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Assessment of kinematic concepts comprehension: A systematic review

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ABSTRACT

A systematic study on the development of the assessment instrument of the concept of kinematics which is one of the basic concepts of physics has not yet been conducted. This systematic study reported the characteristics, quality, effectiveness, and efficiency of the instrument assessment regarding the concept of kinematics. This systematic review method has used a systematic approach based on the practical guidelines of systematic reviews by Petticrew and Roberts and has used PRISMA diagrams for the process of searching and selecting articles, who reviewed 12 articles published between 1985 and 2021. The research findings show that the instrument of concept mastery of kinematics using multiple-choice formats, while others combine the true-false and multiple-choice formats. Almost all instruments of mastery of the concept of widely used kinematics have reported validity assessment (content validity, construct validity) and internal consistency reliability. However, predictive validity, discriminatory validity, and temporal stability reliability have not been reported. Other results indicate that the development of further assessments must pay attention to five important aspects: the validity and reliability of instruments, the scopes and specificity of the concept of kinematics, the conformity with the intellectual level of students, the effectiveness and efficiency of instrument assessment, and the fulfillment of research gaps. This study can help educators and researchers choose and develop an appropriate instrument assessment to reveal students' understanding of the concept of kinematics.

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1. INTRODUCTION

The concept of student knowledge is built by their interactions with the environment. What they are experiencing, what they see, what they feel, will build insight into a particular phenomenon and concept. The investigation into the general understanding of students to the concept of physics is very important research [1]. One of the basic and important concepts in physics is kinematics. The concept of kinematics is one of the very important physics branches. The correct student understanding of the concept of kinematics will affect almost all concepts in physics [2], [3], because kinematics is a basic concept of other physics branches [4] such as mechanics, efforts and energy, impulses and momentum, even the concept of kinematics also becomes the basis for studying thermodynamics, magnetic electricity, and hydrodynamics [5]. So, the

mastery of the concept of kinematics will have a direct impact on mastering the concept of other physics. The simple example is the link between velocity and force on the concept of Newton's mechanics. The correct relationship between velocity and force is that the force is proportional with changes in velocity [6]. Incorrect understanding of velocity causes an incorrect understanding of force. If students cannot distinguish between speed and velocity, between velocity and acceleration [3], [7]–[9], the students will automatically have difficulty understanding the concept of force correctly.

The importance of the concept of kinematics has led to many studies to find out and explore students' understanding of kinematics concepts and the difficulties experienced in understanding the concepts, including investigation of students' understanding of displacement, speed, velocity, acceleration, vector kinematics, linear and angular acceleration, and understanding of graphs in the context of kinematics [3], [7]–[20]. Thus, many studies have been conducted to develop assessments that can be used to investigate the understanding of kinematics concepts. The development of an assessment instrument for understanding the kinematics concept has been initiated by Halloun and Hestenes by developing a mechanic diagnostic test and followed by the development of an assessment instrument by other researchers, such as mechanics baseline test (MBT), test of understanding graphs in kinematics (TUGK), inventory on rotational kinematics (RKI), representational competence in kinematics (KiRC), and kinematics concept test (KCT), force concept inventory (FCI), force and motion conceptual evaluation (FMCE), rotational and rolling motion conceptual survey (RRMCS), representational variant of the force concept inventory (R-FCI), force velocity acceleration (FVA) test, test of understanding of vectors (TUV), and two half-length FCI [2], [7], [21]–[31].

Some research on the review of the development of instrument assessment of the concept of mastery has been carried out. The results show that the diagnostic instruments used in revealing student science concepts include interviews, open tests, multiple choice tests, and multiple tier tests [32]–[34]. Review of the development of concept mastery assessment instruments still reveals in general instruments in the field of science, and still reveals the format of instruments used, the advantages and disadvantages of the instrument format, as well as the validity and reliability of the instrument. However, research conducted to review the instrument assessment article of the special concept of physics, especially the concept of kinematics which is widely used, the concept of kinematics that has been adequately assessed, the effectiveness and efficiency of assessment of kinematic concepts comprehension (KCA) still has not been carried out.

This study has systematically reviewed 12 existing KCA instruments that have been widely used from 1985 to 2021. This study presents and discusses the characteristics and quality of existing KCA instruments, as well as matters that must be considered in developing an adequate KCA instrument in the future. This systematic study aims to presents a systematic and comprehensive study of the characteristics and quality of existing KCA instruments and the things that must be considered in developing further KCA instruments in the future.

2. RESEARCH METHOD

This research has been carried out with a systematic and structured approach based on the practical guidelines of systematic reviews by Pettticrew and Roberts. Systematic review procedures are carried out in a structured and comprehensive in the selection and search literature, identify, assessment, and synthesis of all studies that are relevant to certain topics [35]. The systematic and structured approach consists of several stages that must be done in stages, namely: defining research questions, assigning eligibility criteria, searching and screening article, critically appraising article, deep reviewing of article, and disseminating findings as presented in Figure 1.

The research question of the study has been described as: i) How the characteristics and quality of instrument assessment of the concept of kinematics are?; ii) What kinematics concepts have been adequately assessed; iii) How the effectiveness and efficiency of the KCA are?; and iv) How to develop the next KCA instrument? The second stage is the assign eligibility criteria which is used as the basis for determining the feasibility of the article reviewed. Articles are considered feasible and relevant if they meet some of the following inclusion criteria: i) Article expressly states that the concept of physics studied is the concept of kinematics and or its parts; ii) Articles report and discuss the instruments assessment of the concept of kinematics; and iii) Articles published between in 1985 to 2021, where 1985 was the beginning of the development of a professional understanding of physics concept assessment instrument carried out by Halloun and Hestenes.

The article that is relevant to research is identified in scientific journals in the field of science education, physics education and in several main databases, namely APS Publications, AAPT Publications, IOP Publishing, and other publications. Searches are made using a combination of several terms related to the concept of kinematics (motion, distance, displacement, speed, acceleration, and vector) and instruments (test, size, scale). In addition, the search was also done using a snowball strategy by searching for articles from

the eligible reference article. Search and selection in the article review process used the PRISMA diagram [36], [37] as presented in Figure 2.

The searching for scientific journals in the field of science education and physics education in the main database have found 171 articles. About 22 articles are eliminated because of duplications. The 149 articles are then filtered by title and abstract according to the specified research objectives. About 45 articles include being issued, then 104 remaining articles are evaluated and assessed thoroughly with predetermined inclusion criteria. Finally, there are 12 articles that meet the criteria and conducted a review in depth. The in-depth study on the article was done by criticizing and synthesizing the research findings. Some important data from reviewed articles has been recorded, including: characteristics and quality of KCA instruments that are considered based on general assessment standards used widely, namely validity and reliability, the concept, effectiveness and efficiency of the KCA. After that, the findings and recommendations from the in-depth study were written in the following review article.

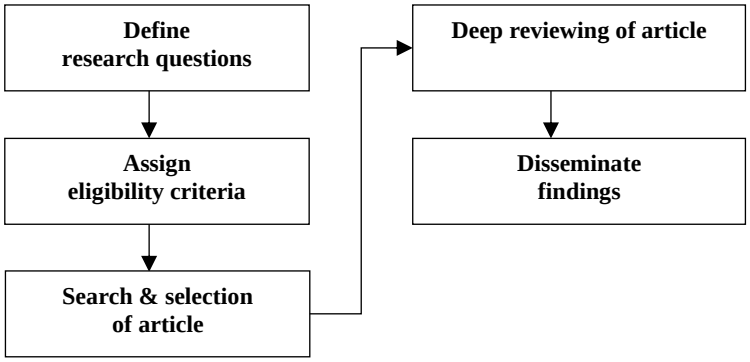

Figure 1. Modification of systematic review [35]

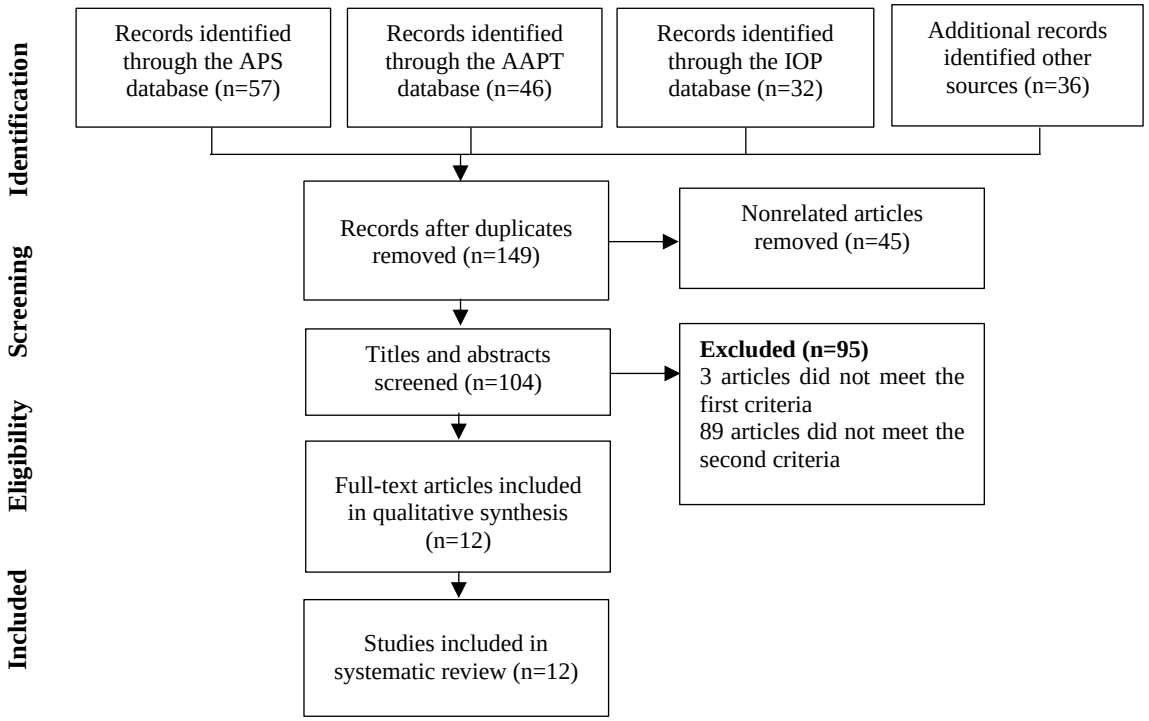

Figure 2. PRISMA Flow diagram of the articles search and selection

3. RESULTS AND DISCUSSION

3.1. Characteristics and quality of the assessment instrument of kinematics concept

Characteristics of 12 KCA instruments that have been reviewed and reported on assessment instruments and student kinematics concepts understanding are shown in Figure 3. Most of the KCA instruments have been developed by 2-3 researchers as seen in Figure 3(b), and have increased the number of research on the development of the KCA instrument in the past few times. The growth of research on the development of the KCA instrument from 1985 until now as seen in Figure 3(a), showed that many researchers considered the development of assessment to reveal students' understanding. Especially revealing students' understanding before implementing the learning process [1], [38]–[40].

Even when compared between the 2011-2020 period with the previous period 2001-2010, there was an increase in the number of developing KCA instruments to 300%. Most of the research samples that have been used are college students as seen in Figure 3(c), with the number of test items that have been developed varied as shown in Figure 3(d). Almost all KCA instruments have been developed using the multiple-choice test (MCT) reaching 92.3% and the rest was developed with the MCT and multiple true false (MTF) format. MCT is a form of assessment that has been widely used in science education to investigate, identify, and assess students' understanding of certain science topics [41]. In fact, many other instruments assessment formats that can be developed include interviews, question test, question test and interviews, multiple choice test, and multiple-tier test.

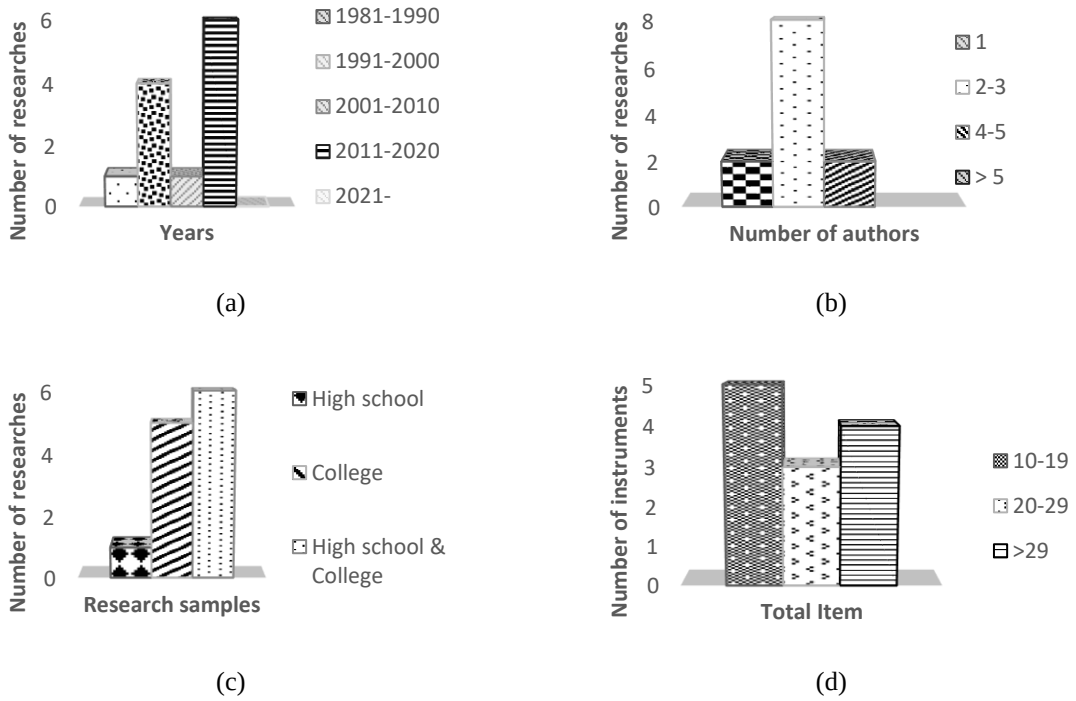

Figure 3. Characteristics of assessment instrument in (a) publication's years, (b) number of authors, (c) research samples, and (d) number of item test

In general, all the instruments' formats have their respective advantages and disadvantages. Of the thirteen developed KCA instruments, none of them use the format of interview, open-ended or other formats, although the interview is one type of instruments that can reveal the understanding of the concept of kinematics in details. Interview is one of the methods to investigate the cognitive structure of students in depth, uncover student misconceptions and knowledge, identify what students think about a concept with a relatively small sample size, and very focused on student understanding [32], [42], [43]. In addition, interviews can be used to strengthen the ability of students in developing ideas and training communication skills. Interview techniques that are widely used to uncover the understanding of the concept of student kinematics are individual demonstration interview, resembles clinical interviews developed by Piaget [16], phenomenographic interviews [18], [44], prediction-observation-explanation [45], [46], and teaching experiment [47].

Interviews are actually a very complex process [48], which allows many things revealed differently from the reality. One problem in implementing interviews is the long time needed. Also, more samples are needed to get more general conclusions and complete the interview. In addition, other difficulties in implementing interviews are needed with its own communication skills to produce good data and analytical processes that tend to be more difficult than other methods. Likewise with the open-ended question that gives the broadest freedom to students to provide reviews, arguments, and respond to questions presented, so that students' understanding of certain concepts will be more overall and deeply revealed [49]. However, the same as the interviews, the student's response to the open-ended question is difficult to analyze and be interpreted due the poor quality of sentences [50].

Among some instruments assessment formats used to reveal the understanding of student concepts, MCT is a format used by almost all KCA instruments, such as the TUGK, RKI, KiRC, and KCT. Likewise other well-known assessments developed with wider concept coverage. However, some of these assessments were used revealing kinematics concepts comprehension, such as mechanics diagnostic test (MDT), MBT, FCI, FMCE, RRMCS, R-FCI, FVA test, TUV, and two half-length FCI. Multiple choice is a solution to the problem of long-time requirements and difficult analysis of interviews and open-ended questions because it is able to assess the students' concept understanding quickly, practically and simpler with a large scale of research samples. However, developing assessments with a good and reliable multiple choices format is not an easy job. Another disadvantage of multiple choices is not able to describe the conceptual understanding of students in depth and detail [51] and cannot distinguish the correct answers for correct or wrong reasons.

3.2. Validity and reliability of KCA instruments

The study of KCA instruments is based on general assessment standards, namely validity and reliability. The nature of the validity and reliability that has been examined is the content validity, construct validity, predictive validity, discriminatory validity, internal reliability of temporal consistency and stability. The KCA instruments are reviewed based on standards that are generally accepted today, namely validity and reliability. Validity and reliability of the instruments are shown in Table 1. However, from the four properties of validity that have been examined, all instruments do not report predictive validity and discriminatory validity. Even some instruments on the original version do not report the validity and reliability of the instruments developed.

Table 1. Validity and reliability on KCA instruments

Instruments	Study	Validity		Reliability
		Content	Construct	
MBT	Hestenes and Wells [2]	E, P		
FVA	Rosenblatt and Heckler [7]	E, P	IRT	KR-20
R-FCI	Nieminen *et al.* [21]	E, P		KR-20
RRMCS	Rimoldini and Singh [22]	E, P		
FMCE	Thornton and Sokoloff [23]	E, P		
TUV	Barniol and Zavala [24]		IRT	
TUGK	Beichner [25]	E, P	IRT	KR-20
FCI	Hestenes *et al.* [28]			
KiRC	Klein *et al.* [29]	E, P	IRT	KR-20
KCT	Lichtenberger *et al.* [30]	E, P	EFA, IRT	KR-20
MDT	Halloun and Hestenes [52]	E, P		KR-20
HFCI	Han *et al.* [53]		IRT	

E: Expert judgement; P: Target population; KR-20: Kuder & Richardson; IRT: Item response theory; EFA: exploratory factor analysis

Table 1 shows that content validity is reported by almost by all KCA instruments involving expert judgment and research target populations. However, construct validity and internal consistency assessments are not reported by all instruments. We do not find evidence of the validity and reliability of the first version of FCI that has been developed by Hestenes *et al*. In fact, in the following research, many studies have analyzed the validity and reliability of the FCI instruments using the response item theory, exploratory factor analysis and confirmatory factor analysis [54], [55]. Content validity is one of the most important validity since it provides important evidence on the extent to which relevant and comprehensive instrument items represent the researched construct, and can determine the extent to which the target population understands and interprets the desired instrument items [34], [56]. Content validity is assessed by the expert panel to check the test item in terms of difficulties, clarity, mistakes, relevance or represent the content domain [57], [58]. Expert assessment of the validity of the contents of the instruments developed can increase the accuracy of the construct measurement studied [59].

In addition to content validity, construct validity is also important in developing an instrument because it determines the extent to which the measurement accurately reflects the construct. Therefore, to test the validity of the constructs, a separate assessment of these constructs is needed using exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). KCA instruments generally only use EFA and/or Item Response Theory in analyzing the validity of the construct. Only KCT instruments use EFA, although there is a recommendation to perform analyzes with EFA and CFA respectively [60].

All KCA instruments did not show evidence of predictive and discriminatory validity. This explains that predictive validity has not been considered important in revealing students' mastery of kinematics concepts. The KCA instrument is not intended to predict students' future success in achievement or career, although students' positive attitudes towards science can affect future achievement or career outcomes [61], [62]. Likewise, discriminatory validity can distinguish attitudes and mastery of concepts between groups of men and women [63]. In addition to the nature of validity, reliability has been shown by several KCA instruments that have been calculated using the KR-20 formula. This formula has been widely used in physics education research to determine stability in measuring student abilities.

3.3. Kinematics concepts that have been assessed

Concept understanding is general and abstract knowledge of the main concept and other supporting concepts [64]. Information on understanding students' initial concepts has important meaning for teachers. Especially information about students' prior knowledge that is not in accordance with general concepts and cannot be accepted scientifically. This information can be used as a reference for developing learning strategies in the learning process [65]. Thus, students' understanding of physics concepts can be improved. In physics learning, one concept mastery will affect the others due to the close relationship between one concept and another. One example is the concept of kinematics, students' understanding of this concept will affect their understanding of the concepts of dynamics, hydrodynamics, and thermodynamics [5]. Other studies have also revealed that helping students understand basic physics concepts and solve problems related to physics concepts is one of the main goals in physics learning [4].

The KCA instrument that has been used to reveal students' understanding of kinematics concepts can be divided into three groups. First, the KCA instrument is only used to reveal the understanding of kinematic concepts, such as TUGK, KiRC, and KCT. Second, assessment instruments that reveal the concept of kinematics and other physics concepts such as MDT, MBT, FCI, FMCE, RRMCS, RKI, FVA, HFCI, and TUV. The kinematic concepts assessed from each of the KCA instruments are shown in Table 2. Each KCA instrument has assessed the basic concepts of kinematics but has not shown a thorough assessment of the kinematics concept if it is based on the basic concepts of kinematics, including position, distance, displacement, time, average velocity, instantaneous velocity, and acceleration [66], [26]. Based on the coverage of the kinematics concept, TUGK, KiRC and KCT are adequate KCA instruments to assess the kinematics concept. However, the instrument still leaves several kinematic concepts that have not been assessed, for example the differences in the concepts of distance and displacement, concept of distance and displacement with mathematical representation.

Table 2. Kinematics concepts assessed by KCA instruments

Instruments	Format	Items	Kinematics concepts assessed
MDT	Multiple choices	36	Speed; Direction change
MBT	Multiple choices	26	Constant acceleration; Average acceleration; Integrated displacement; Tangential acceleration; Normal acceleration
FCI	Multiple choices	30	Velocity and position; Acceleration and velocity; Constant acceleration in a parabolic orbit; Changing speed; Vector of velocities
TUGK	Multiple choices	21	Velocity on the position-time graph; Acceleration on the velocity-time graph; Displacement on the velocity-time graph; Change in velocity on the acceleration-time graph; Determining another suitable graph on the kinematic graph; Determining textual descriptions that match the kinematic graph; Determining the graphic that matches the description of the textual movement
FMCE	Multiple choices	43	A velocity-time graph; Constant velocity; Direction change; Increasing velocity (constant acceleration)
RRMCS	Multiple choices	30	Angular speed; Angular velocity; Angular acceleration
FVA	Multiple choices	16	Velocity; Acceleration
RKI	Multiple choices	18	Angular velocity; Angular acceleration
TUV	Multiple choices	12	Graphical of vectors on 1D in velocity context; Graphical of vectors on 2D in velocity context; Graphic representation of a vector in velocity context
HFCI	Multiple choices	14	Free fall motion; Circular motion; Projectile motion; Kinematics; Force motion
KiRC	Multiple choices, multiple true-false	18	Uniform motion; Angular velocity; Nonconstant acceleration; Constant acceleration; Vector subtraction; Vector decomposition
KCT	Multiple choices	49	Displacement as area; Velocity as rate, 1D and 2D vector; Acceleration as rate and 1D vector; Velocity change as area

3.4. Effectiveness and efficiency of KCA instruments

Based on the number of test items on each developed KCA instrument for revealing students' understanding of kinematics concepts Figure 3(d), the test is divided into 3 groups, namely KCA with 10-19 items, KCA with 20-29 items, and KCA with more than 29 items. Several KCA instruments that have been developed show more than 29 items, including MDT, FCI, FMCE, and KCT. With a very large number of test items, students need a very long time, effort, and high concentration which will drain their energy and mind. For teachers, the very large number of test items will also require a long time in the process of analyzing student responses and interpreting them. KCA instruments with a very large number of test items cannot be used to reveal students' understanding of kinematics concepts quickly and precisely, but rather reveal students' understanding of kinematics concepts in depth. Meanwhile, a very limited number of questions will not be able to reveal a complete understanding of the concept of kinematics. The next KCA must have an ideal number of items, namely an assessment with a small number of questions but able to measure understanding of kinematics concepts as a whole. The ideal number of test items will produce effective and efficient assessment instruments and can be used to measure the exact dimensions and easily measure students' understanding and level of competency [67].

3.5. Implications for further development of KCA instruments

Sustainable research and improvement are an important part to continuously improve and enhance students' conceptual understanding. In this section we propose five things that must be considered for the development of further assessment instruments, especially the development of KCA instruments. Without reducing the importance and great contribution of the previous development of assessment instruments, especially in the field of physics education. It is hoped that the developed KCA instruments will be more adequate to measure and reveal students' understanding of kinematics concepts.

3.5.1. Evidence of validity and reliability

Further research on the development of the KCA instrument is recommended to show evidence of validity (content validity, construct validity, predictive validity, discriminatory validity) and reliability (consistency of internal reliability and temporal stability). The KCA instrument is expected to be able to reveal the students' mastery of kinematic concepts, so assessing content and construct validity is very important to do. The content validity of the KCA instrument to be developed must be checked by a panel of experts in the field of kinematics to determine whether the test item developed has measured the kinematics concept being assessed. After that, a trial should be conducted on the KCA instrument in assessing the validity of the construct, which is used to determine the sample's ability to translate and understand the KCA instrument.

3.5.2. The scope and specification of the kinematics concept

Among the KCA instruments that have been developed to reveal kinematics concepts comprehension, many instruments have only been developed to reveal the part of the kinematics concept that is considered important, such as only about revealing students' understanding of velocity, acceleration, or distance and displacement [3], [38], [39], [68]. The results of the study on the velocity concept revealed that students did not relate speed to the ratio of displacement and time required, also believed that position could be used to measure velocity. The results of research on understanding acceleration show that students assume the same acceleration of two objects is caused by the slope of the plane of the same trajectory and depends on its final position. In addition, research on the concepts of distance and displacement shows that students do not distinguish between the concept of distance and the concept of displacement.

The findings of this study come from different studies with limited and different groups of students, so the results obtained are only part of the student kinematics concepts comprehension. In addition, because the kinematics concept is one of the basic and important concepts and the most difficult concept in mechanics [2], it is important to develop an assessment instrument that is specifically in accordance with the characteristics of the kinematics concept and is not integrated with other concepts so that further development can be more specific. Some of the existing assessment instruments still combine some of the kinematics concepts with other concepts such as force, including MDT, MBT, FCI, FMCE, FVA test, TUV, R-FCI. Therefore, the next assessment instrument is an assessment instrument which was developed to cover the essential concepts of kinematics as a whole [66] and is only used to reveal students' kinematics concepts comprehension.

3.5.3. Conformity to the student's intellectual level

The concept of kinematics is one of the concepts of physics that has been taught to students from middle school to university. Differences in education levels generally affect the intellectual level of students. Therefore, it is very important to develop a quality KCA instrument and specifically adapted to the level of

education taken so that the KCA instrument can work optimally on the intellectual level of students and produce a good picture of students' kinematics concepts comprehension, so that the design of strategies and interventions in learning can conducted properly. Several instruments that have been developed, such as TUGK, MDT, MBT, FCI, and FMCE, are designed to reveal kinematics concepts comprehension from various educational levels ranging from high school to university level. Research that has been done shows that understanding the concept of higher education level is better than that of lower education level. TUGK, MDT, MBT, FCI, and FMCE seem difficult to complete by secondary schools, especially junior high schools.

The next assessment should be developed according to the level of students' intellectual development and education level (junior high school, high school or university), so that the results obtained are not biased. To ensure the validity of the content and process of developing instruments from each level of education, it is necessary to involve appropriate teaching experts so that schools at the lower education level are avoided from the context of complex problems that are suitable for higher education levels. On the other hand, for the higher education level, there will be no simple problems that are suitable for the lower education level.

3.5.4. Effectiveness and efficiency

The next thing that must be considered in the development of KCA is the effectiveness and efficiency of the developed instrument. The next assessment serves to measure, assess and reveal students' kinematics concepts comprehension accurately and quickly by considering the heavy burden for students or teachers in the learning process because physics lessons last about 90-100 minutes per meeting. The student curriculum and the busy teacher activities will make students and teachers tired so that the development of an effective and efficient instrument must be the next assessment option. In the future, the development of an effective and efficient KCA instrument is the right and wise choice. An effective and efficient instrument will not interfere with and increase the burden on students in the learning process, while for teachers, it will require a relatively short time in the assessment process, analysis of assessment results, and interpretation of the results of the analysis that has been carried out.

Based on the number of developed KCA test items, the number of subsequent KCA instrument items should be no more than 30 items because too large number of items will take a very long time in the student response and interpretation process. In addition, it will require high concentration and drain the mind. Several assessment instrument developments have begun to consider the number of test items, such as the development of the HFCI which divides the FCI into two parts, namely from 30 test items divided into two with 15 items each. The basic consideration for this division is the length of time required to complete the test [53]. Then, the test of basic mechanics conceptual understanding (bMCU) has developed an assessment instrument with 12 test items with consideration of efficiency [65].

3.5.5. Fulfillment of research gap

Further development of KCA instruments must be able to improve the instruments that have been developed. KCA instruments are more adequate than before. Some of the gaps in the KCA instrument that have been developed can be based on the scope and specificity of the kinematics concept, suitability to the intellectual level of students, as well as the effectiveness and efficiency of the instrument. Based on the scope of kinematics concepts, further development of KCA must add an assessment of the concepts of distance and displacement differences, the concepts of distance and displacement with mathematical representations. Based on the intellectual level of students, the assessment can be further divided into assessments for junior high school level, senior high school level, and university level.

4. CONCLUSION

This study has reviewed 12 KCA instruments used to reveal students' understanding of kinematics concepts. The results show that all KCA instruments that have been developed use the multiple-choice formats, some instruments have not shown evidence of their validity and reliability, and there are several kinematic concepts that have not been assessed from the instrument. Based on the results of this study, there are five things that must be considered for further research in developing better KCA instruments: validity and reliability, scope and specification of kinematic concepts, student's intellectual level, effectiveness and efficiency, and research gap.

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