Kasuari: Physics Education Journal 7(2) (2024) 236-248
P-ISSN: 2615-2681
E-ISSN: 2615-2673

Kasuari: Physics Education Journal (KPEJ)
Universitas Papua
Web: http://jurnal.unipa.ac.id/index.php/kpej

Instrument Test Kinematics: How Velocity and Acceleration Vectors Captured by High School Students

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Abstract: *Vectors in kinematics are rarely highlighted in high school. Even though vectors are the language used by physicists. This study aims to determine the validity and reliability of the test instrument developed and to explore the ability of vectors in kinematics of high school students. The method used in this research is research and development of the 4D model. The developed test instrument for vectors in kinematics is in the form of multiple choice with an arrow direction accompanied by a command to describe the vector and explain the reason for choosing the vector direction. The test instrument covers one- and two-dimensional kinematics topics by highlighting the concepts of velocity and acceleration. Two-dimensional kinematics is divided into constant velocity and increasing velocity. This test instrument consists of thirteen questions with an average point-biserial coefficient of 0.493 and KR-20 of 0.784. Then, this test instrument was used to measure the vector ability in kinematics of high school students with a sample size of sixty-seven students. It was found that most high school students had difficulty in acceleration as two-dimensional vector, acceleration as one-dimensional vector, and velocity as one-dimensional vector with few obstacles. Learning with the method of integrating vectors in kinematics has the possibility to solve this problem.*

Keywords: *Acceleration, kinematics, vector, velocity*

Instrumen Tes Kinematika: Bagaimana Vektor Kecepatan dan Percepatan Dipahami oleh Siswa SMA

Abstrak: Vektor dalam kinematika jarang disoroti di sekolah menengah. Padahal vektor merupakan bahasa yang digunakan oleh para fisikawan. Penelitian ini bertujuan untuk mengetahui validitas dan reliabilitas instrumen tes yang dikembangkan serta menggali kemampuan vektor dalam kinematika siswa SMA. Metode yang digunakan dalam penelitian ini adalah penelitian dan pengembangan model 4D. Instrumen tes yang dikembangkan untuk materi vektor dalam kinematika berbentuk pilihan ganda dengan arah panah yang disertai dengan perintah untuk menggambarkan vektor dan menjelaskan alasan pemilihan arah vektor tersebut. Instrumen tes mencakup topik kinematika satu dan dua dimensi dengan menekankan pada konsep kecepatan dan percepatan. Kinematika dua dimensi dibagi menjadi kecepatan konstan dan kecepatan meningkat. Instrumen tes ini terdiri dari tiga belas soal dengan rata-rata koefisien point-biserial sebesar 0,493 dan KR-20 sebesar 0,784. Kemudian, instrumen tes ini digunakan untuk mengukur kemampuan vektor dalam kinematika siswa sekolah menengah atas dengan jumlah sampel sebanyak enam puluh tujuh siswa. Hasil penelitian menunjukkan bahwa sebagian besar siswa SMA mengalami kesulitan pada materi percepatan sebagai vektor dua dimensi, percepatan sebagai vektor satu dimensi, dan kecepatan sebagai vektor satu dimensi dengan sedikit hambatan. Pembelajaran dengan metode pengintegrasian vektor dalam kinematika memiliki kemungkinan untuk mengatasi masalah ini.

Kata kunci: Kecepatan, kinematika, percepatan, vektor

INTRODUCTION

Vectors are never separated from physical phenomena. There many physical quantities that have magnitude and direction, so needs mathematical language called vector language (Serway & Jewett, 2014; Walker et al., 2014). The ability to describe vectors and determine vectors is important to tell what is happening in physical phenomena (Redish, 2021). The first topic that applies vectors is kinematics. The quickest way to see what vectors can do in other topics is to use kinematics.

However, in kinematics, the concept of vectors is less well highlighted. The majority of kinematics learning and programming focuses on simple mathematical operations without drawing vectors (Annisa et al., 2019; Nurilma et al., 2023; Sari & Ermawati, 2021; Ulfa & Sucahyo, 2022; Viyanti et al., 2023). Due to the lack of focus on vectors in kinematics, previous studies rarely measure the ability of vectors in kinematics. As a result, the concept of vectors in kinematics is rarely well captured.

Vector ability in kinematics at the higher education level has been captured (Flores & Kanim, 2004; Reif & Allen, 1992; Shaffer & McDermott, 2005). For high school students, previous researchers were limited to photographing students' vector abilities (Susac et al., 2018; Jewaru et al., 2021; Latifa et al., 2021; Tairab et al., 2020). For this reason, the researcher captured vector abilities in kinematics for high school students, which is still rarely done by previous researchers. To capture the ability of vectors in kinematics, a suitable test instrument is needed, especially the vector part in kinematics.

Several previous studies have developed instruments that use vectors on the topic of dynamics (Hestenes & Wells, 1998; Hestenes et al., 1992). Likewise, for rotational dynamics, which already has a test instrument that is useful for knowing students have been able to distinguish rotational and rolling events (Mashood & Singh, 2012). As for kinematics, a test instrument has been developed to determine the ability of students to interpret the motion graphs presented (Beichner, 1996; Zavala et al., 2017). Then proceed with the test instrument used to measure all abilities in kinematics (Lichtenberger et al., 2017). Some instruments are developed in a less complete form or have not completed all stages (Firdaus & Mindyarto, 2021; Handhika et al., 2023). However, it is still rare to find test instruments that can measure students' vector abilities in kinematics by asking students to directly describe the vectors that students mean.

The incomplete stages of the test instrument developed resulted in not seeing the results of concept capture. In addition, the test instrument developed is less focused on vectors in kinematics both one-dimensional and two-dimensional (Agriawan et al., 2020; Sari & Ermawati, 2021). This shows that there is still a need for vector test instruments in one-dimensional and two-dimensional kinematics that are developed through the appropriate stages and have completed all stages.

This article discusses two topics, Q1: How is the Validity and Reliability of the Vector Test Instrument in Kinematics. Q2: How is the concept description of high school students on sub vectors in kinematics. This research was conducted in two stages, namely the instrument development stage to answer the first problem formulation and the instrument use stage to answer the second problem formulation. Sixty-five students from class XI became participants in the instrument development stage and sixty-seven students from class XI and X who had taken vector and kinematics material became participants in the instrument use stage.

METHOD

The research method used is Research and Development with the 4D Model (Thiagarajan et al., 1974). In the first stage of defining, researchers analyzed the needs of test instruments that did not exist and had not been conducted by other researchers or teachers, but students needed these test instruments to measure their abilities. This analysis was conducted by distributing a questionnaire through Google Form. The participants involved in this questionnaire were teachers from four different schools in East Java Province. At the same time, the researcher conducted a literature review to find whether an instrument needed by teachers had been developed. In the design stage, the researcher developed a prototype of the instrument test based on the division of concepts based on Lichtenberger et al. (2017) then selected the sub-concept of velocity and acceleration as one and two-dimensional vectors in one and two-dimensional kinematics which are rarely encountered by teachers and rarely developed by other researchers. Followed by the development stage, the instrument test was validated by Focus Group Discussion (FGD) with faculty. From the revised results, a limited trial was conducted with sixty-five grade XI students who had taken Vector and Kinematics material. All students are given 40 minutes to work on the questions. Then the KR-20 correlation analysis, Point-biserial coefficient, difficulty, and item discrimination index were conducted. The following is a summary of the research flow shown in Figure 1.

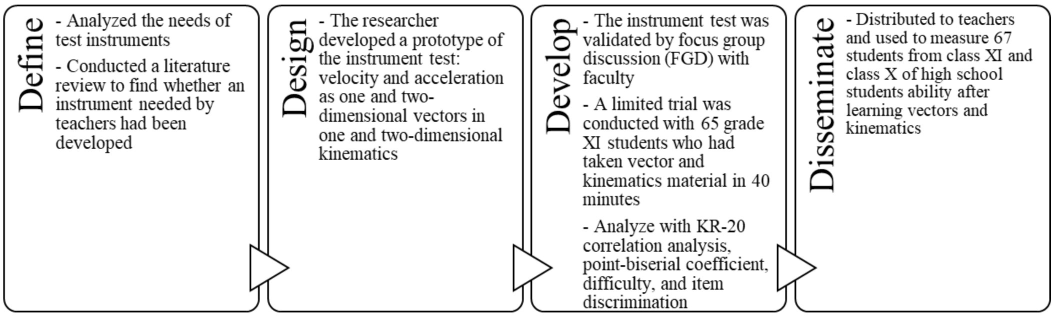


Figure 1. Flowchart of research and development method

The last stage is disseminated, this stage the test instrument is distributed to teachers and used to measure the ability of high school students after learning vectors and kinematics. There are sixty-seven students from class XI and class X who have used the vector test instrument in kinematics. In this section, the developed test instrument was used to capture the vector ability of high school students in kinematics. Students were asked to provide reasons for their answer choices. However, not all students were able to do all thirteen items. Table 1. shows the distribution of the number of students in each topic.

Table 1. Number of students working on each topic

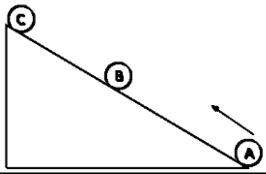
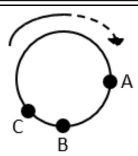
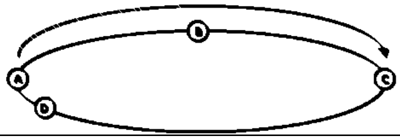
Topic	N
	67
	60
	25

Table 1 shows a decrease in the number of students who were able to work on the questions. We will also discuss this in the results section. The first inclined plane phenomenon represents one-dimensional kinematics. The circular motion phenomenon in the second problem represents two-dimensional kinematics with constant speed. The circular motion phenomenon in the last question represents kinematics two dimension with increasing speed

RESULT AND DISCUSSION

This instrument is based on Lichtenberger et al. (2017) and Shaffer & McDermott (2005) in the concept section Velocity and acceleration as one- and two-dimensional vectors in kinematics. Velocity and acceleration as one- and two-dimensional vectors in one-dimensional kinematics are represented by the phenomenon of a ball moving up and down on an inclined plane. With three main points highlighted, namely the top point, the bottom point, and an arbitrary point on the inclined plane, students are asked to find the velocity and acceleration vectors. Velocity and acceleration as one- and two-dimensional vectors in two-dimensional kinematics are represented by two phenomena, namely a moving object with constant velocity on a circular trajectory and a moving object with increasing velocity on an oval trajectory.

Define

The needs analysis was conducted on two private high school physics teachers, one public high school physics teacher, and 1 Islamic private high school physics teacher who taught vector and kinematics material. The four teachers teach vector and kinematics material separately and give daily vector and kinematics assessments in the form of questions that mostly require mathematical operations.

Tabel 2. Needs questionnaire result

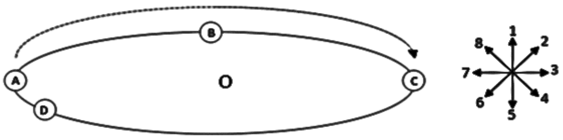
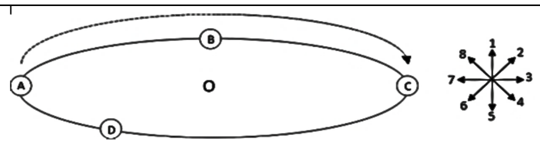
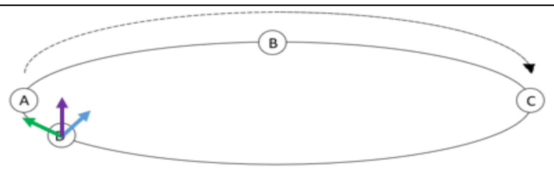
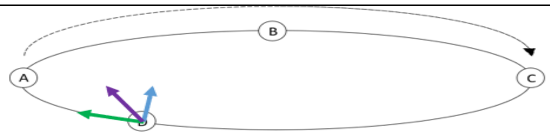
School Category	Kinematics in One Dimension		Kinematics in Two Dimension	
	Velocity Vector	Acceleration Vector	Velocity Vector	Acceleration Vector
Private High School	Yes	No	Yes	Yes
	No	No	No	No
Public High School	No	No	No	No
Islamic Private High School	No	No	No	No

However, the four teachers did not require students to describe the resultant vector qualitatively. Therefore, these teachers need an instrument that can measure students' ability to draw and describe vector quantities in kinematics.

Design

The instrument began to be organized according to the division of one-dimensional kinematics and two-dimensional kinematics. Then, each topic focuses on Speed as a one-dimensional vector and Acceleration as a one- and two-dimensional vector. In one-dimensional kinematics, the researcher chose the event of the motion of a ball on a frictionless inclined plane and asked students to describe the velocity and acceleration vectors of an object moving on an inclined plane. In two-dimensional kinematics, the researcher chose two events, namely objects moving on a circular trajectory and an oval trajectory. On a circular trajectory, the object moves with constant velocity. For the oval trajectory, the object moves from rest with increasing speed. This oval trajectory tests students' ability to determine the direction of the centripetal acceleration vector. After the preparation of the instrument, expert validation was conducted, the following is an example of the results of expert validation conducted by Focus Group Discussion (FGD).

Tabel 3. Expert validation result

After Revision	Before Revision
 The ball starts at rest and then moves clockwise in a circle with increasing speed. What is the direction of total acceleration at point D?	 The ball starts at rest and then moves clockwise in a circle with increasing speed. What is the direction of total acceleration at point D?
Solution	**Solution**
 The green line shows the tangential acceleration experienced by the ball as it moves from rest and its speed continues to increase. The blue line shows the centripetal acceleration at point D. Then the total acceleration experienced by the ball at point D is shown by the purple line. The direction of the total acceleration vector lies in the direction one	 The green line shows the tangential acceleration experienced by the ball as it moves from rest and its speed continues to increase. The blue line shows the centripetal acceleration at point D. Then the total acceleration experienced by the ball at point D is shown by the purple line. The direction of the total acceleration vector lies between the directions of 8-1

Develop

The test instrument was assessed on 65 students who had taken vector and kinematics material. The overall results of the thirteen questions are shown in Table 4 and the individual results of each question are shown in Table 5. In general, the average score obtained is close to half of the total score of 13 points. With reference to Doran (1980), 30% (4) questions are at the difficult level, 23% (3) questions at the moderately difficult level, 38% (5) questions at the moderately easy level, and 7% (1) question at the easy level. But, according to Hutton (2016) only three item are at difficult level (below 0.20) and other are in ideal value difficulty level. Overall, this test instrument is at a moderately difficult level. The reliability of this test instrument has met the minimum limit of 0.7.

Tabel 4. Overall analysis result

Mean	Standard Error	Mean Difficulty	Reliability (KR-20)	Mean Point-Biserial Coefficient	Mean Item Discrimination Index
6.72	0.338	0.52	0.784	0.493	0.43

Tabel 5. Item analysis result

Item	Point-Biserial Coefficient	Difficulty	Item Discrimination Index
1	0.800	0.35	0.95
2	0.530	0.48	0.55
3	0.493	0.82	0.33
4	0.460	0.85	0.29
5	0.605	0.83	0.31
6	0.651	0.83	0.31
7	0.670	0.68	0.52
8	0.440	0.17	0.33
9	-	0	0
10	0.117	0.03	0.04
11	0.455	0.58	0.64
12	0.405	0.82	0.33
13	0.777	0.29	0.96

This test instrument not only measures the entire concept of vectors in kinematics. However, this test instrument is also able to measure each vector concept in kinematics. According to the concept of vectors in kinematics raised, the concept is divided into Speed as a one-dimensional vector and Acceleration as a one- and two-dimensional vector as presented in Table 6.

Tabel 6. Concept analysis result

Concept	(KR-20)	Correlation	Difficulty
All Item	**0.784**		
Velocity as One-Dimensional Vector (5 Item)	0.695	0.807	0.56
Acceleration as One-Dimensional Vector (4 Item)	0.590	0.838	0.55
Acceleration as Two-Dimensional Vector (4 Item)	0.605	0.703	0.43

This test instrument can also measure students' abilities for each kinematics topic. There are two main kinematics topics discussed, namely kinematics in one dimension and two-dimensional kinematics. However, two-dimensional kinematics is divided into two, namely constant velocity and increasing velocity. This is to see students' ability to sum the centripetal acceleration and tangential acceleration vectors. The oval shape is used to see students' ability to determine the center point of the centripetal acceleration direction. The following analysis results for each topic are presented in Table 7.

Tabel 7. Topic analysis result

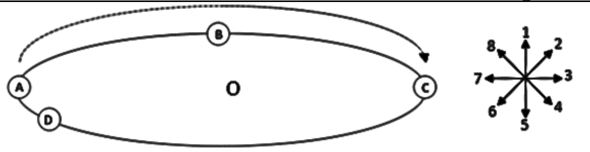
Topic	(KR-20)	Correlation	Difficulty
All Item	**0.784**		
Kinematics in One Dimension (4 Item)	0.636	0.834	0.62
Kinematics in Two Dimension with Constan Speed (4 Item)	0.744	0.788	0.63
Kinematics in Two Dimension with Increase Speed (5 Item)	0.568	0.703	0.43

The vector test instrument in kinematics was developed in the form of multiple choice (MC) and conducted field validation through paper-and-pencil. In the point-biserial

Kasuari: Physics Education Journal 7(2) (2024) 236-248
P-ISSN: 2615-2681
E-ISSN: 2615-2673

coefficient, there are several items that are below 0.2. The following Table 8 presents the text of questions no. 9 and 10.

Tabel 8. Problem script item 9 and 10

 The ball starts out at rest and then moves in a clockwise circle with increasing speed.	9. What is the direction of linear **velocity** at point A? 10. Where is the direction of total **acceleration** at point A?

This is because all students do not realize the initial state of the ball which is initially at rest. Students assume that an object that is initially at rest and will move has a linear velocity perpendicular to the trajectory. Because number 9 students do not realize that the initial linear velocity is zero, students also do not realize that the acceleration that occurs at the starting point is only tangential acceleration. This is because the acceleration is zero, because the object starts from rest. The absence of students who were able to answer correctly in number 9 and there was only one student who answered correctly in number 10, resulted in not being well captured in the level of difficulty and differentiation of the items. However, this does not really interfere with the correlation to the total score on the concept of speed and acceleration. Likewise, the correlation to the total score on the topic of kinematics in two dimensions with increasing velocity. So, both questions are still suitable to be used to capture students' abilities.

Disseminate

The test instrument was distributed through paper-and-pencil. Students were asked to draw vectors according to their ability in each question. However, in each topic the number of students who were able to do so decreased. In 1-dimensional kinematics, all students were able to do it fully. However, in 2-dimensional kinematics, the number of students who were able to work decreased. This is because students are too clueless. Just by looking at problems that students rarely encounter, students already feel they have no idea how to answer the questions given. This situation also been found out by Lichtenberger et al. (2014)

On the topic of one-dimensional kinematics, the average of four items obtained by sixty-seven students with nominal data 1 and 0 is 0.42 with the details of the average of each problem sequentially 0.15, 0.30, 0.54, and 0.64 from numbers one to four. In this topic, students made similar errors. The following Table 9 summarizes the errors often encountered in this topic.

Table 9. Distribution of common errors experienced by students in one-dimensional kinematics topic

Wrong Idea	**N**	**%**
Assuming the direction of acceleration is always the same as the velocity	37	55.22
Did not realize at the turning point the speed was zero	36	53.73
Assumes the acceleration at the turning point is zero	6	8.96
Assumes velocity and acceleration vectors are always on the *x*-axis (horizontal) and *y*-axis (vertical)	13	19.40
Incomplete knowledge of dynamics	5	7.46

More than half of the students (55.22%) thought that the direction of acceleration is always the same as velocity. This has been found in several past research results (Shaffer & McDermott, 2005; Sutopo & Waldrip, 2014; Trowbridge & McDermott, 1981). Since students assume that the acceleration vector is always equal to the velocity vector, they do not realize that at the turning point the velocity is zero. Although students realize that the velocity vector is zero, students make it a memory without realizing why this can happen. Some students who only remember, the memory is mixed with the memory of acceleration. This resulted in students considering the acceleration at the turning point to be zero.

Kinematics in two dimensions with constant velocity is less capable. This is because knowledge of tangential velocity is not often called upon. The average of the four items done by sixty students was 0.60 with the details of the average of each question in order 0.78, 0.72, 0.70, and 0.22. In addition, most students still have the same understanding of one-dimensional kinematics. The following Table 10 summarizes the distribution of errors that are often made by students in this topic.

Table 10. Distribution of common errors experienced by students in kinematics two dimension with constan speed

Wrong Idea	N	%
Unable to draw the tangential velocity vector	18	30
Unable to draw the velocity vector at an arbitrary point	13	21.67
Assuming no centripetal acceleration	4	6.67
Centripetal acceleration is equal to the direction of tangential velocity	31	51.67
Assumes velocity and acceleration vectors are always on the x-axis (horizontal) and y-axis (vertical)	2	3.33
Incomplete knowledge of dynamics	2	3.33

The most common error is dominated by students' assumption that the direction of centripetal acceleration is the same as tangential velocity (51.67%). This error is carried over from the knowledge of 1-dimensional kinematics. Students assume that 2-dimensional kinematics in a circular trajectory is the same as 1-dimensional kinematics. In addition, some students do not fully understand how to draw tangential lines. Students do not understand the meaning of tangential which has the conditions "to touch" and perpendicular to a radius. Tangential should touch only one point, but students draw tangential velocity vectors by touching two points like drawing a secant. The combination of these two errors resulted in students drawing the acceleration vector as they would a secant. On the other hand, some students have been able to draw tangential velocity vectors with vertical and horizontal parallel directions. However, when asked about the tangential velocity vector at an arbitrary point, students returned to drawing a secant line. Overall, this was still better because students realized that they were drawing vectors with straight lines. A small proportion of students drew acceleration vectors using curved lines (18.33%) following the shape of the trajectory.

The last topic was kinematics in two dimensions with increasing velocity. In this topic, the number of students who were able to do the work decreased significantly. Twenty-five students were able to work on this topic, although not all of them were able to answer correctly. The oval shape of the trajectory left students with no ideas for solutions because they had never encountered it before, so the other forty-two students chose not to work on this topic. The average of the five problems done by twenty-five students was 0.11 with the details of the average of each problem sequentially 0, 0, 0.2, 0.2, and 0.16. However, on two questions none of the students were able to answer correctly. The following Table 11 summarizes the errors made by twenty-five students working on the topic of kinematics in two dimensions with increasing speed.

Table 11. Distribution of common errors experienced by students in kinematics two dimension with increase speed

Wrong Idea	N	%
Unable to draw tangential velocity/velocity vectors	4	16
Draw acceleration as equal to the trajectory to be traveled	7	28
Not realizing a stationary object has zero velocity	25	100
Did not realize stationary objects do not have centripetal acceleration	25	100
Assuming the center of the oval as the center of centripetal acceleration	21	84
Assuming linear acceleration is different from tangential acceleration	8	32
Incomplete knowledge of dynamics	1	4
Drawing velocity/acceleration vectors with curved lines	1	4
Assuming the resultant of centripetal acceleration and tangential acceleration must be triangular	9	36

There were two questions that none of the twenty-five students answered correctly. The first question asked students to describe the velocity vector in the initial state (at rest). All students did not realize that if the object is at rest or the velocity is zero, then the velocity vector does not point anywhere. Since the initial state of velocity is zero, the centripetal acceleration is zero. This is because centripetal acceleration is obtained from the division of velocity squared to radius (v^2/r) with the initial state velocity value is zero, then zero divided by any radius value is zero. These two problems are interconnected. When students do not know that the initial velocity is zero, they do not know that the centripetal acceleration is also zero. In the initial state, the acceleration only consists of a tangential acceleration component that serves to increase the value of speed. In this topic, the changing radius of centripetal acceleration makes students inconsistent in describing the acceleration vector. This can be seen in the problem that asks students to describe the acceleration vector at any point. Eighty-four percent of students answered incorrectly because students described the centripetal acceleration towards the center of the oval trajectory.

This test instrument was developed to capture the ability of vectors in kinematics for high school students. Most students have not been able to describe vectors in kinematics (Tables 10-11). Students make think that they are physicists (Olsho et al., 2023). However, there is still a recurring error in each topic, namely students view vectors must be parallel to the cartesian *x*-axis and *y*-axis. Students tend to be capable when represented using the ij format (cartesian x and y axes), but students have difficulty with the arrow format (Heckler & Scaife, 2015). This is related to students' assumption that the way to add vectors is that the resultant vector becomes the hypotenuse of the two vectors being added. Students know the existence of tangential acceleration and centripetal acceleration due to curved motion, but students are unable to operate to determine the total acceleration vector of the two (Reif & Allen, 1992). These events indicate that vectors in kinematics phenomena are rarely used so that students assume that past knowledge of vectors does not need to be used again in kinematics material. In addition, most students draw vectors following their trajectories only. This error results in the assumption that the velocity vector is equal to the position vector (Trowbridge & McDermott, 1980), the acceleration vector is equal to the velocity, drawing vectors with curved lines, and drawing vectors with secant lines.

Discussion

Capturing Students conceptual understanding is an important area of research (Wandi et al., 2023). This study aimed to develop a test instrument and capture the vector ability in kinematics of high school students. Kinematics is highlighted in one-dimensional and two-dimensional kinematics. Overall, the reliability of the test instrument was 0.784 and reliable (Hutton, 2016). With some constraints due to test subjects not being able to do two questions due to lack of accuracy, the overall point-biserial of this test instrument is 0.493. This test instrument has been used to measure the ability of sixty-seven students in grades X and XI. The results show that there are still problems with the concept of vectors in kinematics.

Because there is no kinematics test instrument that focuses on vectors, the researcher compares it with a similar instrument even though it does not discuss vectors. The results obtained showed better results than the research of Agriawan et al. (2020). The research focuses on one-dimensional kinematics. In addition, there is research and development from Ramadhani & Ermawati (2021) which showed better results. However, in that study, only a few problems focused on vectors in two-dimensional kinematics. There is an instrument rotational kinematics but it focuses in rigid body and suitable to collage students (Mashood & Singh, 2015). However, kinematics for particle (non rigid body) and suitable for measuring high school students does not yet exist.

This research is suitable for regular high school students in Indonesia, but needs to be tried further for high school students with higher ability levels such as acceleration classes and superior classes as has been done by Mashood & Singh (2012) in accordance with the suggestions of Jufriadi et al. (2023) to expose the diversity of ability levels. The problem that has been encountered in regular students can be overcome by learning kinematics that still brings vectors in the learning process. However, the teaching process is complex, in addition to the factors already mentioned, many other factors cause this incident such as a variety of learning strategies and classroom management that varies based on the typical class handled (Kuo et al., 2020). In explaining vectors in kinematics, teachers can use the "toy model" method (Redish, 2021) to enable students to transfer observed phenomena with physics events that occur and form them into appropriate mathematical symbols. In addition, further research can also try to incorporate vector material into kinematics material in the learning process.

CONCLUSION

The test instrument developed has an average Point-Biserial Coefficient of 0.493 and reliability (KR-20) of 0.784 although there are two questions that experience problems. However, this happened because small field test samples were able to work because they were not familiar with the form of the phenomenon displayed. After the test instrument was used to measure students' vector ability in kinematics, it was found that 55.22% of students considered acceleration to be in the same direction as velocity in one-dimensional kinematics. 51.67% of students think centripetal acceleration is in the same direction as tangential velocity. 100% of students considered that a stationary body still has tangential velocity and centripetal acceleration vectors. In general, most students experienced problems in two-dimensional kinematics and the concept of acceleration vectors.

For future research, limited trials can be conducted using a larger sample and from a variety of abilities. Starting from expert students to novice students with the same proportion. With the variety of samples used, the point-biserial and reliability of the test instrument will be more precise and on target.

REFERENCES

Agriawan, M. N., Saldi, M. & Kadir, M. R. (2020). Pengembangan Instrumen Asesmen Gerak Lurus pada Mata Pelajaran Fisika SMA. *Phydagogic Jurnal Fisika dan Pembelajarannya*, *2*(2), 45–48. https://doi.org/10.31605/phy.v2i2.1492

Annisa, R., Astuti, B. & Mindyarto, B. N. (2019). Tes Diagnostik Four Tier untuk Identifikasi Pemahaman dan Miskonsepsi Siswa pada Materi Gerak Melingkar Beraturan. *Jurnal Pendidikan Fisika dan Keilmuan (JPFK)*, *5*(1), 25. https://doi.org/10.25273/jpfk.v5i1.3546

Beichner, R. J. (1996). The Impact of Video Motion Analysis on Kinematics Graph Interpretation Skills. *American Journal of Physics*, *64*(10), 1272–1277. https://doi.org/10.1119/1.18390

Doran, R. I. (1980). *Basic Measurement and Evaluation of Science Instruction*. National Science Teacher Association.

Firdaus, H. N. & Mindyarto, B. N. (2021). Pengembangan Instrumen Soal Berbasis Badge dalam Moodle pada Materi Gerak Lurus. *Unnes Physics Education Journal*, *11*(1), 109–118.

Flores, S. & Kanim, S. E. (2004). Student Use of Vectors in Introductory Mechanics. *American Association of Physics Teachers*, *72*(4), 460–468. https://doi.org/10.1119/1.1648686

Handhika, J., Sasono, M., Huriawati, F., Maisaroh, M. & Aritonang, J. (2023). Development of an Instrument to Test Understanding Kinematic Concepts. *Jurnal Pendidikan Fisika dan Keilmuan (JPFK)*, *9*(2), 79–86. http://doi.org/10.25273/jpfk.v9i2.17978

Heckler, A. F. & Scaife, T. M. (2015). Adding and Subtracting Vectors: The Problem with the Arrow Representation. *Physical Review Special Topics - Physics Education Research*, *11*(1), 1–17. https://doi.org/10.1103/PhysRevSTPER.11.010101

Hestenes, D. & Wells, M. (1998). *Mechanics Baseline Test*. American Modeling Teachers Association.

Hestenes, D., Wells, M. & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher*, *30*(3), 141–158. https://doi.org/10.1119/1.2343497

Hutton, S. (2016). Formative Assessment in the Classroom. In *Center For Teaching and Learning Excellence, Park University* (Issue May). http://www.park.edu/cetl/quicktips/formative.html

Jewaru, A. A. L., Umrotul, U., Kusairi, S. & Pramono, N. A. (2021). Senior High School Students Understanding of Vector Concepts in Mathematical and Physical Representations. *AIP Conference Proceedings*, *2330*(March). https://doi.org/10.1063/5.0043433

Jufriadi, A., Sutopo, Kusairi, S. & Sunaryono. (2023). Assessment of Kinematic Concepts Comprehension: A Systematic Review. *International Journal of Evaluation and Research in Education*, *12*(3), 1449–1459. https://doi.org/10.11591/ijere.v12i3.24546

Kuo, E., Hull, M. M., Elby, A. & Gupta, A. (2020). Assessing Mathematical

Sensemaking in Physics Through Calculation-Concept Crossover. *Physical Review Physics Education Research*, *16*(2), 020109. https://doi.org/10.1103/PhysRevPhysEducRes.16.020109

Latifa, B. R. A., Purwaningsih, E. & Sutopo, S. (2021). Identification of Students' Difficulties in Understanding of Vector Concepts Using Test of Understanding of Vector. *Journal of Physics: Conference Series*, *2098*(1), 012018. https://doi.org/10.1088/1742-6596/2098/1/012018

Lichtenberger, A., Wagner, C., Hofer, S. I., Stern, E. & Vaterlaus, A. (2017). Validation and Structural Analysis of The Kinematics Concept Test. *Physical Review Physics Education Research*, *13*(1), 1–13. https://doi.org/10.1103/PhysRevPhysEducRes.13.010115

Lichtenberger, Andreas, Vaterlaus, A. & Wagner, C. (2014). Analysis of Student Concept Knowledge in Kinematics. *Proceedings of the ESERA the 2013th E-Book Conference: Teaching and Coherence in Learning Science Education Research for Evidence Based*, *11*, 38–50.

Mashood, K. K. & Singh, V. A. (2012). An Inventory on Rotational Kinematics of A Particle: Unravelling Misconceptions and Pitfalls in Reasoning. *European Journal of Physics*, *33*(5), 1301–1312. https://doi.org/10.1088/0143-0807/33/5/1301

Mashood, K. K. & Singh, V. A. (2015). Rotational Kinematics of a Rigid Body About a Fixed Axis: Development and Analysis of an Inventory. *European Journal of Physics*, *36*(4), 45020. https://doi.org/10.1088/0143-0807/36/4/045020

Nurilma, F. R., Supriana, E. & Diantoro, M. (2023). Using STEM-Based 3D-Multimedia to Improve Students' Critical Thinking Skills in Uniform Circular Motion. *Jurnal Pendidikan Fisika*, *11*(2), 193–201. https://doi.org/10.26618/jpf.v11i2.10785

Olsho, A., Zimmerman, C. & Brahmia, S. W. (2023). *A framework for Characterizing Covariational Reasoning in Physics*. 1–17. http://arxiv.org/abs/2310.06941

Ramadhani, N. N. & Ermawati, F. U. (2021). Five-Tier Diagnostic Test Instrument for Uniform Circular Motion Concepts: Development, Validity, Reliability and Limited Trials. *Jurnal Pendidikan Fisika*, *9*(1), 73–90. https://doi.org/10.26618/jpf.v9i1.4763

Redish, E. (2021). Using Math in Physics: 4. Toy models . *The Physics Teacher*, *59*(9), 683–688. https://doi.org/10.1119/5.0025840

Redish, E. F. (2021). Using Math in Physics: 7.Telling the story. *The Physics Teacher*, *59*(7), 525–529. https://doi.org/10.1119/5.0159037

Reif, F. & Allen, S. (1992). Cognition for Interpreting Scientific Concepts: A Study of Acceleration. *Cognition and Instruction*, *9*(1), 1–44. https://doi.org/10.1207/s1532690xci0901_1

Sari, I. P. M. & Ermawati, F. U. (2021). Instrumen Tes Diagnostik Konsepsi Lima Tingkat pada Materi Gerak Lurus: Pengembangan, Uji Validitas dan Reliabilitas serta Uji Coba Terbatas. *Pendipa Journal of Science Education*, *5*(2), 152–162. https://doi.org/10.33369/pendipa.5.2.152-162

Serway, R. . & Jewett, J. . (2014). *Physics for Scientist and Engineers with Modern Physics 9th Edition*.

Shaffer, P. S. & McDermott, L. C. (2005). A Research-Based Approach to Improving Student Understanding of The Vector Nature of Kinematical Concepts. *American Journal of Physics*, *73*(10), 921–931. https://doi.org/10.1119/1.2000976

Susac, A., Planinic, M., Klemencic, D. & Milin Sipus, Z. (2018). Using the Rasch Model to Analyze the Test of Understanding of Vectors. *Physical Review Physics Education Research*, *14*(2), 23101.

https://doi.org/10.1103/PhysRevPhysEducRes.14.023101

Sutopo & Waldrip, B. (2014). Impact of a Representational Approach on Students' Reasoning and Conceptual Understanding in Learning Mechanics. *International Journal of Science and Mathematics Education*, *12*(4), 741–765. https://doi.org/10.1007/s10763-013-9431-y

Tairab, H., Al Arabi, K., Rabbani, L. & Hamad, S. (2020). Examining Grade 11 Science Students' Difficulties in Learning About Vector Operations. *Physics Education*, *55*(5). https://doi.org/10.1088/1361-6552/aba107

Thiagarajan, Si, Semmel, DS, Semmel, M. (1974). *Instructional Develoment for Traning Teacher of Exeptional Children: A Sourcebook* (p. 194).

Trowbridge, D. E. & McDermott, L. C. (1980). Investigation of Student Understanding of the Concept of Velocity in One Dimension. *American Journal of Physics*, *48*(12), 1020–1028. https://doi.org/10.1119/1.12298

Trowbridge, D. E. & McDermott, L. C. (1981). Investigation of Student Understanding of the Concept of Acceleration in One Dimension. *American Journal of Physics*, *49*(3), 242–253. https://doi.org/10.1119/1.12525

Ulfa, M. & Sucahyo, I. (2022). Development of HOTS-Based E-Modules Using Sigil Applications on Circular Motion Materials. *Jurnal Pendidikan Fisika*, *10*(2), 130–143. https://doi.org/10.26618/jpf.v10i2.7411

Viyanti, V., Rosidin, U., Suyatna, A. & Laraswati, M. (2023). Pengembangan Instrumen Soal Hots dengan Variasi Stimulus Berbasis IT pada Materi Kinematika. *Jurnal Inovasi dan Pembelajaran Fisika*, *10*(1), 1–20. https://doi.org/10.36706/jipf.v10i1.18632

Walker, J., Halliday, D. & Resnick, R. (2014). Fundamentals of Physics. In *Wiley* (10th ed.).

Wandi, W., Mardianti, F., Suwarma, I. R. & Liliawati, W. (2023). Theory and Practice of Conceptual Understanding in Physics Education: A Literature Review and Bibliometric Analysis of the Recent Decades. *Kasuari: Physics Education Journal (KPEJ)*, *6*(2), 107–117. https://doi.org/10.37891/kpej.v6i2.483

Zavala, G., Tejeda, S., Barniol, P. & Beichner, R. J. (2017). Modifying the Test of Understanding Graphs in Kinematics. *Physical Review Physics Education Research*, *13*(2), 1–16. https://doi.org/10.1103/PhysRevPhysEducRes.13.020111