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Analysis of the Concept of Friction Force, Centripetal Force, and Maximum Speed on The *Piket Nol* Lumajang's Route as a Physics E-Module Design

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a b s t r a c t

The cause of students' difficulties in understanding physics material is that students cannot relate formal knowledge to everyday life, and there is a lack of contextual teaching materials. One way to overcome these problems is to examine examples of events in students' lives to serve as a reference for designing teaching materials. The Lumajang' *Piket Nol* line has extreme track characteristics, and accidents often occur. This analysis aims to examine the friction force, centripetal force, and maximum speed on the *Piket Nol* Line. The results of the analysis are used as a reference for designing physics teaching materials in the form of e-modules. The method used in this research is content analysis. The object of this research is four trajectories chosen by the researcher because of an accident. The four tracks include a straight track, a straight incline/decline, a flat bend, and an uphill/downhill bend. This analysis shows that the amount of friction force, centripetal force, and maximum speed increases when the initial speed is greater. The analysis results were used as a reference for the design of contextual e-modules in the form of flipbooks.

1. Introduction

Physics is one of the subjects with fun and interesting material to learn because it has a lot to do with everyday life (Harefa, 2019). Many students think physics is difficult, scary, boring, unrelated to everyday life, and monotonous because textbooks are limited and less interesting for students to learn (Astutik, Lesmono, & Adani, 2019; Haryadi & Nurmala, 2021). As many as 82.21% of students have difficulty understanding friction force material (Soif, 2022). The centripetal force material discussed in almost all secondary school curricula is also considered difficult because students consider centripetal force material to be identical to mathematical equations (Pierratos, Sotirios, & Eirini, 2022; Negoro, 2019). The causes of students' difficulties in understanding the material are that students cannot relate formal knowledge to everyday life, lack teaching materials that provide examples of the application of the material in a real-world context, and use language that is difficult to understand (Azizah et al., 2021; Qondias, Winarta, Siswanto, 2019). Contextual learning needs to be considered to overcome these problems because this learning can help relate the material learned to real life and make the learning process meaningful (Nupus, Triyogo, & Valen, 2021; Primayana et al., 2019).

Contextual learning can be done by examining several events that exist in the daily environment of students. One event close to students is an accident (Azizah, Handayani, & Maryani, 2021). The *Piket Nol* Line is on Jalan Dampit, Supiturang Village, Pronojiwo Sub-district, Lumajang Regency. Bamin Laka Kasat Lantas Polres Lumajang explained that in the last 5 years, 19 accidents have occurred on Dampit Road in Lumajang District. On the *Piket Nol* Line, there were only 3 accidents because in 2021 to 2023, the route was closed due to the eruption of Mount Semeru. The *Piket Nol* Line has the characteristics of a track consisting of several sharp turns with uphill and downhill conditions (Wulandari et al., 2021). One of the causes of accidents that occur on the *Piket Nol* Line is the speed of drivers who exceed the maximum limit. The higher the speed, the higher the risk of an accident (Mauliza, Sabrina, & Maulana, 2019). In addition, accidents are also caused by a lack of traffic signs, while traffic signs or warning signs are invaluable for drivers to know the road conditions ahead (Agustin, Rifai, & Ediyono, 2022). Traffic signs will be effective if installed under technical standards and traffic management studies (Pramesti & Budiharjo, 2020).

Appropriate teaching materials between context and material are needed to realize contextual learning (Azizah et al., 2021). Preliminary research conducted in several schools around the Piket Nol Line shows that teachers have never used contextual teaching materials. Teachers still use standardized textbooks from the government that do not contain local wisdom. According to the Ministry of Education and Culture (2016), on the analysis of Local Wisdom Viewed from Cultural Diversity, local wisdom is the value system or life behavior of local communities in interacting with the environment where they live wisely. Therefore, local wisdom is often the basis for making policies in several fields, including education. Module is one of the printed teaching materials that, along with the development of technology, has developed into an innovation in the form of electronic modules (e-modules) generally presented in the form of Flip HTML 5 (Kemendikbud, 2017). E-modules can be used anywhere, so they are more practical to carry. E-modules make navigation easier, display images, videos, and animations, and are equipped with formative tests that allow automatic feedback (Fadieny & Fauzi, 2021). In addition, e-modules present engaging and structured information because they use print and computer media (Ariyanti, Lesmono, & Supriadi, 2019).

Several studies examine several events in everyday life to be used as teaching materials. Research conducted by Azizah et al. (2021) analyzed the kinematics and dynamics of motion based on accident events on the sharp bend blackspot lane to be used as a contextual e-module design. Another research conducted by Virani, Supeno, and Supriadi (2018) examined kinematics in accident events in blackspot areas and was used as contextual learning resources. In addition, research conducted by Ruspitasari et al. (2022) on the Ngawi Regency road can be studied for the kinematics of motion in motorized vehicles and used as a physics learning resource because it can show the characteristics of the type of motion. Tracks with characteristics like cornering, plowing, or descending also need to be studied. This analysis examines the friction force, centripetal force, and maximum speed on the Lumajang *Piket Nol* Line, which has the characteristics of a track in the form of a cornering and uphill or downhill road, whose analysis results are used as a reference for designing physics e-modules.

2. Method

This type of research is qualitative research with an ethnographic type. The analysis method used in this research is content analysis. The stages in the content analysis method include unitizing which is the stage of collecting data or information behind the research, sampling the summarizing stage of all types of data, reducing which is the stage of simplifying or selecting data, inferring which is the stage of drawing conclusions, and narrating which is the stage of narrating the answers to research (Krippendorf, 2004). The research was conducted at the Dampit Road *Piket Nol* Line, Pronojiwo District, Lumajang Regency. There were four research points on the *Piket Nol* line, namely a straight track, a straight climb or descent, a flat bend, and an uphill or downhill bend chosen based on the location where the accident had occurred.

Data collection was carried out by observation at four research points. The tools and materials used are truck vehicles, stopwatches, meters, Garmin GPS, pendulums, and bows. The research was carried out by simulating trucks passing through the four research points. On straight trajectories and straight climbs, it is done in a downhill position. Trucks passed at speeds of 15 km/h, 25 km/h, and 35 km/h which after a distance of 2 meters were fully braked. In the simulation, the distance and braking time can be measured. On flat curves and uphill or downhill curves, simulations of trucks traveling uphill at 15 km/h, 25 km/h, and 35 km/h for 40 m without braking were conducted. In the simulation, the truck time can be calculated when crossing the curve. Each measurement is done 3 times to get valid results. On the trajectory of flat bends and uphill or downhill bends, the slope of the vehicle is measured using a pendulum placed in the car. When crossing the bend, the pendulum slope states the slope of the vehicle, which can be measured using an arc. Each research point was measured using Garmin GPS to determine the track's slope. The analysis results of friction force, centripetal force, and maximum speed are used as a reference for designing e-modules. The e-module design was designed using Canva and the e-module in the form of a flipbook using Flip HTML 5.

3. Result and Discussion

The research point in a straight track is located at 8°11'4.06 "S and 113°1'6.75 "E. This track has the characteristics of a straight road with a road width of 4.63 meters and is at an altitude of 573.33 meters above sea level. The research point in the form of a straight climb or descent is located at 8°11'15.94 "S and 113°1'3.13 "E. This track has the characteristics of a straight road that goes uphill or downhill, with a road width of 4.68 meters. The road condition is quite good, with no potholes and bumpy asphalt. At this point of the straight track and uphill or downhill, the straight examines the friction force in vehicle braking.

Table 1. Measurement results on a horizontal straight track and a straight uphill or downhill track

Starting Speed (v_0)	Horizontal Straight Track		Straight Uphill or Downhill	
	Kinetic Friction Force (f_k)	Coefficient of Kinetic Friction (μ_k)	Kinetic Friction Force (f_k)	Coefficient of Kinetic Friction (μ_k)
15 km/j	11939.49 N	0.37	18983.60 N	0.59
	11939.49 N	0.37	19043.01 N	0.59
	11347.45 N	0.35	19043.01 N	0.59
25 km/j	15358.41 N	0.48	21496.71 N	0.67
	15462.18 N	0.48	21601.06 N	0.67
	15782.09 N	0.49	21566.00 N	0.67
35 km/j	17798.69 N	0.55	23450.46 N	0.73
	18203,20 N	0.56	23751.11 N	0.74
	18203,20 N	0.56	23828.90 N	0.74

Based on the results of friction force studies conducted on straight tracks and straight climbs or descents, it can be seen that the friction force depends on the vehicle's initial speed. The greater the speed, the greater the kinetic friction force. Style is part of mechanics (Addinni, Bachtiar, & Prastowo, 2017). The friction force is a force that occurs because all surfaces are rather rough and the two surfaces stick or interlock at various points (Cari et al., 2019). In this case, the friction force is referred to as the kinetic friction force in the form of braking force (Laumma, 2022). Speed affects braking time because higher speeds have greater kinetic friction forces that need to be eliminated through braking, so the process takes a long time (Mara et al., 2023).

The results of the kinetic friction force are getting bigger on a straight uphill or downhill track. The increase in kinetic friction force is due to the difference between the conditions of a straight track and a straight uphill or downhill track. Straight inclines or descents have sloping road conditions. The track's slope is a straight track that goes uphill or downhill in the geometric location of the road. Vehicles traveling without brakes on a sloping track will increase their speed due to acceleration. The acceleration arises because the vehicle load shifts forward while traveling downhill. These conditions can cause accidents if the visibility between other vehicles is short (Syifaurrahman et al., 2019).

Picture 1. Horizontal Straight Track

Picture 2. Straight Uphill and Downhill

On a downhill trajectory, the vehicle speed increases naturally due to the gravitational force acting downwards. The momentum generated in this case depends on the vehicle's initial speed. This is because momentum is proportional to speed and mass (Rahmadi, 2022). Greater speed and momentum create a greater kinetic friction force. Braking will be more complex because the kinetic friction force increases due to the greater momentum of the high speed. In every vehicle braking process, friction plays a central role between the vehicle's tires and the asphalt surface. When braking, the surface of the vehicle tire will come into contact with the asphalt surface and generate a kinetic friction force that inhibits the vehicle's movement. This kinetic friction phenomenon is the determining factor of how effectively the vehicle can be stopped.

The research point in a flat bend is located at 8°11'23.83 "S and 113°1'23.43" E. This track has the characteristics of a flat bend with a road width of 4.37 meters. The research point is an uphill/downhill bend at 88°11'25.85 "S and 113°1'11.78 "E. The road condition is quite good, with no potholes and bumpy asphalt. An assessment of centripetal force and maximum speed was carried out on the trajectory of flat bends and uphill or downhill bends.

Table 2. Measurement results on flat curves and uphill or downhill curves

Starting speed (v_0)	Flat Bend			Uphill or Downhill Bends		
	Centripetal Force (FR)	Centripetal Force (β)	Maximum Speed (v_{max})	Centripetal Force (FR)	Centripetal Force (β)	Maximum Speed (v_{max})
15 km/h	1371.29 N	5°	14.98 km/h	1283.60 N	7°	14.94 km/h
25 km/h	3809.13 N	11°	24.97 km/h	3565.65 N	15°	24.89 km/h
35 km/h	7465.89 N	13°	34.96 km/h	6988.49 N	18°	34.85 km/h

The results of centripetal force studies conducted on flat bends show that the centripetal force is getting bigger because the initial speed is increasing. A simple pendulum measures the vehicle tilt angle on a flat bend trajectory. If the angle of inclination of the vehicle is greater than the angle of inclination of the bend, the vehicle has the potential to slip or skid. The analysis results show that the greater the vehicle speed, the greater the vehicle tilt angle generated. The slope of the road affects the amount of static friction force. In addition, the roughness of the asphalt surface also affects the amount of friction force (Pasaribu, Siregar, & Susilo, 2023). The static friction force generated in this analysis gets bigger as the centripetal force increases. The centripetal force in the results of this analysis is smaller than the static friction force. This is per the theory that the centripetal force acting on a curve must be smaller so that the vehicle does not slip out of its circular path (Giancoli, 2014).

Picture 3. Flat Bend

The results of centripetal force studies conducted on uphill or downhill bends show that the centripetal force on uphill or downhill bends is smaller than the centripetal force on flat bends. The difference is due to the radius of the bend on an uphill or downhill track is greater than on a flat bend track. Centripetal force is inversely proportional to the radius of the bend (Giancoli, 2014). The relationship is stated in the mathematical equation as follows.

$$\sum \boldsymbol{F_R} = \frac{\boldsymbol{m.v^2}}{\boldsymbol{R}} \quad (1)$$

F_R being the centripetal force (Newton), m being the mass (kg), v being the speed (m/s), and R being the radius of the bend (meters).

Picture 4. Uphill/Downhill Bends

Measurements of the vehicle tilt angle show that the greater the vehicle speed, the greater the resulting vehicle tilt angle. Drivers must pay attention to the maximum speed limit of the vehicle used when crossing bends. Drivers who drive a vehicle at a safe average speed will not experience a slip caused by the effect of centrifugal force when going through a bend (Widiastuti, 2020). The centrifugal forces are fictitious in Newtonian mechanics and only appear in rotating frames of reference (Ng, 2024). If it gets faster, the angle will increase and cause the vehicle to slip. Drivers must pay attention to the maximum speed limit of the vehicle used when crossing the curve because if it gets faster, the angle will increase and cause the vehicle to skid. The rate of traffic accidents on sharp bends is quite high. One of the causes is the mismatch of the bend design with the applicable planning standards and exacerbated by driving behavior at speeds that exceed the maximum speed or plan speed. Poor road conditions such as sharp bends need to be equipped with road markings in the form of maximum speed limit signs to avoid motorist accidents (Syifaurrahman, Fauzan, &Sudibyo, 2019).

The results of the analysis of friction force, centripetal force, and maximum speed on the Lumajang *Piket Nol* Line are used as a reference for designing contextual teaching materials in the form of physics e-modules. The design of physics e-modules on friction force, centripetal force, and maximum speed material consists of learning outcomes and objectives, general description, concept map, material description, summary, formative test, practice, glossary, and bibliography. The e-module design has several stages: problem analysis, literature study and observation, and e-module preparation. The first step is analyzing problems that can be reviewed based on literature reviews in articles and preliminary research. In this analysis, there are three problems, namely the assumption that physics is difficult and tedious by students and the limitations of teaching materials that apply real-world contexts that result in students being less able to relate formal knowledge to everyday life, as well as the lack of traffic signs on the *Piket Nol* Line which causes frequent accidents.

The second step is a literature study that reviews several theories related to the problem. Observations were also made to analyze friction force, centripetal force, and maximum speed, which would later be used as contextual e-module design material. This analysis was conducted on the Lumajang *Piket Nol* Line because accidents often occur, and the condition of the line is interesting to analyze because it is an uphill and sharp bend. The selection of the *Piket Nol* Line is also related to the suitability of friction force material, centripetal force, and maximum speed. The third step is e-module design. Researchers determine learning outcomes and objectives for e-modules based on the Merdeka Curriculum. The e-module design uses the Canva application, which is then designed using Flip HTML5. The e-module design is published as an e-book so students can access it via a link or QR Code.

Previous research has explained that contextual e-modules can create meaning in learning (Puspita & Purwo, 2019). The advantages of e-modules are that they are easy to carry anywhere, effective, and can train students' independence in understanding material and solving problems obtained in learning activities (Cahyanto, Handayani, & Lesmono, 2022). In addition, e-modules are a form of interactive multimedia teaching materials that convey messages by combining two or more media components (Fadieny & Fauzi, 2021).

4. Conclusion

Based on the results of the research that has been done, the analysis of friction force, centripetal force, and maximum speed on the Lumajang *Piket Nol* Line is carried out on several trajectories, namely straight trajectories, straight climbs or descents, flat bends, and uphill/downhill bends. On a straight track and uphill or downhill, examine the braking force in the form of kinetic friction force that often increases with increasing initial speed and momentum. On the flat and uphill/downhill trajectory, the friction force, centripetal force, and maximum speed increase with the increase in the initial speed value of the vehicle. The results of the friction, centripetal force, and maximum speed analysis on the *Piket Nol* Line are used as a reference for designing physics e-modules presented in flipbook form. This e-module design is contextually based and can be used by teachers in learning.

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