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Some Results and Evaluation of Training for the Development of Students' Spatial Visualization

Suvd Erdenechimeg
School of Civil Engineering and Architecture
Mongolian University of Science and Technology
Ulaanbaatar, Mongolia
suvd.e@must.edu.mn

Ganbat Danaa*
Open Education Center
Mongolian University of Science and Technology
Ulaanbaatar, Mongolia
ganbatda@must.edu.mn

***Abstract*— This article discusses the results and evaluation of a training course focused on developing spatial visualization using interactive dynamic tools. The course aims to effectively integrate technology with the Descriptive Geometry course by combining content, pedagogy, and technology while considering the course's characteristics. The training course consists of three phases: seeing, imagining, and drawing. Each phase has different tasks that involve manipulating 3D objects in a virtual environment, corresponding to the level of geometric thinking and cognitive steps of mental rotation. The results of the organized training showed a statistically significant increase in student's spatial skills, and the evaluation of students using the SURE (Structure-Oriented Evaluation) model was deemed sufficient.**

Keywords*— *Mental rotation, spatial ability, SURE model, learning model, spatial transformation, spatial visualization

I. Introduction

In modern education, there is a shift from the traditional teaching paradigm to the learning paradigm. A key aspect of student-centered learning is the outcome-based approach, which focuses on what the student is capable of after completing the training program [1]. In this context, 21st-century students' basic learning skills include communication skills, which encompass verbal, written, and graphic communication skills [2].

According to research, graphic communication makes up 92% of all engineering activities, while mathematical calculations and oral and written communication account for the remaining 8% [3]. Graphic communication is the process of using representations, illustrations, and graphics to convey information visually during the implementation of engineering ideas and solutions. The primary language of graphic communication is engineering drawings represented by projection, and the basis of engineering drawing theory is known as "Descriptive Geometry" [4].

When reading and processing engineering drawings, the human brain processes spatial information. The method of processing spatial information depends on how the information is received, such as through listening, seeing, or haptic means. Since spatial information is received in different ways, individuals process it using their spatial abilities [5].

In our research, it is important to consider the processing of visual information in detail. This requires a thorough examination of the complex concept of visuospatial working memory. This type of memory processes visual information, including colors and images, as well as their positioning and movement, enabling individuals to encode, recall, and manipulate the information. Neuroscience research indicates that the human brain processes visual information in two primary ways: "space" and "object." The object-based processing is based on color, shape, size, and structure, while spatial path processing involves transformations, transitions, and movement [6].

The processing of spatial information depends on an individual's spatial ability. According to Howard Gardner's multiple intelligence theory, spatial ability is considered an important independent ability of human intelligence [7]. Spatial ability enables individuals to read, understand, visualize, and manipulate spatial information. It is a complex structure that includes various components, such as spatial visualization, spatial orientation, spatial relations, mental rotation, and spatial perception. Although subcategories are often considered, researchers have not yet come to a single decision on the categorization of spatial ability.

McGee [8] categorized spatial ability into two main components: spatial orientation and spatial visualization. Tartre also considers the same two categories, but includes mental rotation and mental transformation as subcomponents of spatial visualization [9].

Spatial visualization refers to the ability to mentally manipulate two- and three-dimensional figures. It involves the ability to mentally rotate, twist, transform, and control stimuli given by figures. On the other hand, spatial orientation is the ability to find one's direction without doubt when changing direction in space [8]. Spatial visualization involves mentally moving an object, while spatial orientation refers to the ability to mentally change the direction of vision when an object in space is stationary. Mental rotation is the ability to rotate the entire object in space, whereas mental transformation involves transforming and changing a certain part of the object [10], [11]. According to a longitudinal study conducted by Sorby, a researcher at Michigan Technological University, between 1993 and 2012, which included more than 7,000 students over a period of 19 years, students with high levels of spatial visualization were more likely to successfully study engineering courses and graduate from the university compared to students with low abilities [12]. Since individual abilities differ, it is important to provide opportunities for individuals to develop their spatial abilities, interact with spatial information, and process it effectively. This should be a significant goal of education [13], [14].

The focus of this study is to discuss spatial visualization and explore the possibility of developing it through the Descriptive Geometry course. The study will involve conducting an experiment to observe the growth of students' spatial visualization skills and to evaluate their feedback regarding the training.

II. DEVELOPMENT OF A TRAINING MODEL

To develop spatial visualization skills through the Descriptive Geometry course, the training program consists of three phases: seeing, imagining, and drawing. Each phase includes different tasks that involve manipulating 3-D objects in a virtual environment, corresponding to the level of geometric thinking and cognitive steps of mental rotation [15]. The methodology for delivering content will utilize interactive dynamic tools to ensure an accurate combination of the content and training (GeoGebra) (Figure 1).

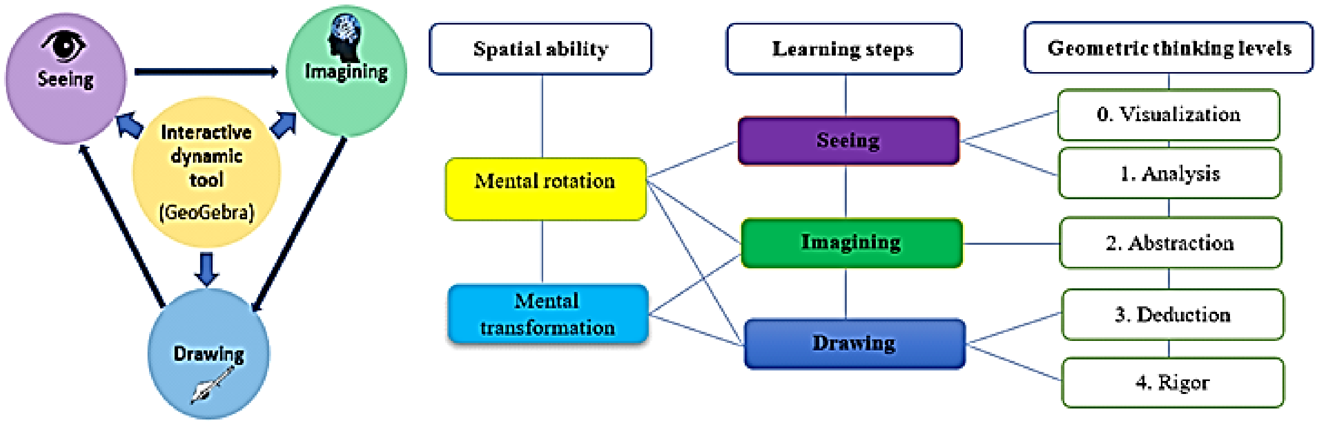

Fig. 1. Relationship diagram among the subskills of spatial visualization and geometric thinking levels with the learning steps.

The Descriptive Geometry course aims to develop spatial visualization skills by providing students with systematic geometric thinking. Students create knowledge through their own intellectual activities, based on cognitive and information processing theories. Geometric thinking has five levels, which are as follows: 0. Visualization: The ability to identify and name geometric elements in terms of shapes; 1. Analysis: The ability to name the elements of geometric shapes and distinguish them by their characteristics; 2. Abstraction: The ability to understand the interrelationship and definition of geometric elements; 3. Deduction: The ability to think about how to apply axioms and theorems, deriving a problem; 4. Rigor: The ability to explain and prove the problem, which involves training students in geometry [16]. Angel conducted a study on 3-dimensional geometry in relation to Van-Hiele's level of geometric thinking and spatial ability [17]. In high school geometry training, he organized a course in relation to the level of geometric thinking and spatial ability. There are also experiences of van Hiele teaching methods combined with the level of geometric thinking in teaching [12]. Since descriptive geometry involves manually solving problems in three-dimensional geometry by generating two-dimensional views (projections), students must be able to perform mental rotations to read and understand projections [18]–[21]. Once the projection is read and understood, it becomes possible to visualize the geometric elements and solve their spatial relationship and dimension problems. Throughout each stage of the Descriptive Geometry course, mental rotation is carried out with the help of interactive dynamic tools, which are designed to correspond to each level of geometric thinking. For example, in the seeing section, students are asked to closely examine a virtual geometric element and encode it in their mind. In the imagining phase, tasks such as rotating and comparing how that geometric element can be represented by orthogonal projection are performed. Since the information related to the geometric elements is sufficiently understood from the projection, the drawing stage involves tasks to think about the actions to be performed on the elements, spatial relationship and dimension problems, and verifying their solutions (Table I).

TABLE I. RELATIONSHIP OF TASKS TO DEVELOPMENT OF SKILLS FOR ROTATIONS IN MIND AND TRANSFORMATION IN MIND

Tasks	Goal	Reasons	A cognitive steps of mental rotation	Geometric thinking levels	Tests
			Seeing		
Manipulate 3D virtual objects and observe them from multiple views.	Observe the 3D virtual object until it is retrieved and visualized in your mind.	Observing 3D virtual objects from multiple views will help you encode them in their minds.	Encoding (to form a mental representation of an object).	Visualization: identifying and naming geometric elements in terms of shape and image, Analysis: Name the elements of geometric shapes and distinguish them by their characteristics	Rotation-PSVT

Imagining					
Rotating an object in an orthogonal direction (perpendicular) to the projection plane. Visualize a 3D virtual object by comparing it with orthogonal projections and identify the correct answer in a multiple choice test.	To support the visualization of 2-dimensional to 3-dimensional and vice versa by comparing virtual objects with their projections, and to be able to read projections.	Viewing a 3D object upside-down can help you determine how it would appear in an orthogonal projection. Comparative reading of multi-dimensional projection images promotes the development of 2D to 3D and vice versa	Rotation (to rotate the object mentally) Comparison (Make a comparison- Compare that the projection corresponds to the object)	Abstraction: Understand the interrelationship and definition of geometric elements; Comparison: (Comparison of the mutual location of the projection plane and surface and relative points, lines, planes and surfaces)	Rotation – PSVT View-PSVT
Drawing					
Solve problems given by projections	Familiarize yourself with the order and methodology of problem solving, think about problems, and check the correctness of your answers	Since the object can be imagined from the projection, it becomes possible to easily understand the geometric operations performed on it	To form a mental representation of an object; To rotate the object mentally; To make the comparison; To make a judgement; Report a decision	Deduction: Thinking about how to apply axioms and theorems, making a policy solution, Rigor: Explain and confirm the policy	SBST PSVT

Analyzing how individuals solve real spatial problems is crucial in organizing training and preparing tasks to develop these skills [22]. People solve spatial problems in different ways, and the strategies they use change depending on the level of the task [23], [24]. However, it is challenging to determine exactly how the task executor found the solution, and this type of research is rare. Currently, there are several methods used to find strategies to solve tasks. The most widely used method is the introspective method. Other methods aim to detect task performance strategies by monitoring and analyzing response times and eye movements.

It seems that understanding the cognitive steps of mental rotation is crucial, as it has been discovered that performing mental rotation is necessary for reading projection. To complete this type of task, complex and analytical strategies are utilized [25]. Compounding requires the parallel operations of mentally rotating the entire object to match the answer options, or rotating each individual answer to match the data. The analytical method usually solves the problem by spending more time than the complex strategy, as it involves determining the object's components, shape, structure, and counting.

Therefore, we believe that training on how to perform the task will be more effective in developing this ability. To do so, we suggest developing the task based on the cognitive steps of mental rotation [15] defined by Johnson (Table I). It is assumed that the mind's transformational abilities, such as the mental cutting ability, visualization of surface development, and visualization of the views of objects, can be developed to a certain level during related topic studies. Table I outlines the relationship between the tasks to develop mental rotation and mental transformation skills.

III. METHODOLOGY

In this study, we will only present the outcomes of the group that underwent training to develop spatial visualization and the evaluation made by the students in that course. The experimental design is depicted in Figure 2.

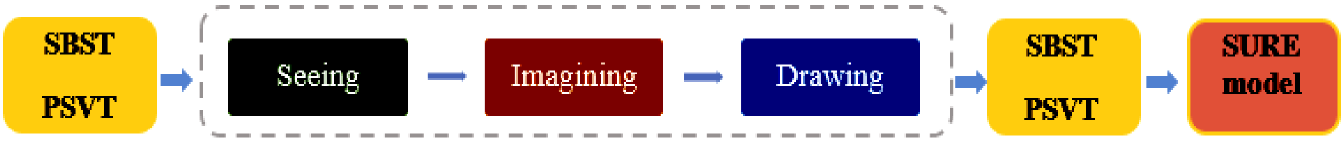

Fig. 2. Experimental Design of Spatial Visualization Development

A. Participants

Out of all the students enrolled in the descriptive geometry course during the fall semester of the academic year 2022-2023, a total of 28 students were studied using the learning model developed by us to develop spatial visualization. Data from 23 students who did not drop out of the classes and participated in both pre- and post-tests of the spatial visualization training course were analyzed using the SPSS 26 statistical program. The students' evaluation of the course was assessed based on the structure oriented evaluation (SURE) model [26]. This model applied for evaluation of different cases [27-29].

B. Spatial Visualization Tests and SURE assessment model

To assess the students' spatial visualization, the levels were compared before and after the training using the mental cutting ability test (SBST) [30] and rotation, development, and view (PSVT) [31].

SURE, evaluation model [26]: We follow the eight steps of the structure-oriented SURE model for the evaluation of our training (Figure 3).

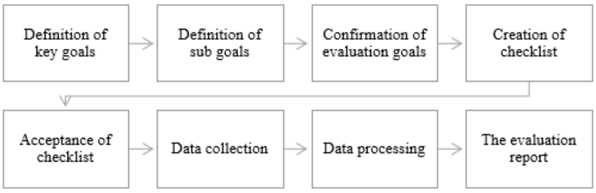

Fig. 3. Steps of the SURE model

Defending the Key Goal: We have identified seven key goals to uncover the actual learning outcomes, which includes learning materials and content (B1), learning environment and equipment (B2), teaching methodology (B3), teacher readiness and skills (B4), difficulty level of tasks (B5), student understanding, mastery, and task performance (B6), and task execution time (B7).

Defining sub-goals and reinforcing them: As part of the key goal, the following sub-goals are defined in order:

A11: The training materials in GeoGebra were interesting; A12: The training material was clear and the illustrations were good; A13: It was related to the content of the topic "Surface projection" seen in the lecture; A14: The content of the course corresponded to the need to understand geometric methods; A15: The course content was helpful in developing my spatial visualization. A21: The laboratory environment created favorable conditions for focused learning; A22: Computers and hardware were adequate and functional; A23: The Internet network was good and the speed was sufficient; A24: Working in the GeoGebra classroom environment was easy and intuitive; A25: There were no difficulties when working on tasks in GeoGebra. A31: The structure (steps) of the training was clear; A32: The format and method of delivering the course content was good; A33: 3D objects in GeoGebra were an aid to the task given by its associated orthogonal projection; A34: The task was clear and easy to work on independently; A35: There was little need for teacher assistance during assignments. A41: The teacher was available when help was needed; A42: Teacher explained clearly when asking for help; A43: The teacher managed the lesson skillfully. A51: Performing the seeing part was easy; A52: Performing the imagination part was easy; A53: Completing the drawing part was easy; A61: Your previous knowledge and skills (studied in lectures) were needed to complete the task; A62: A moving virtual model (3D object) can help you overcome the difficulties of imagining when performing tasks; A63: Doing tasks with GeoGebra can increase your understanding of a given group of topics; A64: Gained the ability to perform independently with confidence; A65: I participated in the training with great effort. A71: There was enough time to work on the theme of points and lines where surfaces are located; A72: There was enough time to work on the topic of the intersection of surfaces and planes; A73: There was enough time to work on the topic of intersection of surfaces and lines; A74: There was enough time to work on the topic of intersection of surfaces; A75: There was enough time to work on the theme from the surface display.

The level of agreement of the students will be evaluated between 0-4 based on the following criteria:

0: Strongly disagree; 1: Disagree; 2: Neutral; 3: Agree; 4: Strongly agree.

Collecting data: Students completed the survey using the Google Form.

Data Processing: The SURE online calculator was used to process data from a total of 23 students, which included information about key goals, sub-goals, evaluation interval, total number of data, and evaluation agreement level. These were represented in different colors ranging from red to green, as shown in Figure 4.

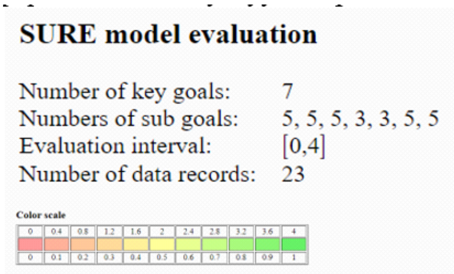

Fig. 4. SURE the data processing part of the online calculator

IV. RESULTS

A. *Results of a comparison of students' spatial visualization before and after the training:*

The collected data was first tested for distribution using the Shapiro-Wilk test. For comparison of the SBST and total PSVT test, a parametric method or paired sample t test was used with a normal distribution ($p<0.05$) as shown in Table II. For the PSVT test, variables outside the distribution range were removed, and the rotation and status types were analyzed using the non-parametric method (Wilcoxon Signed Ranks Test) as the distribution was not normalized ($p>0.05$), as presented in Table III.

TABLE II. PAIRED SAMPLE T TEST COMPARING THE RESULTS BEFORE AND AFTER TRAINING

Тест	Paired Differences					t	df	p
	M	*SD*	*Std. Error Mean*	*95% Confidence Interval of the Difference*				
				Lower	*Upper*			
SBST	6.54	6.1	1.27	3.89	9.19	5.12	22	**.000**
PSVT	8.66	5.43	1.18	6.19	11.14	7.30	20	**.000**

As shown in Table III, the post-training results for both the SBST and PSVT tests showed a significant increase from the pre-training results.

TABLE III. RANKING AND COMPARISON OF RESULTS BEFORE AND AFTER TRAINING (WILCOXON SIGNED RANKS TEST STATISTICS)

Tests	Statistics results	N	Mean Rank	Sum of Ranks
Development	*Negative Ranks*	17[b]	9.00	153.00
	Positive Ranks	0[c]	.00	.00
	Ties	2[d]		
	Total	19		
	Z	-3.635[a]		
	Asymp. p	**.000**		

Rotations	***Negative Ranks***	19[e]	10.92	207.50
	Positive Ranks	1[f]	2.50	2.50
	Ties	2[g]		
	Total	22		
	Z	-3.861[a]		
	Asymp. p	**.000**		
Views	***Negative Ranks***	20[h]	10.50	210.00
	Positive Ranks	0[i]	.00	.00
	Ties	2[j]		
	Total	22		
	Z	-3.936[a]		
	Asymp. p	**.000**		

According to Table III, the post-training results revealed that 17 students performed better in the development test, 19 in the rotation section, and 20 in the view test compared to their pre-training results. However, one student had a lower performance in the rotation test after training, while maintaining the same level of performance in the development and view tests. Additionally, two students had the same level of performance before and after training in each section. Our results showed that all types of PSVT tests had a statistically significant increase.

Step 8 of the SURE model is to report the results of the evaluation. Figure 5 shows the detailed results of the SURE online calculator for each student.

	B_1					B_2					B_3				
k	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{21}	A_{22}	A_{23}	A_{24}	A_{25}	A_{31}	A_{32}	A_{33}	A_{34}	A_{35}
1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0
2	1	1	1	1	1	1	0.5	0.5	1	1	1	1	0.75	0.75	0.5
3	1	0.75	1	1	1	0.75	0.5	0.5	1	1	1	1	1	0.75	1
4	1	0.75	0.75	0.75	0.75	1	0.75	1	1	0.25	0.75	1	1	1	0.5
5	1	1	1	1	1	0.75	0.5	0.75	0.75	1	0.75	1	0.75	0.75	0.25
6	1	1	0.75	1	1	0.75	0.75	0.75	1	1	0.75	0.75	0.75	1	0.75
7	0.75	1	1	0.75	0.75	1	0.75	0.75	1	1	1	1	1	0.5	0.5
8	1	1	1	1	1	1	0.5	1	1	1	1	1	1	1	0.5
9	1	1	1	1	1	0.75	0.75	0.5	0.75	0.75	0.75	1	0.75	0.75	0.5
10	0.75	0.75	0.75	0.75	1	0.5	0.25	0.5	0.75	1	1	1	0.75	1	0.75
11	0.75	0.75	0.75	0.75	0.75	1	0.75	0.75	1	1	0.75	1	1	1	0.5
12	1	1	1	1	1	0.75	1	0.75	0.5	0.75	1	0.75	0.75	0.75	0.25
13	1	1	1	1	1	1	0.75	1	1	0.5	1	1	0.75	0.75	0.75
14	0.75	0.5	1	0.75	0.5	1	1	0.75	1	0.75	1	1	1	1	1
15	0.5	0.5	0.5	0.5	0.5	0.75	0.25	0.25	1	1	0.75	0.75	0.75	0.75	0.25
16	1	1	1	1	1	1	1	1	1	0.25	1	1	1	1	0
17	1	1	1	1	1	0.75	0.75	1	1	0.5	1	1	1	0.75	0.5
18	0.75	0.75	0.75	0.75	0.75	1	0.75	1	1	1	1	1	1	1	0.5
19	0.75	0.5	0.75	0.5	0.75	1	0.5	1	1	1	1	1	1	0.75	0.75
20	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
21	0.75	0.75	0.75	0.75	0.75	0.5	0.25	0.75	0.75	0.5	1	0.75	0.5	0.75	0.75
22	1	1	1	1	1	1	0.75	0.75	0.75	0.25	0.75	1	1	0.75	0.25
23	0.75	0.75	0.75	0.75	0.75	1	0.75	0.75	0.75	0.75	1	1	1	1	0.5
$Q^*(A_{ij})$	0.89	0.86	0.89	0.87	0.88	0.86	0.66	0.76	0.89	0.73	0.9	0.93	0.87	0.84	0.51
$Q_e^*(B_i)$	0.92					0.95					0.96				

	B_4			B_5			B_6					B_7					
k	A_{41}	A_{42}	A_{43}	A_{51}	A_{52}	A_{53}	A_{61}	A_{62}	A_{63}	A_{64}	A_{65}	A_{71}	A_{72}	A_{73}	A_{74}	A_{75}	$Q_{e,k}^*(C)$
1	1	1	1	1	0.75	0.75	1	1	0.5	0.75	1	0.5	0.5	0.5	0.5	0.5	0.91
2	0.75	0.25	1	0.75	0.5	0.75	1	1	1	1	1	0.75	1	1	0.5	1	0.95
3	1	1	1	1	1	1	0.75	0.75	1	1	1	1	1	1	1	1	1
4	0.75	1	0.75	0.75	0.75	0.75	1	0.75	0.5	0.75	0.75	0.25	0.25	0.5	0.5	1	0.96
5	0.75	0.75	0.75	0.5	1	0.75	0.75	0.25	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.87
6	1	1	0.75	0.75	1	0.75	0.75	0.75	1	0.5	0.75	0.25	0.25	0.75	0.25	0.25	0.88
7	1	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.5	0.5	0.5	0.5	0.5	0.5	0.83
8	0.5	1	1	1	1	1	1	0.75	1	0.75	0.75	1	1	1	1	1	1
9	1	0.75	0.75	0.75	0.75	0.75	0.75	1	0.75	0.75	0.5	1	1	1	1	1	0.91
10	1	1	1	0.75	0.75	1	1	1	0.75	0.75	0.75	0.5	0.25	0.25	0.5	0.5	0.88
11	1	0.75	1	0.75	1	1	0.5	0.5	1	0.75	0.75	0.25	0.25	0.25	0.25	0.25	0.79
12	0.75	0.75	0.75	0.75	1	0.75	0.75	1	0.5	0.5	0.5	0	0	0	0	0	0
13	1	0.75	1	0.75	1	0.75	0.75	1	0.5	0.75	0.5	1	1	0.75	0.5	0.5	1
14	1	1	1	1	1	1	1	0.75	1	0.75	1	0.75	0.75	0.5	0.25	0.5	0.93
15	1	1	1	0.75	1	1	0.5	0.75	1	1	1	0.75	0.75	0.75	0.75	0.75	0.82
16	1	1	1	1	1	1	1	1	1	1	1	1	0.75	0.75	1	0.75	1
17	1	1	0.75	1	1	0.75	0.5	0.25	1	0.75	0.5	0.25	0.25	0.25	0	0	0.77
18	1	1	1	1	1	1	1	0.75	1	0.75	1	0.25	0.25	0.25	0.25	0.25	0.79
19	0.75	0.75	0.75	1	1	1	0.75	0.75	1	0.75	0.75	0.25	0.25	0.25	0.25	0.5	0.77
20	0.5	0.5	0.5	0.75	0.75	0.75	0.75	0.75	0.5	0.5	0.5	0.25	0.25	0	0	0	0.49
21	1	0.75	0.5	0.75	0.5	1	1	1	0.5	0.25	0.75	0.5	0.5	0.75	0.5	0.75	0.83
22	1	1	1	0.75	1	0.75	0.75	1	0.75	0.75	0.75	0.5	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	0.25	0.25	0.25	0.25	0.25	0.79
$Q^*(A_{ij})$	0.9	0.86	0.87	0.84	0.89	0.87	0.83	0.8	0.82	0.75	0.77	0.54	0.55	0.57	0.5	0.57	$Q_e^*(C) = 0.8327$
$Q_e^*(B_i)$	0.95			0.94			0.96					0.6					

Fig. 5. Details of the assessment given to the key and sub-objectives (by each student).

The teaching methodology (B3), understanding of the students, acquisition of abilities, and performance (B6) were rated at 96%, while learning environment and equipment (B2), and readiness and skills (B4) were rated at 95%. The difficulty level of the tasks (B5) was rated at 94% and the main purposes of the learning materials and content (B1) were rated at 92%, indicating that all these areas received a rating above 90%. However, the task completion time (B7) had the lowest rating of 60%.

Regarding the evaluation of subgoals, the rates for A11-A15 belonging to the key goal B1 were uniformly rated between 86-89%. For key goal B2, computer hardware availability and operation (A22) had the lowest rating of 66%, while the need for teacher's help was less when working on tasks belonging to goal B3. Sub-goal A35 had a low rating of 51%. The sub-goals belonging to B4, B5, and B6 had a relatively uniform rating, while all the sub-goals of key goal B7, task execution time, were rated with a low percentage between 50-57%.

V. Discussions

The interactive dynamic course aimed to help students overcome visualization difficulties by using a 3D virtual model. More than half of all students (14 students) used the virtual model 3 or more times, while 6 students used it 2-3 times, 2 students used it 1-2 times, and 1 student did not use it. This indicates that the virtual model supported students in executing the task and strengthening their understanding and visualization.

The learning stages were designed to support each other, with the seeing stage intended to support the imagining stage, and the seeing and imagining stages intended to support the drawing stage. 91.3% of all students agreed that seeing supported imagining, while 86.94% reported that seeing and imagining supported the drawing part. Student comments further support these findings, with positive feedback about the relatedness of the stages, the ease of seeing and analyzing, the helpfulness of the imagining part in the drawing part, and the better visualization and understanding of the image when working first by looking at the picture and then working on the task.

According to the survey, when asked about their interest in the stages of training, 73.91% of students reported being more interested in performing the task compared to the projection. It was also noted that the drawing stage might be particularly interesting for students who could solve given problems in time.

The students' comments and impressions indicated that they found learning using interactive dynamic tools interesting *and helpful in understanding the course content and overcoming visualization difficulties. They appreciated the clear 3D model, easy-to-understand tasks, and effective guidance from the lecturer. The use of a computer instead of a ruler and chalk was also seen as an advantage.*

However, there were also negative comments on the tight completion time for tasks, slow internet speed, technical problems with heavy elements getting stuck, and difficulty understanding some explanations of the problem. As a result, students suggested improvements such as increasing the number of computers, improving internet speed, making part 3 more understandable, adding more time for completing tasks, adding audio to the captions of given problems, increasing student participation, providing reinforcement tasks, adding laboratories, making computers fully functional, and clearly writing the number of options for some assignments.

Overall, the comments and impressions from students suggest that interactive dynamic tools are effective in helping them understand course content and overcome visualization difficulties. However, improvements in hardware, internet speed, task data, and task completion time are necessary to further enhance the learning experience.

VI. CONCLUSION

In general, these findings suggest that training based on the cognitive steps of mental rotation can be an effective way to develop students' spatial visualization skills.

According to the evaluation report, the execution time was not sufficient for all students, and half of the students needed help during these tasks. The availability and operation of computers and hardware, the speed and internet network, and difficulties while working on tasks in GeoGebra received low ratings, which was attributed to issues such as computer availability, slow internet speed, and hardware problems when loading tasks. However, other sub-goals received scores of more than 80%, indicating that their goals had been achieved. Although there were some sub-goals with low ratings, the overall rating was 83%, suggesting that the training was successful.

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