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Comparison of University Students' Graphic Interpretation Skills

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ABSTRACT Graphic interpretation is as critical in physics education as problem-solving. However, we know that today's classes focus more on problem-solving. This study uses a survey to determine college students' graphic interpretation skills. The study consists of two phases. The first phase includes the development and statistical analysis of the survey. The second phase includes comparing and discussing the data resulting from the application of the developed survey. The research data were analyzed using both exploratory factor analysis and confirmatory factor analysis techniques. The survey on graphic interpretation skills, including the understanding and analysis processes, consisted of 17 items based on analysis results. The survey data were collected using purposive sampling from 113 college volunteers during the fall semester of 2022-2023 at Dokuz Eylul University in Turkey. The participants consisted of 57 geoscience students and 56 mining students. The survey results showed that the kinematic interpretation skills of mining engineering students were higher than those of geoscience students. These differences between geoscience and mining engineering students in cognitive, affective, and psychomotor behaviors were discussed.

Keywords Analysis process, graph interpretation, multiple representations, understanding process

1. INTRODUCTION

Multiple representations (diagrams, formulas, graphs, pictures, etc.) in physics, science, and mathematics education play an essential role in learning and facilitate knowledge acquisition and problem-solving (Bursal & Yetis, 2020; Savinainen et al., 2013; Wong et al., 2011). Munfaridah et al. (2021) explained that students can use multiple representations when drawing a diagram or solving a problem. Multiple representations (MRs) are used to establish a relationship between a motion's verbal and mathematical representations. MRs also facilitate the transition of information from the concrete to the abstract. Students who use multiple representations solve problems more efficiently and perform deep learning by analyzing concepts more easily (Gok & Gok, 2022). Many studies have shown that the use of multiple representations can improve student learning (Klein et al., 2018; Maries & Singh, 2018; McPadden & Brewe, 2017; Susac et al., 2017; Susac et al., 2019; Sutopo & Waldrip, 2014).

Many instructors use MRs as a teaching strategy. This is because MRs can easily illustrate abstract concepts and interpret the relationships between concepts. They believe that using MRs is very useful to promote scientific thinking among students based on data obtained in the laboratory environment (Gok & Gok, 2022). Wong et al. (2011) pointed out that students should learn the format of representations and explain how multiple representations can represent certain concepts (e.g., kinematics for motion diagrams, geometry for ray diagrams, forces and dynamics for free-body diagrams, etc.). In learning multiple representations, students should be able to interpret the given representations, construct representations, and eventually switch between different representations (Gok & Gok, 2022).

One of the MRs is the graph. Graphs are an efficient and effective tool to understand and grasp the basics of physics. Nixon et al. (2016) stated that students try to understand graphs by thinking like physicists. Because graphics are one of the essential parts of scientific communication. Physicists create graphs to communicate their thoughts. Physicists also like to interpret graphs created by others to evaluate thoughts. Students are expected to interpret the messages through graphics to understand physics. This expectation can only be achieved if students are taught how to interpret and create graphs. One of the ways to accomplish this is for educators to

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employ effective teaching strategies in their classes. Educators should utilize various instructional methods and tools to enhance students' graph interpretation skills. This may involve teaching skills such as accurately reading graphs, analyzing data, drawing conclusions, and visually presenting results. Additionally, providing students with opportunities for practice, problem-solving activities, and working with real-life examples is crucial for interactive learning. Through these approaches, students can strengthen their graph interpretation skills and reach the desired level of proficiency.

Several classification studies have been conducted to understand and interpret the graphs. Some of the pioneers of these studies are briefly described below. Kosslyn (1985) reports that understanding graphics involves two processes. The first process is visual perception. This process involves the perception of the visual image of the graphic. The second process is graphic cognition. This process is about converting the visual image into meaningful information. Ainsworth (1999) divides it into two categories. The first category is external representations, such as pictures, graphs, diagrams, symbols, etc. The second category was internal representations. The internal representations were called mental models that function as structural analogies of situations/processes. Lienhardt et al. (1990) found that graphs have two dimensions. The first dimension is drawing a graph, and the second is interpreting a graph. These dimensions require graph interpretation skills, including classification, prediction, scaling, and transformation. Meltzer (2005) explained four different modes of representation: verbal, mathematical, graphical, and diagrammatic to assess students' problem-solving performance. De Cock (2012) pointed out the importance of the different forms of representation, which include verbal, pictorial, and graphical, in isomorphic problem-solving. Based on the studies reviewed, graph interpretation can be examined using two processes. The first process (UP) is to understand the graph; the other process (AP) is to analyze the graph.

One of the most commonly used graphical topics in physics is kinematics. Therefore, kinematics can be explained to students in three ways. The first way is to use kinematic formulas. The second way is to use kinematic graphs. The last way is to use the relationship between kinematic formulas and graphs. The most important thing is that students connect concepts, formulas, and graphical representations when solving kinematics problems (Nixon et al., 2016).

Many students have difficulty understanding the basic concepts of kinematics (position, displacement, velocity, acceleration, slope, area, height, etc.), explaining the relationship between the basic concepts, interpreting graphs given for these concepts, calculating the slope of graphs and area in kinematic graphs, and switching from one given graph to another (e.g., acceleration-time graph from the velocity-time graph, velocity-time graph from the position-time graph, etc.). Because they see graphs as pictures, they interpret position-time, velocity-time, and acceleration-time graphs similarly. Many students generally do not know how to make drawings related to the basic concepts of kinematics. They generally do not know how to recognize increases/decreases in variables on both axes and how to interpret increases/decreases in a linear/non-linear graph. The studies examined multiple representations (MRs) that can be evaluated in three groups: conceptual learning, problem-solving, and difficulty interpreting graphs.

Klein et al. (2018), Korff and Robello (2012), and Sutopu and Waldrip (2014) showed that students' reasoning ability and conceptual understanding improved after learning with the MRs approach. Susac et al. (2017) showed that MRs reduced working memory load, provided data estimation, and helped students understand concept measurement.

Rosengrant et al. (2009) reported that the problem-solving performance of students who used free-body diagrams was higher than that of students who did not draw free-body diagrams. Maries and Singh (2018) indicated that the drawn diagrams caused students to spend less time understanding and analyzing the physical problem. Kuo et al. (2013) and Susac et al. (2019) revealed that MRs used to understand physics problems were found to help students solve the problems correctly.

McDermott et al. (1987) studied the difficulty of interpreting graphs in college and high school students. The first level was the difficulty in relating graphs to physical concepts. The second level was difficulty relating graphs to real-world phenomena. Sengel and Ozden (2010) highlighted students' difficulties in interpreting graphs. These difficulties involved analyzing and interpreting kinematic graphs due to their complex motion, describing specific events in velocity-time, acceleration-time, and position-time, and analyzing deceleration/acceleration. Planinic, Ivanjek, and Susac (2013) pointed out three main difficulties in interpreting graphs for students. These difficulties were interval-point confusions, slope-height confusions, and iconic confusions.

Amin, Sahib, Harianto, Patandean, Herman, and Sujiono (2020), Beichner (1994), Bollen, Van Kampen, Baily, Kelly, and De Cock (2017), Ergul (2018), Maries and Singh (2013), Maries et al. (2017), McDermott, et al. (1987), Zavala (2017) reported that students had difficulty distinguishing the symbols of the variables on the graph, determining the known quantity and the required quantity on the graph, identifying the mathematical formulas for solving problems in the kinematic graph, transforming information based on graphs, explain the relationship between variables. Ergul (2018) found that pre-service teachers did not successfully interpret the given graph, draw the graph, and determine the variables for a given problem. Some studies (Gok & Gok, 2022; Nixon et al., 2016) have shown that many students do not know the graph's meaning even though they draw a kinematic graph. This result shows that students' graph interpretation skills are not developed enough.

Planinic et al. (2013) and Ivanjek, Susac, Planinic, and Andrasevic (2016) investigated the graph interpretation strategies and difficulties in all three domains (mathematics, physics, and contexts other than physics) of college students using parallel questions (isomorphic). They found that the strategy students preferred was using formulas, that the strategies used in parallel questions were often context-dependent and domain-specific, and that students used more creative strategies in problems in other contexts than in physics problems. Besides, they reported that students in all domains had similar difficulties interpreting graphs.

This study aimed to determine the graphic interpretation skills of college students using a survey. The students' graphic interpretation skills were investigated in two processes. The processes to be investigated were understanding the graphic and analyzing the graphic as stated in the literature. The survey developed will fill the gap in the literature. In addition, with the help of the developed survey, the educators will be able to determine the graphic interpretation skills of high school and university students. This study investigated the following research question: Is there a significant difference between geoscience students and mining engineering students regarding graph interpretation skills?

2. METHOD

2.1 Procedures

The investigation consisted of two phases. The first phase examined the procedures used to develop the pilot survey. In this phase, a literature review was conducted, a large pool of items was created, expert opinions were obtained, and a factor analysis was conducted. The second phase involved administering the survey developed for the kinematic interpretation skills of two-year College of Geosciences and four-year College of Mining Engineering students.

2.2 Development Procedures of the Pilot Survey

The literature on graph interpretation skills (Amin et al., 2020; Manurung et al., 2018; Munfaridah et al., 2021; Petrova, 2016; Vaara & Sasaki, 2019) related to kinematics was examined using ERIC and Science Direct. Volunteer 18 students were asked to write down their views on kinematics graph interpretation skills. An attempt was made to determine the similar statements made by the students regarding their interpretation of kinematic graphs. The studies reviewed, and the students' written opinions helped determine the items for the pilot survey. A pilot survey with 23 items was created based on the assessments conducted. The survey was sent to four physics instructors to assess the content and construct validity of the pilot survey. After the necessary corrections were made according to the experts' suggestions, the survey was given its final form. The pilot survey was named the Graph Interpretation Skills Survey (GISS). The items of the pilot survey were scaled from always "5" to never "1".

2.3 Participants

Pilot survey data were collected from 261 two-year geoscience students at a state college in western Turkey who had successfully completed the introductory calculus-based physics course in the 2021-2022 academic year. The survey data were collected using a purposive sampling technique from 113 college volunteers during the fall semester of 2022-2023 at Dokuz Eylul University in Turkey. The participants consisted of 57 geoscience students and 56 mining students. The author was present when the survey was administered and when the students answered the questions. Student volunteers were given 5 minutes to complete the survey. The author secured the personal information of the students who completed the survey.

2.4 Data Analysis

Statistical analysis was examined in two subtitles. First, explanatory factor analysis of the pilot survey was conducted using SPSS Statistics 25. Confirmatory factor analysis was also performed using the graphing program AMOS 25.

The Pilot Study's Explanatory Factor Analysis (EFA)

The EFA results show that the pilot survey comprises 17 items (see Table 1). Bartlett's test for sphericity and the

Table 1 Statistical results of the GISS

	Item	AP	UP
1	I can draw a velocity-time graph from a position-time graph.	.834	
2	I can draw velocity-time graphs from acceleration-time graphs.	.792	
3	I can calculate the velocity of a motion from a position-time graph.	.777	
4	I can interpret the motion of an object from the different graphs given.	.771	
5	I can interpret velocity-time graphs.	.750	
6	I can draw an acceleration-time graph from a velocity-time graph.	.745	
7	I can draw the motion graph of the object using the given figure for the problem.	.735	
8	I can interpret the motion types that the object makes more than once on a graph.	.734	

Table 1 Statistical results of the GISS (*Continued*)

	Item	AP	UP
9	I can interpret position-time graphs.	.726	
10	I can interpret linear graphs.	.725	
11	I can interpret acceleration-time graphs.	.717	
12	I can determine the type of motion according to a graph.	.707	
13	I can solve kinematic problems by using the equation		.741
14	I can interpret the given and required information regarding the graph.		.739
15	I can solve graph problems based on interpretations.		.720
16	I can draw the graph of a motion according to given values.		.695
17	I can draw a graph when solving motion problems.		.576
Cronbach's Alpha of the sub-factor		.95	.80
Eigenvalue		9.34	1.32
Percentage of explained variance		42%	21%

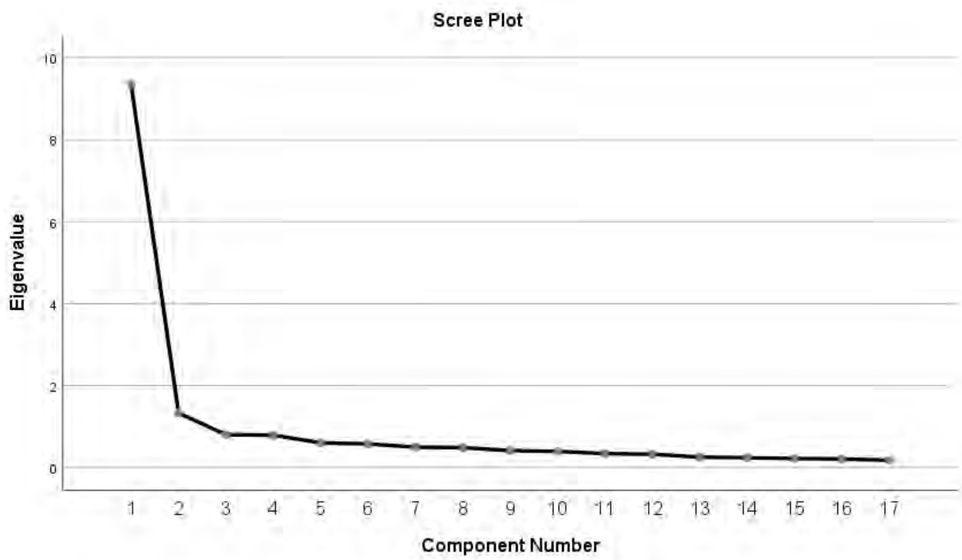

Figure 1 Relationship between the Items and Eigenvalues

value of total explained variance was measured as 3052.862, df=136, p<.001, and 62.80%, respectively. The KMO (Kaiser-Meyer-Olkin) value and Cronbach's alpha value were calculated to be .95 for the pilot survey. The statistical data showed appropriate factor analysis (Hair, Black, Babin, & Anderson, 2014).

The results of the EFA showed that the pilot survey had two subfactors. The identified subfactors were named according to the purpose of the survey. The first factor, labeled "Analysis Process" (AP), included 12 items. The second factor, labeled "Understanding Process" (UP), included five items. The relationships between the items and eigenvalues are shown in Figure 1. The factor loadings and eigenvalues of the items were above .55 and "1," respectively, as shown in Table 1. Considering the reviewed studies (Hair et al., 2014; Tabachnick & Fidell, 2012), it can be said that the results of EFA are "high" and "acceptable".

The Pilot Survey's Confirmatory Factor Analysis (CFA)

The CFA was performed to support the results of the EFA. The confirmatory factor analysis scores are generally expected between "acceptable fit" and "good fit." The obtained CFA results show that the modification index values are between "acceptable fit" and "good fit" (see Table 2).

When the examined studies (Byrne, 2013; Hu & Bentler, 1999; Karagoz, 2016; Schermelleh-Engel et al., 2003) were interpreted, the calculated measurements were "valid" and "reliable." The path diagram of the CFA is shown in Figure 2.

3. RESULT

3.1 The Application of the Developed Survey

The developed survey was administered to 113 students (56 mining engineering students and 57 earth science students) during the fall semester of 2022-2023.

The Mining Engineering course (ME) lasts four years in Turkey and is held at the Faculty of Engineering. Mining engineering is based on fundamental sciences, processing, and economics. Earth Sciences (ES) takes two years at the Vocational and Technical School of Higher Education. Earth science courses are based on fundamental sciences

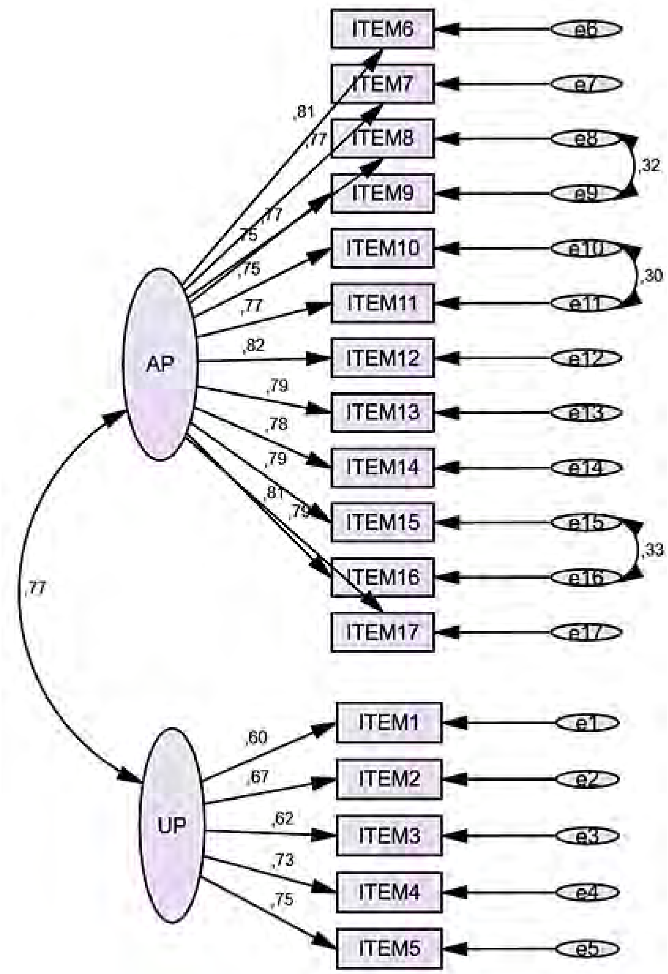

Figure 2 Relationship between the items and subfactors according to CFA

and technical earth science (drilling, mining, geotechnical engineering, etc.).

In the general analysis of the GISS data, as seen in Table 3, the graphical interpretation skills of the geoscience students, including the understanding and analysis processes, are sometimes used. In contrast, the graphical interpretation skills of the mining students are often used.

Table 4 shows the mean score of students' kinematic interpretation skills related to GISS. The mean scores of mining engineering students ranged from 34 to 83 points, while the mean scores of geoscience students ranged from 21 to 80 points. The arithmetic means of the mining engineering students' graph interpretation skills were generally higher than those of the geoscience students, as seen in Table 4.

Student outcomes in mining engineering and earth science were compared using the independent samples t-test. Statistical analyzes were calculated as $t(111)=7.59$ $p<.05$ for "analysis process-AP", $t(111)=6.36$ $p<.05$ for "understanding process-UP", and $t(111)=7.08$ $p<.05$ for "GISS". The results obtained were found in favor of the mining engineering students.

4. DISCUSSION

When the research results were discussed in general, the mean scores of geoscience students in the analysis and understanding processes of the kinematics graph were lower than the mean scores of mining students. When the GISS mean scores of the students were compared based on statistical analysis, similar results to the sub-factors were obtained in favor of the engineering students. The kinematic graphical interpretation skills of the mining engineering students were higher than those of the

Table 2 The confirmatory factor analysis' fit indexes

		Reference Value*	
Fit Indexes	**Measurement**	**Acceptable Fit**	**Good Fit**
CMIN/df "Chi-Square Goodness of Fit for AMOS."	2.52	$x^2/df \leq 5$	$x^2/df \leq 3$
NFI "Normed Fit Index"	.91	$.90 \leq NFI$	$.95 \leq NFI$
TLI "Tucker-Lewis Index"	.93	$.90 \leq NNFI$	$.95 \leq NNFI$
IFI "Incremental Fit Index"	.94	$.90 \leq IFI$	$.95 \leq IFI$
CFI "Comparative of Fit Index"	.94	$.95 \leq CFI$	$.97 \leq CFI$
RMSEA "Root Mean Square Error Approximation"	.07	$RMSEA \leq .08$	$RMSEA \leq .05$
GFI "Goodness of Fit Index"	.88	$.85 \leq GFI$	$.90 \leq GFI$
AGFI "Adjusted Goodness of Fit Index"	.85	$.85 \leq AGFI$	$.90 \leq AGFI$
RMR "Root Mean Square Residual"	.05	$0 < RMR \leq .08$	$0 < RMR \leq .05$
SRMR "Standardized Root Mean Square Residual"	.04	$0 < SRMR \leq .08$	$0 < SRMR \leq .05$

Note: * Reference Value: (Karagoz, 2016; Schermelleh-Engel, Moosbrugger, & Müller, 2003)

Table 3 The descriptive statics of the items

		ES		ME	
		M	SD.	M	SD.
1	I can draw a velocity-time graph from a position-time graph.	2.45	1.07	3.85	1.01
2	I can draw velocity-time graphs from acceleration-time graphs.	2.31	.96	3.69	1.07
3	I can calculate the velocity of a motion from a position-time graph.	2.54	1.08	3.94	.90
4	I can interpret the motion of an object from the different graphs given.	2.71	1.09	3.50	1.19
5	I can interpret velocity-time graphs.	2.98	1.21	3.82	1.06
6	I can draw an acceleration-time graph from a velocity-time graph.	2.35	1.04	3.60	1.00
7	I can draw the motion graph of the object using the given figure for the problem.	2.50	1.21	3.28	1.05
8	I can interpret the motion types that the object makes more than once on a graph.	2.45	1.15	3.41	1.07
9	I can interpret position-time graphs.	2.78	1.06	3.69	.97
10	I can interpret linear graphs.	2.71	1.04	3.67	1.09
11	I can interpret acceleration-time graphs.	2.66	1.13	3.53	.99
12	I can determine the type of motion according to a graph.	2.43	.96	3.51	1.02
13	I can solve kinematic problems by using the equation	2.36	1.02	3.42	1.12
14	I can interpret the given and required information regarding the graph.	2.66	1.20	3.26	1.03
15	I can solve graph problems based on interpretations.	2.66	1.17	3.48	1.00
16	I can draw the graph of a motion according to given values.	2.54	1.13	3.42	1.10
17	I can draw a graph when solving motion problems.	2.70	1.03	3.19	1.11

Table 4 The mean of the students' survey

	Group	N	M	SD.
AP	ES	57	13.01	4.30
	ME	56	18.82	3.79
UP	ES	57	30.87	9.54
	ME	56	41.53	8.20
GISS	ES	57	43.89	13.25
	ME	56	60.35	11.37

geoscience students. These differences between geoscience and mining engineering students in cognitive, affective, and psychomotor behaviors can be explained as follows.

Cognitive behaviors

- ✓ The academic background of earth science students may not have been sufficient to understand and interpret kinematic diagrams.
- ✓ In the different types of high schools (private, public, technical, vocational, etc.) where students learn, high school physics teachers may not have given enough importance to graphical topics and solutions.
- ✓ Physics teachers, in particular, may have focused on formulas when teaching kinematics to their students.
- ✓ Many students may have preferred formulas rather than solving their kinematics problems with graphs.
- ✓ The concepts of kinematics may have seemed abstract to the students.
- ✓ Physics teachers may not have used alternative teaching methods (peer instruction, just-in-time instruction, STEM, etc.) to facilitate students' understanding of kinematic topics.

Affective behaviors

- ✓ Students may not like graphic interpretation.
- ✓ Students may find it challenging to interpret kinematic diagrams.
- ✓ Students may not be interested in graphical analysis.
- ✓ Students may be embarrassed to ask class questions and call the instructor on points they do not understand.

Psychomotor behaviors

- ✓ High school teachers may not have let their students experiment in the laboratory while explaining kinematics.
- ✓ After the topics of kinematics were explained, students may not have been allowed to work in a laboratory setting and develop projects based on investigations of the topic.

Mining engineering students' ability to interpret kinematic graphs was higher than that of geoscience students. Reasons for engineering students' ability to interpret kinematic graphs more easily are presented below. Engineering students may have taken a more intensive calculus-based physics course. Students may have applied the theoretical courses in the laboratory. Students may have applied the topics covered in the physics course with simulations in the computer laboratory. Students may have been interested in graphing. Instructors may have used alternative teaching methods and strategies that could capture students' attention when teaching kinematics topics.

The results of some studies (Bektasli & White, 2012; De Cock, 2012; Ergul, 2018; Haratua & Sirait, 2016; McDermott et al., 1987; McPadden & Brewe, 2017; Petrova, 2016; Planinic et al. 2013, Theasy, Wiyanto, & Sujarwata, 2018) were supported by the results of the present study. The studies' results indicate that using MRs helps students improve their problem-solving skills, develop better conceptual understanding, interpret the relationship between graphs and mathematical formulas, and visualize the concepts given in the kinematics problems before using mathematical formulas. It could be said that using MRs improves students' reasoning skills. De

Cock (2012) showed a positive relationship between problem-solving ability and the use of MRs. Podolefsky and Finkelstein (2006) also indicated a correlation between students' reasoning ability and representation choice. Celik and Pektas (2017), Kohnle and Passante (2017), Magana, Serrano, and Robello (2019), and Vaara and Sasaki (2019) emphasized the effects of computer-aided applications, video analysis, simulations, etc., on the understanding and interpretation of MRs. Manurung et al. (2018) suggested that hypertext instructional media has significantly developed students' graphic interpretation skills. The studies revealed that students' graphic interpretation skills should be developed in a laboratory environment with knowledge and technology based on students' cognitive, affective, and psychomotor behaviors.

When the items in the GISS were generally discussed, the engineering students' interpretation skills based on the transition from one graph to another were higher than the earth science students' interpretation. The results show that although engineering students were interested in interpreting graphics, they did more calculations while solving graphic questions. The students in the groups found it easier to interpret the velocity-time graph according to the acceleration-time graph. If the kinematics problems do not contain graphics, it can be said that the students have relatively difficulty in drawing graphics related to the problems.

5. CONCLUSION

In physics teaching, students must have graphic interpretation skills, including understanding and analysis processes, regardless of their level and field. With the help of the instructors' alternative teaching methods and strategies, students can develop their skills in interpreting graphics, creating, and understanding the relationship between axes. Instructors should help students draw and analyze graphs by experimenting in the laboratory so that they can easily interpret kinematics graphs. They should both draw graphs and use formulas when solving kinematics problems. Instructors should ask students parallel questions based on kinematic graphs. They can also use isomorphic problem-solving strategies to help students distinguish between different graphs and allow them to interpret graphs easily. They should emphasize the importance of drawing graphs and using formulas in kinematic problems and that they are an inseparable whole. They can be recommended to make many applications, especially for graphic transitions. In addition, they can give students assignments on graphic interpretation.

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