiment, the researchers trained the teachers on the operation of the 3D AR stereogram on a smartphone (see Figure 3). Further, both teachers received the same lesson plans and training schedules to ensure that their classroom practice and learning content aligned with the research design. At the onset of the study, all participants in their respective classes undertook a spatial ability test for 27 minutes to rate their spatial ability levels and categorization. The experimental group used smartphones with a stereogram AR app during the lessons, while the control group used the lecture method. Each lesson began with instructions from the teacher to the class and a systematic demonstration of the 3D drawing concept in orthographic projection to enable the students to grasp the general purview of the unit. Next, the experimental group used the stereogram mobile AR app and worksheets for 3D visualization of the reality integrated with the virtual. In contrast, the control class used a normal view of 2D drawings from the textbook with a manual worksheet to perform the task. Each lesson lasted one hour weekly for six weeks, a total of 6 lessons for the entire unit. During the final class in week 6, the researchers concluded the scheduled activities and administered the final course assessment test to all participants. The teachers also reviewed and scored all drawing sheets to evaluate students' general performance in this unit.

Measuring instruments

Spatial scale

The spatial ability test had 20 items adapted from Vandenberg and Kuse (1978) as its measure of mental rotation ability among middle-school students was accurately compatible with the aim of this study. The Cronbach's α coefficient for overall spatial ability in the present study was α = .91, implying strong reliability and consistency of the scale. The items were related to 3D object rotation and 3D spatial organization, which are core to successful spatial visualization in orthographic projection (Samsudin et al., 2011). A correct answer got 1 point, whereas a wrong answer was zero. The

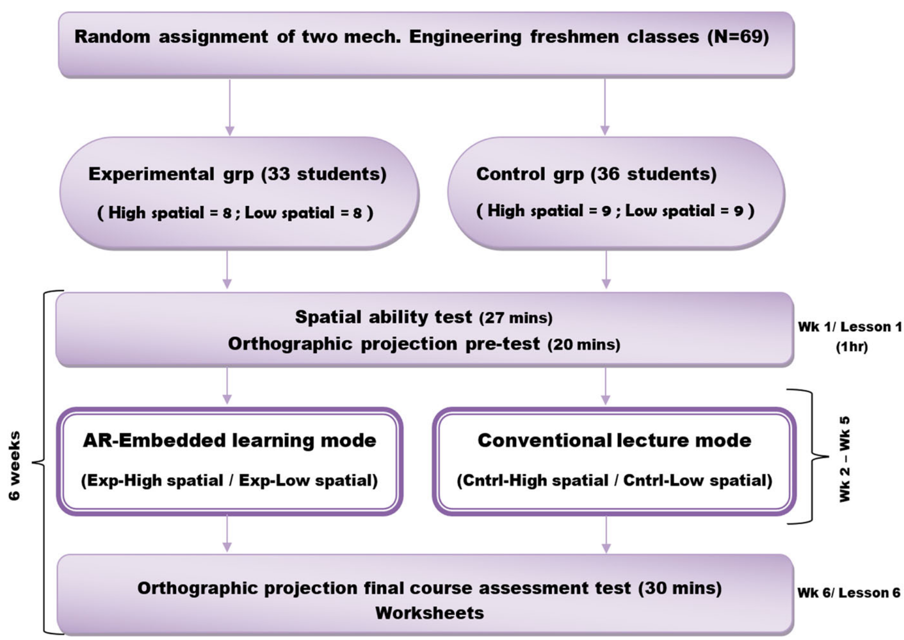

Figure 3. Study framework.

purpose of this test was only for categorization during the analysis. An example item was "select the correct right-side view in the direction shown by the arrow."

fx1

Weekly worksheet

Worksheets were useful in assessing the conceptual understanding and learners' actual drawing skills of orthographic projection views. Each worksheet consisted of 3 drawing questions arranged according to the three domains of cognitive ability: remembering, understanding, and applying. The questions were the same for both classes. Two teachers did the preparation and classification of these drawing questions to those domains. One was a university professor who had taught engineering drawing and had engaged in this kind of research for more than ten years. The other was a teacher at the vocational high school where the study was conducted with six years of experience teaching this course. Cohen's kappa coefficient denoted the inter-rater reliability between the two, $\kappa = .913$ implying strong agreement. Hence, the study assumed that the questions perfectly fit into those domains. Students received worksheets weekly during the lesson time for six weeks, completed them individually, and collected them in class. The teachers awarded scores to correct lines and positions; otherwise, a zero score. The total time to answer each worksheet was approximately 25 minutes, with each worksheet scored out of 30 points.

Final course evaluation test

This study used 20-item multiple-choice test questions on an orthographic projection unit adopted from the standardized test for vocational high school engineering drawing basics, designed and developed by the Sanfoundry global education platform. The same test was administered to both groups to ensure uniformity. The items were based on Bloom's taxonomy's first three levels: remembering, understanding, and applying. Remembering items consisted of questions based on recalling what students had learned from the unit. Understanding items measured students' ability to construct and interpret meanings from graphical illustrations. The application items measured students' ability to carry out correct procedures and implementation on 3D objects and their 2D projections.

Three experts classified these items; two were teachers in the vocational high school who have been teaching there for more than six years, while one was a university professor with experience and relevant background information on this kind of research. The three agreed on classifying items into three categories; remembering had items 1–6, understanding 7–13, and application 14–20, as shown in Table 2. It is key to note that the experts had different scores on the scale. Thus, for intragroup similarity of their scores, the researchers computed Kendall's W coefficient of concordance, yielding $W = .86$, $p < .05$, meaning they were homogenous and highly associated. Therefore, the items were fit to measure the learning outcomes. Examples of test items under the three domains included:

(1) . Where is the viewpoint of the orthographic projection?

Table 2. Final course evaluation test classification.

Item	1. Remembering	2. Understanding	3. Applying
Numbering of test questions	(1)	(7)	(14)
	(2)	(8)	(15)
	(3)	(9)	(16)
	(4)	(10)	(17)
	(5)	(11)	(18)
	(6)	(12)	(19)
		(13)	(20)
Number of questions	6	7	7

(A) **At the observation point.** (B) Near the observation point. (C) Is double the distance. (D) At infinity

(2) What is the view in the orthographic projection if the object is further from the projection surface?

(A) Bigger. (B) Smaller. **(C) Unchanged.** (D) A point (very small).

(3) In orthographic projection, an object is represented by two or three views on different planes which __?

(A) a viewer can visualize different angles from different directions.
(B) **are mutually 900 from the projection planes.**
(C) are parallel but at different cross-section
(D) are found by taking prints from 2 or 3 sides of object.

A correct answer got 1 point, while a wrong answer got zero.

Findings

Spatial ability test

Since spatial ability was a classification criterion in this study, the researchers ascertained if there existed any significant differences between the two groups using an independent sample t-test. That was preceded by Levene's test that showed $F = 1.28$, $p = .31 > .05$, implying a homogeneity in variance between them. Further, the t-test yielded $t(67) = .721$, $p = .473 > .05$, which was insignificant. The results meant that although the experimental group ($M = 18.23$, $SD = .489$) seemed to have higher spatial abilities than the control group ($M = 16.62$, $SD = .613$), those differences had no statistical implication or bias in this study. So, the spatial ability was only used to categorize the participants during the analysis.

Worksheet

Descriptive statistics results indicated that students from the experimental group with high spatial ability had the highest scores ($M = 28.8$, $SD = 1.577$) from the worksheets, followed by the control group with a high spatial ability ($M = 26.4$ $SD = 1.645$). The lowest scores were from low spatial ability in the control group ($M = 22.4$, $SD = 1.893$), as Table 3 illustrates. That shows that AR and high spatial ability enabled learners to acquire salient skills in orthographic projection drawing.

Table 3. Mean of students' overall learning outcome between levels and groups.

	Spatial Ability level ($\eta^2 = .25$)		
Group ($\eta^2 = .16$)	High	Low	*N*
Experimental	**16.25**	**12.88**	16
Remembering	4.88	4.22	
Understanding	7.00	5.50	
Applying	3.75	2.63	
Worksheet	**28.8**	**24.9**	
Control	**13.56**	**11.44**	18
Remembering	4.38	3.89	
Understanding	6.33	5.22	
Applying	3.11	2.24	
Worksheet	**26.4**	**22.4**	
N	17	17	**34**

Final course assessment test

The results from the final course assessment in Table 3 show that learners in the experimental group with high spatial ability outperformed all the rest ($M = 16.25$), followed closely by those in the control group with high spatial ability ($M = 13.56$). Learners of low spatial ability in the experimental group were moderately low performers ($M = 12.88$), while those with low spatial ability in the conventional teaching class registered the least scores ($M = 11.44$). Notably, high levels of spatial ability were synonymous with higher scores than low spatial ability. Similarly, the experimental group performed better than the control group, a trend maintained across all three levels of Bloom's taxonomy, with the "understanding" level recording the highest scores. That implied the possibility of a special relationship between spatial ability and AR in this drawing course. The researchers then scrutinized the variables in this study to confirm if there was any statistical significance behind this pattern.

Learning outcomes between different teaching strategies and different spatial abilities

A Two-way ANOVA was conducted at a confidence interval of 95% to explore the differences in learning outcomes between the groups and varying spatial abilities. Thus, a *p*-value of .05 was set as the level of significance. A prior Levene's test of students' overall learning outcomes yielded $F = 1.41$, $p = .24 > .05$, confirming the homogeneity of variance between the groups. The findings in Table 4 depict no significant interaction between groups and spatial ability levels ($F(1,30) = .54$, $p = .47 > .05$). Thus, this study used the main effect to explain the differences between the independent variables under respective conditions. From the results, main effects for both the groups and spatial ability levels were statistically significant with $F(1,30) = 5.73$, $p = .02 < 0.05$ for the groups and $F(1,30) = 10.13$, $p = .00 < 0.05$ for spatial ability. It means that learning outcomes depend on the teaching strategy employed (conventional or AR-embedded) and the level of spatial ability exhibited. However, spatial ability had greater influence denoted by higher effect size (Partial $\eta^2 = 0.25$) than the groups, Partial $\eta^2 = 0.16$.

Further, an in-depth investigation with learning outcomes categorized into three (3) levels of Bloom's taxonomy followed. The aim was to establish whether the infusion of AR into an engineering drawing course and learners' levels of spatial ability had a meaningful impact on any of these hierarchies of cognitive skills.

Bloom's taxonomy – "Remembering"

The first level, "remembering," reported a homogeneity in variance as confirmed by an insignificant Levene's test result, $F = .29$, $p = .59 > .05$. A Two-way ANOVA followed. As illustrated in Table 5, there was no significant interaction effect between the groups (AR or Conventional) and spatial ability (High or Low) with $F(1,30) = .72$, $p = .40 > 0.05$. That necessitated the use of main effects to explore the differences in either teaching strategies or level of spatial ability. As seen, main effects for both groups ($p = .26 > .05$) and levels of spatial ability ($p = .87 > .05$) yielded insignificant effect

Table 4. Two-way ANOVA of overall learning outcome between the two groups with different spatial abilities.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2
Corrected Model	101.65[a]	3	33.88	5.38	.00	.35
Intercept	6203.68	1	6203.68	985.65	.00	.97
Group	36.03	1	36.03	5.73	.02	.16
Spatial ability	63.74	1	63.74	10.13	.00	.25
Group*Spatial ability	3.38	1	3.38	.54	.47	.02
Error	188.82	30	6.29			
Total	6460.000	34				
Corrected Total	290.47	33				

[a]R Squared = .35 (Adjusted R Squared = .29).
Dependent Variable: Overall learning outcome.

Table 5. Two-way ANOVA of "remembering" level of Bloom's taxonomy.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial η^2
Corrected Model	4.25[a]	3	1.42	.69	.56	.11
Intercept	638.28	1	638.28	312.91	.00	.90
Group	2.75	1	2.75	1.35	.26	.03
Spatial ability	0.06	1	0.06	.03	.87	.00
Group*Spatial ability	1.47	1	1.47	.72	.40	.08
Error	61.20	30	2.04			
Total	701.00	34				
Corrected Total	65.44	33				

[a]R Squared = .11 (Adjusted R Squared = .02).
Dependent Variable: "remembering".

in the "remembering" category. It implies that the difference in learning outcomes was neither an influence of the teaching strategy nor levels of spatial ability at the "remembering" level.

Bloom's taxonomy – "Understanding"

In the "understanding" category, Levene's test yielded $F = 1.28$, $p = .26 > .05$, confirming evenly spread data. Further, there was no significant interaction effect between the groups (AR or conventional) and spatial ability with $F(1,30) = .18$, $p = .68 > .05$, as detailed in Table 6, prompting the use of main effects to explore the differences in learning outcomes. Only spatial ability had a statistical significance with $p = .01 < .05$. Teaching strategy did not exhibit any significance by reporting $p = .31 > .05$. It implied that the difference at this Bloom's taxonomy level was mainly because of varying spatial abilities and not instructional strategy employed. Those with high spatial ability performed better than low spatial ability.

Bloom's taxonomy – "Applying"

For the "applying" level, this study confirmed an equal variance due to insignificant Levene's test result, $F = 1.16$, $p = .29 > .05$. Also, there was no significant interaction effect between the groups and the spatial ability levels with $F(1,30) = .01$, $p = .93 > .05$, as shown in Table 7. Main effects were therefore used to explore the differences in learning outcomes. The teaching strategy (AR or conventional) was statistically insignificant, with $p = .24 > .05$. Else, the varying levels of spatial ability were significant, with $p = .04 < .05$. This finding implies that at the "applying" level of cognitive skills for this drawing course, differences in learning outcomes were not a result of the teaching strategy but rather the learners' levels of spatial ability. Students with high spatial abilities outperformed those with low spatial abilities.

Both "understanding" and "applying" levels of Bloom's taxonomy were statistically significant regarding spatial ability. However, it was apparent that the "understanding" category had a larger effect size of **partial $\eta^2 = .21$** compared to the "applying" level **partial $\eta^2 = .12$**. It indicates that

Table 6. Two-way ANOVA of "understanding" level of Bloom's taxonomy.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2
Corrected Model	16.44[a]	3	5.48	3.07	.04	.24
Intercept	1225.42	1	1225.42	686.44	.00	.96
Group	1.89	1	1.89	1.06	.31	.03
Spatial ability	14.44	1	14.49	8.09	.01	.21
Group*Spatial ability	.32	1	.32	.18	.68	.01
Error	53.56	30	1.79			
Total	1294.00	34				
Corrected Total	70.00	33				

[a]R Squared = .33 (Adjusted R Squared = .26).
Dependent Variable: "understanding".

Table 7. Two-way ANOVA of "applying" level of Bloom's taxonomy.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η^2
Corrected Model	15.78[a]	3	5.26	1.85	.16	.16
Intercept	274.00	1	274.00	96.53	.00	.76
Group	4.00	1	4.00	1.41	.24	.05
Spatial ability	11.67	1	11.67	4.11	.04	.12
Group * Spatial ability	.020	1	.020	.01	.93	.00
Error	85.15	30	2.84			
Total	372.00	34				
Corrected Total	100.94	33				

[a]R Squared = .16 (Adjusted R Squared = .07).
Dependent Variable: "applying".

learners' spatial ability influences their understanding and application of concepts in this engineering drawing course. Still, the effect is greater on the "understanding" level.

Discussion and conclusion

This study proposed the integration of augmented reality (AR) into an engineering drawing course in vocational high school to explore how it impacted the learning outcomes exhibited by the learners. The researchers also stratified the students into two levels of spatial ability (High and Low) to showcase if this quality could have been an influential determinant of learning outcomes.

From the empirical results, students in the experimental group with high spatial ability displayed better drawing skills of orthographic projection views on the weekly worksheets. It confirms that AR created a stimulating environment for engaging in spatial phenomena, leading to accelerated visualization processes, enhanced mental rotation accuracy, and acquisition of better cognitive abilities and skills to perform orthographic drawing (Samsudin et al., 2011; Shelton & Hedley, 2004).

Another striking revelation was that the experimental group (AR) recorded relatively high scores compared to the control group in the final course assessment test. However, it was interesting that statistical significance was only registered on the overall learning outcome but not at the three levels of Bloom's taxonomy. The effect sizes for individual levels were probably too small to cause an impact in isolation. Else, when considered collectively, they created a stronger effect size to cause significance in overall outcomes. Also, a recent study by Thees et al. (2020) found that utilizing AR in a temporal contiguity scenario, like in this study, did not show any significant difference in the cognitive knowledge test. It instead had a greater impact on the affective domain, such as motivation and attitude. Since Bloom's taxonomy dwells on the cognitive domain, the diminishing significance likely resulted from viewing outcomes along hierarchies of cognitive skills. Perhaps higher scores by the experimental group herein emanated from the fun, enjoyment, motivation, and engaging nature of the classroom experience created by this novel technology for a drawing course.

This study further established that learners with high spatial ability performed better than those with low spatial ability across the groups. The finding is similar to that of Hannafin et al. (2008), who reported significantly higher performance in a geometry course among students of high spatial ability. By categorizing learning outcomes into levels of Bloom's taxonomy, the research revealed that spatial ability only influenced students' "understanding" and "applying" levels. The non-significance in "remembering" was perhaps because, at that stage, learners only needed to recall, memorize, repeat and duplicate information which they could easily achieve without any comprehension. On the contrary, "understanding" and "applying" levels require deep conceptualization, mental visualization, manipulation, and formulating connections and links, all of which are enabled by spatial skills. A uniform trend of optimal scores by learners of high spatial ability and taught using the AR application was observed. However, it is imperative to recall that there was no interaction effect between the groups and spatial ability; hence, this pattern could indicate a possible relationship that this research did not reveal. Perchance the discord arose from the relatively low sample size and the smaller screen sizes of the smartphones utilized in this exercise. The teachers' observation and report showed that the participants spent much time performing the task through narrow screens and were occasionally wary of power consumption. That could have hampered their overall productivity and output regardless of spatial ability level or teaching strategy.

Implications to practice

This study has evidently proved that digital learning and the integration of novel technologies in instruction extend traditional learning boundaries and offer an avenue toward attaining greater academic success. Embedding AR in this engineering drawing course has yielded better learning outcomes. Therefore, curriculum designers and teachers should leverage such multimedia strategies to enrich the content and depth of learning materials. The approach creates an interactive and exciting classroom environment by adding layers of digital information to what we can see through the naked eye. That makes learning content more engaging, immersive, and easier to grasp. AR is also a great visualization aid in education that unlocks the learners' imagination potential and creative thinking faculties leading them to formulate valuable links between the virtual and real-world, a requisite characteristic for learners in the twenty-first century and beyond. As a rich source of motivation and conscious of its universal applicability across numerous subjects and curricula, this study recommends the integration of AR into the learning process for subjects requiring imagination and mental visualization. In addition, the spatial ability has proved a great impetus to learning in this drawing course. Even though there was no interaction between spatial ability and AR in this study, spatial ability significantly impacted overall learning outcomes and "understanding" and "applying" levels of Bloom's taxonomy. That makes it an essential attribute, especially for science and technical subjects. Another fundamental aspect is the teachers' observation of learners' challenges with their mobile devices as they navigated the software interface to accomplish this task. The researchers, thus, advise instructional designers and teachers that while adopting AR in pedagogy, they should concentrate on the design and content of the software and pay considerable attention to the choice of delivery hardware. Devices with a larger screen and low power consumption could accord learners a more conducive environment to perform the assigned tasks, maximizing learning outcomes.

Limitations and future research

Despite the numerous benefits of AR in engineering drawing courses, as posted by the findings of this study, a few challenges existed. First, this study only considered one unit of drawing course undertaken in just a few lessons. While the outcome is a valuable pointer that spatial ability influences learning in an AR-integrated course, more research is still needed to reduce the learning differences between students with different spatial ability levels. Studies in the future should expand the scope by applying it in the entire course, other subject areas, or involving students of different ages and levels to draw comparative deductions. Also, extending the exercise duration could allow students ample time to complete all the tasks effectively. Secondly, the size and power consumption of mobile devices used in this research seemed problematic to students during the interaction with the 3D models and orthographic projection drawing. As the course required numerous instances of taking measurements and rotations, performing it on smaller screens of smartphones appeared tedious and inconvenient. In addition, the battery life for the devices when running the AR app. was far too short, sending learners into panic mode, hence performing the tasks hurriedly or not being able to complete the task(s). In the future, devices of low power consumption and wider screens, for instance, iPads, should be used to ascertain if there could be an improvement in learning outcomes. Finally, this study only employed quantitative statistical techniques in exploring learning outcomes. However, there were strong indicators that other human aspects like attitude, interest, or motivation could have influenced learning outcomes in AR embedded strategy. Future work should consider conducting an in-depth qualitative analysis to get a broader perspective of such behavior-related characteristics and their impacts on AR-aided learning.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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