The application of smartphone sensors to promote cognitive abilities easier and more effective physics learning

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Abstract. The use of sensor on smartphones as physics learning media encourages teachers to reconstruct teaching methods. This paper presents the effect on students’ cognitive abilities using an accelerometer and a gyroscope sensor simultaneously in learning circular motion, as well as students’ responses and the effectiveness of sensor media on smartphones used. A pre-experimental research design was used in this study which involved 12 students of XII MIPA at SMA Negeri 1 Pagaden Subang Jawa Barat. They learned circular motion guided by the smartphone sensors-based worksheets and were tested using an essay test for cognitive abilities measurements. Meanwhile, students’ responses and the effectiveness were obtained using a Likert scale questionnaire. The improvement of students’ cognitive abilities was significantly higher than the pretest which was obtained from the N-gain with a final value of 0.41. Worksheets using smartphone sensor media were more effective than conventional learning. In addition, students showed a positive response in which 93.75% of students were interested, 85.42% were motivated to learn the circular motion, and 91.14% of students became easier in understanding physics concepts.

1. Introduction
Education is an effort to develop individual abilities and personalities through the teaching process, guidance, and interaction with the environment in a conscious and planned manner to achieve full human potential [1]. Effective education will be able to produce better quality future generations.

Education cannot be separated from the learning and teaching process. This makes efforts to improve the quality of education need to be balanced with efforts to improve the effective teaching and learning process. An effective learning process can be demonstrated by creating a conducive learning atmosphere. One of the components that plays an important role in creating an interactive, effective, and constructive learning atmosphere is the use of learning media. Learning media can be able to stimulate students’ thoughts, learning motivation, and curiosity, and able to focus students’ attention in the learning process [2].

Nowadays, learning media is not only focused on conventional media, but also new media. Along with the development of technology, it leads educators to always link the learning process with the latest technology. Many of them are competing to develop attractive learning media, such as Flipbook which is Islamic literacy-based physics learning media [3], Physics-Science Monopoly (MOFIN) game media on Particle Dynamics material [4].

The type of learning media that has not received much attention is the use of smartphones as a media for learning physics. The use of smartphones as a learning media in physics is considered unusual
by some educators. The unusuality occurs due to the lack of educators' knowledge regarding the procedures for optimizing smartphones as a learning media, as well as educators' ignorance in managing classes that involve learning with the use of mobile devices or smartphones [5,6].

Whereas, smartphones have features that can be used as physics practicum-based learning media. One of the features that can be used as practicum media is the sensor which is embedded in each smartphone. Several sensors are found on smartphones, such as accelerometer, gyroscope, proximity, light, pressure, orientation, GPS, humidity, and magnetometer [7].

The use of various sensors on smartphones for measuring physical quantities is quite interesting to study, and it becomes an ongoing research in recent years [8,9]. Research that uses one sensor to find real physical quantities is a magnetometer sensor to find gravitational acceleration value [10], an accelerometer sensor to measure free-fall motion [11], a light sensor that can be used to study oscillations [12], and magnetic sensor to measure the magnetic field of a small magnet [13]. While research that uses two sensors simultaneously is the gyroscope and accelerometer sensors to study the oscillation material [14], rotation and accelerometer sensors to examine the relationship between angular velocity and centripetal acceleration [15], rotation and accelerometer sensors to find the rotation angle and the acceleration of physical pendulum [16], and two sensors (gyroscope and accelerometer) combination to get accurate orientation estimates [17].

The use of sensors on smartphones will continuously develop to date, including the use of accelerometer and gyroscope sensors simultaneously in a circular motion [8,14,15,16,17]. This paper describes the effect of using two smartphone sensors (accelerometer and gyroscope sensors simultaneously) based on learning media on cognitive abilities. It also reveals students’ responses and the effectiveness of using smartphone sensors in learning circular motion. Therefore, this study is expected to provide an overview of the use of smartphone sensors in learning physics and its effect on cognitive abilities, motivation, learning easiness, and learning effectiveness.

2. Experimental Method
The research method used in this study was before-and-after design, employed one group pretest-posttest design, which was carried out only by one experimental class without a control class. Before students take measurements using smartphones, students were introduced to the use of smartphone sensors as a previous measurement device [18].

The sample of this study consisted of 12 students who were determined using a purposive sampling technique from the population of XII MIPA students at SMA N 1 Padegan (Senior High School 1 Padegan) in the 2020/2021 academic year as a result of the COVID-19 pandemic. Students as sample learned circular motion material twice, assisted by worksheets based on smartphone sensors (simultaneous use of an accelerometer sensor and a gyroscope) and worksheets without smartphone sensors.

Students’ cognitive abilities were measured using an instrument test consisting of indicators of applying, analyzing, and evaluating dimensions [19]. The test instrument is provided in the form of questions and arranged in the form of a worksheet. The effect of learning media is determined by analyzing student’s cognitive abilities from the score of each question and the score of each student, comparing them before and after treatment (N-Gain Score) [20]. The final results were categorized into four groups, namely poor \((x \leq 50)\), fair \((50 < x \leq 65)\), good \((65 < x \leq 80)\), excellent \((x \geq 80)\). Meanwhile, the students’ responses and the effectiveness of using two smartphone sensors in circular motion learning were obtained using a Likert scale questionnaire in the range 1-4 [21].

3. Result and Discussion
Students’ cognitive abilities were revealed from the answers on the worksheets. Each indicator on the worksheet was able to show students’ cognitive abilities. The analysis results of students’ cognitive abilities on the worksheet are shown in Table 1.
The data in Table 1 shows the diverse cognitive abilities of students. Several indicators are categorized as fair or even poor, and there are also several indicators that are categorized as good to excellent. Indicators that are categorized as poor are the indicator of deriving the equations of the relationship between linear velocity and angular velocity, the indicator of calculating the angular velocity based on practicum results data, the indicator of analyzing the comparability equations of non-uniform motion in a straight line to non-uniform circular motion, and the indicator of proving the comparability of the theoretical calculated angular acceleration to the sensor readings on the non-uniform circular motion material. While indicators that have less average scores or are categorized as fair are the indicators that use practicum results data which are converted into the answers that can be used in the calculations and the indicators that prove the comparability of the score obtained in the

| Table 1. Average N-gain for each indicators of cognitive abilities. |
|---------------------------------------------------------------|
| Aspect | Indicators | Pre test | Post test | N Gain | Interpretation | Final result |
|--------|-------------|----------|-----------|--------|----------------|--------------|
| Analyzing | Analyzing the magnitude of frequency and period | 64.83 | 92.36 | 0.78 | High | Excellent |
| | Analyzing linear distance and angular position | 51.39 | 58.33 | 0.14 | Low | Fair |
| | Deriving the equations of the relationship between linear velocity and angular velocity | 40.51 | 50.00 | 0.16 | Low | Poor |
| | Analyzing the relationship between angular velocity with the period and frequency | 60.51 | 83.33 | 0.58 | Moderate | Excellent |
| | Analyzing the comparability of the theoretical calculated angular velocity to the sensor readings on the Uniform Circular Motion. | 45.54 | 79.17 | 0.62 | Moderate | Good |
| | Analyzing the comparability equations of non-uniform motion in a straight line to non-uniform circular motion | 46.82 | 55.21 | 0.16 | Low | Fair |
| | Analyzing the comparability of velocity graph in non-uniform motion in a straight line to the velocity graph in a non-uniform circular motion | 53.97 | 82.29 | 0.62 | Moderate | Excellent |
| | Analyzing centripetal acceleration | 59.67 | 81.25 | 0.54 | Moderate | Excellent |
| | Analyzing centripetal force | 49.75 | 68.75 | 0.38 | Moderate | Good |
| | Analyzing two wheels and a belt | 55.85 | 83.33 | 0.62 | Moderate | Excellent |
| | Calculating the period and frequency | 43.95 | 68.75 | 0.44 | Moderate | Good |
| Applying | Calculating the angular velocity based on practicum results data | 40.38 | 52.08 | 0.20 | Low | Fair |
| | Calculating the angular displacement in a uniform circular motion. | 42.76 | 65.63 | 0.40 | Moderate | Good |
| | Calculating centripetal acceleration | 57.74 | 85.42 | 0.65 | Moderate | Excellent |
| | Calculating the linear and angular speeds in two wheels and a belt | 44.15 | 58.33 | 0.25 | Low | Fair |
| | Proving the comparability of the theoretical calculated angular velocity to the sensor readings on the non-uniform circular motion | 40.67 | 77.08 | 0.61 | Moderate | Good |
| Evaluating | Calculating the angular displacement in a uniform circular motion. | 42.76 | 65.63 | 0.40 | Moderate | Good |
| | Calculating the linear and angular speeds in two wheels and a belt | 44.15 | 58.33 | 0.25 | Low | Fair |
| | Proving the comparability of the theoretical calculated angular acceleration to the sensor readings on the non-uniform circular motion | 41.27 | 53.13 | 0.20 | Low | Fair |
practicum with the theoretical calculation results. Students had difficulty in choosing practicum data needed for calculations and analysis with the other data that are not needed. Errors in choosing these data eventually led students to get inappropriate answers. Meanwhile, indicators that have the highest score category which is categorized as excellent are the indicator of analyzing the magnitude frequency and period, the indicator of analyzing the relationship between angular velocity with the period and frequency, the indicator of analyzing the comparability of velocity graph in non-uniform motion in a straight line to the velocity graph in a non-uniform circular motion, the indicator of analyzing centripetal acceleration, the indicator of calculating centripetal acceleration, and the indicator of analyzing two wheels and a belt. Most of the indicators that get high scores are indicators of the cognitive ability to analyze. The analysis that was carried out is the analysis based on the relevant theory which leads students to not experience errors in choosing practicum data. The absence of these errors made students be able to analyze circular motion material based on the theory properly.

Although there are several indicators that are still in the low category, overall the three indicators of cognitive ability tested on students have increased in value from the pretest to the posttest. The average pretest value of students was 49.40 and an increase of increased by 20.86 become to 70.26 in the posttest. The increase in student scores shows that smartphone sensor-based worksheets are able to help students improve the quality of learning so as to improve students' cognitive abilities. The magnitude of the increase is measured in N-gain with a final value of 0.41. The results of the N-gain calculation are in the medium category because they are in the range 0.3 < N-gain > 0.7.

The acquisition of students’ cognitive abilities on several indicators which have not been maximized might be caused by the increase in the complexity of the experimental task [22]. Conducting experiments requires more skills and knowledge [23]. Skills in experimental activities involve a sensual part, an intellectual part, and a kinetic part [24]. Students are also required to be able to analyze experimental data and compare it with the theoretical models [23].

![Figure 1. Students’ responses](image)

However, although students’ cognitive abilities achievement has not been maximized, the use of smartphone sensors in learning activities provides easiness, motivational encouragement, and interest in learning for students. The data from the questionnaire presented in Figure 1 shows that 93.75% of students were interested in learning using smartphone sensors and 85.42% were motivated to learn the circular motion. Moreover, 91.14% of students also stated that the worksheets based on the use of smartphone sensors were able to make them easier in understanding physics concepts.

This students’ easiness is supported by the presence and application of mobile devices and network technology [24]. There are a lot of hardware and software on smartphones that can be used as learning media, not only sensors, but also other applications such as cameras, portable digital assistants (PDAs), Short Message Service (SMS) via mobile phones, and podcasts via MP3 players [25]. However, the use of sensors on smartphones in physics learning can be used as a measuring tool to provide easier learning
The validity and reliability of sensors on smartphones are also reliable and have been reviewed by experts, for example on the practical measurements of the hip rotation angle [26].

The effectiveness of students’ worksheets with smartphone sensor media on the aspects of speed, productivity, and learning convenience showed a higher percentage compared to the effectiveness of worksheets without smartphone sensor media as presented in Figure 2. Students were able to understand and carry out the tasks given on worksheets based on the use of smartphone sensors more quickly. Students also became more productive and more comfortable in learning when working on the worksheets based on the use of smartphone sensors than on the worksheets without the use of smartphone sensors. The combination of accelerometer and gyroscope sensor data provides more comprehensive data in circular motion learning. The accelerometer sensor measures the motion or acceleration from one position to another with 3 axis points, namely the X, Y, Z axes [11]. While the gyroscope sensor is used to track the rotation or the rotation of object motion [8, 9]. The use of accelerometer and gyroscope sensors simultaneously provides data on radial acceleration, tangential acceleration, and angular velocity, as well as providing trajectory data on the motion of objects directly which will make the learning effectiveness of students high [8, 9]. Finally, the use of smartphone sensors in the form of worksheets can attract students’ interest to learn physics concepts that will improve students’ cognitive abilities.

4. Conclusion
The accomplishment of students in understanding the concepts of physics can be demonstrated through the ability to apply (C3), analyze (C4), and evaluate (C5). The magnitude of the increase was measured by the magnitude of the N-gain value obtained, which is 0.41. The increase in cognitive abilities based on the calculation of N-gain is in the moderate category. The increase in the measured value from the comparison of the pretest and posttest scores was 20.86. The cognitive abilities obtained by students are supported by the use of two smartphone sensors. Worksheets that utilize two smartphone sensors provide motivational encouragement and easiness for students to understand the concepts of physics, especially the concept of circular motion. Moreover, worksheets that utilize two smartphone sensors are also effective in helping students to learn the concept of circular motion.

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