



CAN EINSTEIN'S THEORY OF GENERAL RELATIVITY BE TAUGHT TO INDONESIAN HIGH SCHOOL STUDENTS?

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ABSTRACT

The detections of gravitational waves, which culminated in the 2017 physics Noble Prize award have again confirmed the triumph of the general relativity theory. This theory, together with quantum mechanics, forms the backbones of our modern understanding of the world and significantly contributes to modern technologies we are using today. Despite the importance of these theories, they are still rarely part of high school physics curricula worldwide, including the Indonesian physics curriculum. This is due to the assumption that these theories are too difficult for students to grasp. However, there has been a growing interest to bring these theories to younger students and the general public. There is growing evidence that appropriate teaching can result in measurable learning. The purpose of this research was to explore the impact of activity-based learning using models and analogies on high school students' conceptual understanding of general relativity related concepts. The research was an exploratory study conducted in one class of 31 students who participated in three weeks program. Testing of their conceptual understanding used identical pre/posttests. The results indicated a strong and statistically significant improvement in students' conceptual understanding with a large effect size. Interestingly, the results showed that the change in the physics conceptual understanding of girls was higher than boys. The results of this program indicate that further research can be conducted with a larger number of students and in a longer period and thus provides a promising prospect for future research in Indonesia.

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Keywords: general relativity; activity based learning; models and analogies; conceptual understanding

INTRODUCTION

The victorious detection of gravitational waves, which culminated in the 2017 physics Noble Prize award and the first capture of the black hole picture recently has again confirmed the triumph of the theory of general relativity; the new theory of space, time and gravity formulated by Albert Einstein in 1915 (Cheng, 2009; Weinberg, 1972). According to the theory of general relativity, gravity is not perceived as the force acting between masses but a manifestation

of curved spacetime produced by the existence of massive objects (Huggins, 2018; Stannard, 2018). Together with the theory of quantum mechanics, the theories of general and special relativity represent our modern understanding of the world. These theories are sometimes called the physics theories of the twentieth century (Velentzas & Halkia, 2013), or sometimes the term Einsteinian Physics is also used to refer to the theories (Blair, 2012; Choudhary et al., 2018; Kaur et al., 2017; Pitts et al., 2014).

Even though these theories form the backbone of our modern understanding about the world and significantly contribute to modern

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technologies, they are still rarely part of high school physics curricula worldwide (Pitts et al., 2014). Like in other countries such as Norway and Australia, in Indonesia, the place where this research was conducted, topics related to special theory of relativity are taught in year 12, while general theory of relativity is not included in high school physics curriculum (Budiyanto, 2009; Kanginan, 2004; Made & Setiyawan, 2008). Einsteinian physics, especially the theory of general relativity, is rarely discussed in classrooms due to the assumption that it needs advanced mathematics and is conceptually too difficult (Blair et al., 2016; Kaur et al., 2017). There is also a belief that students studying Einsteinian physics require a solid background in classical physics (Walwema et al., 2016). In addition, most teachers are not equipped with enough knowledge, as well as pedagogical skills, to teach the subject (Buabeng et al., 2016; Yavaş & Kizilcik, 2016). Meanwhile, in Indonesia, the search on the physics education department's curricula revealed that almost all physics education departments don't include the theory of general relativity as a compulsory subject in their curricula.

The idea that Einsteinian physics is too difficult can be challenged. Numerous educational researchers and physicists have been trying to test whether concepts of Einsteinian physics can be taught to young students without requiring them to master advanced mathematics (Henriksen et al., 2014; Kersting et al., 2018; Ryston, 2019). Walwema et al. (2016) revealed that undergraduate students do not need to have a solid background in classical mechanics to study modern physics. Zahn & Krauss (2014) suggested that the approach chosen to teach general relativity to students must be a concept based approach rather than a mathematical one. Baldly (2007), who conducted a research to assess the effectiveness of a new educational perspective for teaching gravity on French 15-year old ninth-graders based on an analogical presentation of space-time deformation by Einstein's theory, found that Einstein's theory can be understood by ninth-graders and promotes conceptual understanding more effectively than a method based on Newton's theory of bodies interacting at a distance.

It is true that apart from its elegance and beautiful logical structure, ideas related to relativity theories are sometimes difficult to comprehend due to their abstractness and our limited daily exposures to relativistic phenomena. To make abstract concepts more easily understandable to students, science teachers can use models, metaphors, analogies, animations, simulations, role-

plays or other analogical methods (Aubusson et al., 2006; Coll et al., 2005; Jonāne, 2015; Kersting & Steier, 2018). In the Einstein-First Project, for instance, essential ideas related to general relativity such as the ideas that mass causes curvature in space-time, that freely falling bodies follow the shortest paths in space-time, and that geometry on curved space are introduced using models and analogies that use a space-time simulator, marbles, toy cars, billiard balls, woks, etc (Kaur et al., 2017). Previous programs conducted by researchers in the Einsteinian-First Project revealed that grades 6, 9, 10 and 11 students who were taught concepts related to general relativity using these models and analogies could easily cope with the materials presented and considered that they are not too young to learn Einsteinian physics (Kaur et al., 2017).

In the context of Indonesia, this research was worth doing for the following reasons. Firstly, most of the research about bringing the theory of general relativity to high schools so far was conducted in developed countries (Choudhary et al., 2019), and very few were found in developing countries, including Indonesia. A search of the literature revealed that research concerning teaching general relativity to high school students has not been conducted in Indonesia; secondly, the research could potentially provide promising prospects for the future research in this field; thirdly, the research could potentially contribute to the Indonesian high school physics curriculum, especially about the possibility to include the theory of general relativity into the high school physics curriculum.

The research was designed to be an exploratory study aiming at examining the impact of activity-based learning using models and analogies on Indonesian year 10 students' conceptual understanding of the theory of general relativity. The research was guided by the question: can activity-based learning using models and analogies help Indonesian students understand concepts related to the general relativity theory?

METHODS

This research was an exploratory study conducted in a private catholic senior high school in Flores Island, East Nusa Tenggara, Indonesia. The participants of this research were 31 students from grade 10 consisting of 13 girls and 18 boys, aged around 16-17 years old, who participated in three weeks program.

Topics covered in this program consisted of nine main topics. Namely, introducing space-

time; the universality of the speed of light; the universality of free fall and equivalence principle; geometry on curved space; gravity; gravitational deflection of light; perihelion shift of Mercury; black holes and gravitational waves. Besides, there were two additional topics presented, namely the motion of Comet Shoemaker Levy-9 and the figure 8 Orbit.

These contemporary ideas were designed and presented in activity-based learning using videos, PowerPoint presentations, and hands-on activities. Besides, models and analogies were also used. For example, we used tungsten balls to represent massive objects, toy cars to model starlight, upturned woks for curved space, and leaking water-filled balloon to perform ideas related to Einstein's happiest thought. We also used a tightly-stretched membrane called space-time simulator, on which ideas about the curvature of space-time (Einstein's gravity), gravitational lensing and the effect of curved space on orbits were presented.

Activity-based learning was divided into three phases. The first phase was the PowerPoint presentation by the authors to explain general relativity concepts visually (using pictures, video clips, animations, and keywords). The second phase was hands-on activities using models and analogies. In this phase, students were grouped into six groups (five groups consisted of five students and one group consisted of six students) and encouraged to do hands-on activities using models and analogies to deepen their understanding of general relativity concepts. They were provided with the guidance worksheet when doing hands-on activities. And the third phase was work time. In this phase, students were given time to complete worksheets and allow class discussions.

In order to measure students' conceptual understanding of the general relativity theory, the author used identical conceptual understanding pre/posttests questionnaire. Students' pre/posttest questions used in this research were based on the validated questions developed and used by Kaur et al. (2017) from Einsteinian-First Research Group, the University of Western Australia. Twelve questions provided in the pre/posttest students' conceptual understanding questionnaires were four additional questions developed by the author, which had been discussed and validated by the author's supervisor and one experienced physics professor. The questionnaire was first provided in English and then translated into Indonesian before being administered to participating students.

The questions focused on the students' understanding of the straight-line versus geodesic, the speed of light as the terminal speed of the universe and its consequences, geometry on curved space, represented by their understanding of the angles of a triangle, ideas related to the weak and strong equivalence principle, how gravity affects time, the gravitational deflection of light, black holes and gravitational waves. Most of the questions were open-ended so that students could be encouraged to demonstrate their comprehension of ideas asked. However, questions related to black holes and gravitational waves only test students' lower-level knowledge, demonstrated by a recall.

A marking rubric with a total score of 24 points was developed by the author to score the students' responses to the questionnaire. The author then marked student responses to the questions with increasing marks, up to a maximum of two for each question, as follow:

Table 1. The Marking Rubric for Students' Response

Score	Students' Response
0	No response, incorrect or unsure
1	Partially correct and/or could be interpreted as being partially consistent
2	Correct and consistent answer

To measure the impact of an activity based learning using models and analogies on students' conceptual understanding of the general relativity theory, Statistical Program for the Social Science (SPSS) was being used. A paired sample t-test was used to determine whether there was any significant statistical difference in students' mean scores before and after the research and an *eta squared* effect size statistic was calculated. The guidelines for interpreting this value are 0.01= small effect, 0.06= moderate effect and 0.14= large effect (Cohen, 1988; Pallant, 2011).

RESULTS AND DISCUSSION

Students' conceptual understanding of Einsteinian Physics was measured by comparing their pre and posttest scores statistically. Figure 1 presents the findings from students' pre/posttest scores, arranged in ascending order by pretest score. Based on the following figure, one can see that before becoming exposed to an activity based learning program, none of the students could achieve 50% of the total score. After joining the program, all students could improve their score, with 22 students achieving scores more than 75% (three of them achieving maximum score) and 8

students achieving scores more than 50% but less than 75%. However, there was still one student scoring less than 50%.

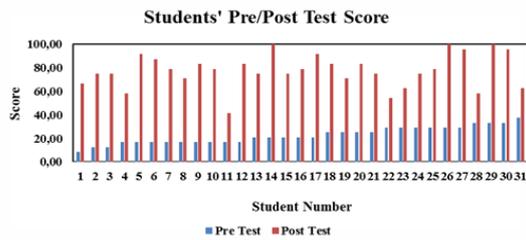


Figure 1. The Pre/Posttest Scores Result from the 31 Year 10 Students

Statistically, there was a significant difference in students' score from the pretest (Mean=22.58, SD=7.28) to the posttest (Mean=77.69, SD=14.25), $t(30)=19.98$, $p=0.0001$. The mean difference between posttest and pretest was 55.11 with 95% confidence interval ranging from 49.47 to 60.74. The eta squared statistic (0.86) indicated a large effect size.

The fact that none of the students achieved more than 50% of the total score in the pretest indicated that most ideas related to Einsteinian Physics were still new to them. Although concepts such as straight line, parallel lines, the sum of angles in a triangle are familiar to the participating students, their answers to questions 1 and 2 in the pretest which asked, "What is a straight line?" and "How can you tell if a straight line is really straight?" showed that they took the concept of straight line for granted. For example, to answer question 1 about "what is a straight line?" student 21 wrote, "A straight line is a line that is straight", or "A straight line is a line that has a straight path, from initial point to the ultimate point" (student 13). While the keywords of this question are 'shortest distance' and 'flat space', none of the students pointed these words out in their pretest answers.

On the posttest questionnaires, 12 students perfectly described a straight line as the shortest distance between two points on a flat space, 13 students described a straight line as the shortest distance between two points but did not mention 'on the flat space' which were considered to be partially consistent, and 6 students gave inconsistent answers, such as "a straight line is a line that locates on the flat space and can be measured" (student 9) or "A line that connects two points" (Student 28).

Questions 3 and 4 were designed to measure students' understanding of geometry on curved space. Question 3 asked "Can parallel lines ever meet? Circle Yes or No. Please give

reasons for your answer". Before the program, 25 students gave answers which were considered inconsistent with Einsteinian physics, for example, "No. Parallel lines never meet because they are parallel and separated" (student 10), or "No. Parallel lines never meet because parallel lines never cross each other regardless of how far they move" (student 5), one student (student 18) answered "not sure", four students gave partially consistent explanations, for example, "Yes, they can meet if one of the lines is bent" (Student 2) and only student 28 gave consistent explanations: "Yes. Parallel lines move parallel and in one direction, except when they move around the sphere, they will meet" (Student 28).

The explanation why most students believed that parallel lines never meet is that these students have been taught and introduced only to the concepts of Euclidean geometry, which is the geometry concerning the flat space and has never been introduced conceptually to the Riemannian geometry or geometry on the curved space. In the Indonesian curriculum, concepts related to Euclidean geometry such as parallel lines are introduced to students in the fourth grade of elementary school level.

On the posttest questionnaire, 27 of 31 students provided correct answers, such as "Yes. Parallel lines can meet on the space whose positive curvature while on the flat space, parallel lines cannot meet" (student 14), 3 students gave partially consistent answers, and there was one student whose answer remained the same between pretest and posttest, which was not consistent (Pre-Program: No, Parallel lines never meet; Post Program: No. The parallel lines will not meet. They keep going on their paths)

Question 4 asked "Can the sum of the angles in a triangle be different from 180° ? Circle Yes or No. Please give reasons for your answer". Before the program, a majority of the students (28/31) answered that the sum of angles in a triangle is always 180° , and this was empirically explained due to their prior knowledge about geometry on the flat space, and three students (3/31) provided a partially consistent answer, for example, "Yes. In my opinion, the sum of all angles in a triangle is not always 180° . It is determined by its sides (Student 19), Or "Yes. Because there are triangles whose sum of their all angles is not equal to 180° " (Student 22) and "Yes. When we bend the sides of the triangle, the sum of the angles can change" (Student 25).

On the post-instruction questionnaires, 29 of 31 students (29/31) gave consistent answers, such as "Yes. Based on the theory and the expe-

periments we conducted, on the curved space, the sum of angles in a triangle can be more or less than 180° , one student (1/31) gave the partially consistent answer, "Yes. On the curved space, the sum of angles in a triangle is different from 180° depending on the size of triangle; if the triangle is small, the sum of angles is less than 180° and if the triangle is big the sum of angles is more than 180° " (Student 5), and one student (1/31) provided an inconsistent answer, "No, the sum of angles in a triangle is 180° " (Student 11)

Students' answers in their posttest questionnaires regarding questions 1-4 showed that not only could they remember the ideas presented during the program, they could also apply these ideas to answer more complicated questions given. For example, before the program, almost all students in the class took for granted ideas about a straight line, parallel lines and the sum of angles in a triangle. Their understanding of these concepts was based on Euclidean geometry they had learned before. After the program, a majority of the participating students could present their understanding about the meaning of straight line as the shortest distance between two points on the flat space and could provide good explanations why two straight lines can meet or diverge, as well as the reason why the sum of angles in a triangle could be different from 180° . This again confirmed that the activities we conducted during the program were retained in their memories.

Question 5 and 6 concerned ideas related to special relativity, focusing on the universality of the speed of light and how it is enforced. The key concept to be addressed was moving objects get heavier through the relativistic mass increase and hence no object can exceed the speed of light. For example, question 5 asked, "Can the velocity of an object influence its mass? Circle Yes or No. Please give reasons for your answer!" On the pre-instruction questionnaire, 22 students (22/31) answered that the velocity of an object does not influence its mass with distinct reasons, which were considered incorrect, and 9 students (9/23) answered that the velocity of an object can influence its mass with explanations which were considered partially consistent, for example, "Yes, we can feel it when we run. The faster we run, we feel our body becomes heavy" (Student 27) or "Yes. The mass of an object can decrease because of friction when it is moving" (Student 16).

On the post-instruction questionnaire, 8 students (10/31) described how the velocity of an object influences its mass based on the Einsteinian physics understandings like, "Yes. The faster

an object moves, its mass will get increased and when the object's velocity is equal to the velocity of light, its mass becomes infinite" (Student 9), 13 students (13/31) provided answers with explanations which were considered partially consistent with Einsteinian Physics, like "Yes. Because the higher the velocity of an object, the bigger the mass of the object" (Student 2), and the remaining 10 students (10/31) provided answers inconsistent with Einsteinian Physics, like "The faster an object moves, its mass will get decreased and the slower an object moves, its mass gets increased". (Student 8).

The participating students showed improvement in understanding the special theory of relativity-related concepts, such as why the speed of light is the speed limit of the universe. This idea had been intuitively perceived by most of the students before the program but none of them could provide the reasons scientifically. After joining the program, several students could explain what enforces the speed limit of the universe, which seems to be counterintuitive and hence could relate the ideas of how the velocity of an object influences its mass when the object is experiencing relativistic motion. It was found that while all students agreed that the velocity of an object influences its mass, only a few students could provide answers consistent with Einsteinian physics

Questions 7 and 8 were about the equivalence principle. Question 7 was about the weak equivalence principle. The concept emphasized in this question was that the inertial mass and gravitational mass are the same. Therefore, in the absence of air resistance, two objects (for example a feather and a hammer) dropped from a certain height will reach the ground at the same time. Before the program, 22 students (22/31) correctly indicated that a feather and a hammer will reach the ground at the same time while the nine remaining students' responses (9/31) indicated an incorrect answer that a hammer will reach the ground first (2 students) and that the hammer will initially go faster than the feather, but they will finally reach the ground at the same time (7 students). After the implementation of the program, only 2 students (2/31) still provided incorrect responses and 29 students (29/31) responded consistently with Einsteinian physics.

Question 8 was designed to test students' understanding of a fundamental concept of the strong equivalence principle. Question 8 asked, "A pendulum on earth swings with the period 3 s. If the pendulum was put in the rocket in deep space (free from the influence of gravity) and the

rocket was accelerating at 9.8 m/s^2 (the acceleration of an object when it falls on earth). What would be the period of the swinging pendulum in the rocket measured by a person in a rocket? Please explain your reason". The expected answer to this question is that the physical effects due to gravity and acceleration are indistinguishable. As a result, all physical measurements conducted on a gravitational field and in an accelerating reference frame show the same result. Therefore, the period of the pendulum is 3 seconds. Before the program, 15 of 31 students responded that the period of the pendulum in the rocket is 3 seconds, with the explanations considered to be partially consistent with Einsteinian physics, 4 students provided answers inconsistent with Einsteinian physics and the remaining 12 students were unsure.

On the post-instruction questionnaire, 10 students (10/31) could provide answers with explanations considered to be consistent with Einsteinian physics. These students pointed out that the period of the pendulum measured is 3 seconds and they could explain that the observer in the rocket cannot distinguish whether the acceleration he/she is experiencing is due to gravity or an accelerating reference frame. 17 of 31 students (17/31) responded correctly that the period of the pendulum is 3 second but their reasons were partially consistent with Einsteinian physics such as "The period is 3 s because the acceleration of the rocket is the same as the free-falling object, 9.8 m/s^2 " (Student 16), or "The period is 3 s. because the gravitational acceleration on earth is the same as in the rocket" (Student 15). The remaining 3 students (3/31) gave incorrect responses and surprisingly, one student (Student 22) who already gave a partially consistent answer on the pretest was unsure about this item on the posttest.

Question 9 concerned with how gravity affects the flow of time. Question 9 asked, "Does the flow of time measured by a clock on the top of Mount Jaya Wijaya flow differently from the flow of time measured by a clock at sea level? Circle Yes or No. Please give reasons for your answer." While most of the students provided inconsistent or partially consistent answers on their pre-instruction questionnaires, 2 of 31 students (2/31) could provide an answer considered to be consistent with Einsteinian physics. Student 8 wrote, "Yes, because the higher the place, the faster the time" and according to student 17, "Yes, clock on the Mount Jaya Wijaya flows faster, although only few seconds". 6 of 31 (6/31) students said that there is a difference in the flow of time but provided incorrect or partially correct reasons,

for examples, "Yes, because the rotation of earth causes time on the high land faster than the sea level" (Student 2) or "Yes. Because one clock is put higher than others" (Student 28). 21 of 31 students (21/31) pointed out on the pre-instruction questionnaire that there is no difference in time flow between the two places and the remaining two students (2/31) were unsure.

After joining the program, 25 students (25/31) managed to provide correct responses, like "Yes. Time on the top of the amount and at the sea level is different. Time measured on the sea level runs slower because time is slower when it is closer to the source of gravity" (student 16), 1 student (1/31) gave a partially correct answer and the remaining 5 students (5/31) indicated incorrect responses, like "Yes. Clocks closed to the center of gravity are running faster than clocks far from the gravity, because the gravitational field is like a magnet that attracts everything" (student 4).

Question 10 concerned gravitational deflection of light by massive objects. Before the program, 15 of 31 students (18/31) indicated incorrect responses, 13 students responded that light can be bent by a massive object but provided incorrect reasons, such as "Yes. Because if the light hits a very massive object, it is possible that light will be slightly deflected from the object because light has a smaller mass than the object" (student 26), and the remaining 3 students (3/31) were unsure. On post-instruction questionnaires, 17 students (17/31) provided answers supported by explanations consistent with Einsteinian Physics, like "Massive object causes the curvature of space-time. This curvature causes other surrounding objects to move. When light passes that curvature, the light will be deflected. This phenomenon is called gravitational deflection of light" (student 26). While 10 students (10/31) pointed out that massive objects can bend light but did not provide convincing reasons, and the remaining 4 students (4/31) provided incorrect responses.

Questions 11 and 12 concerned black holes and gravitational waves, testing students' understanding at the knowledge level. Prior to the program, only four students indicated the correct response to the question concerning black holes, while none of the participating students indicated the correct answer concerning gravitational waves. After the program, all students could respond correctly to questions 11 and 12.

Students' answers to questions 7-12 show that regarding the general theory of relativity-related concepts such as the equivalence principle, how gravity affects time, and gravitational deflec-

tion of light, there were significant improvements in students' understanding. Although very few students knew about the black holes ideas and none of the participating students had ever heard about gravitational waves before the program, all students could recall these two phenomena when asked on the posttest questionnaire. The results of the research confirm what highlighted by Zahn & Krauss (2014) that the approach chosen to teach general relativity to students must be a concept based approach rather than a mathematical one. Besides, the results of the research also confirm that students can learn concepts related to the general theory of relativity conceptually without requiring them to study classical physics as suggested by Walwema et al. (2016).

In terms of the students' conceptual understanding achievement based on gender, it was found that before the implementation of Einsteinian Physics activity based learning program, there was no significant difference in boys' (Mean=22.69, SD=7.18) and girls' (Mean=22.44, SD=7.71) conceptual understanding of Einsteinian physics. After joining the program, girls (Mean= 82.37, SD=12.05) scored higher than boys (Mean=74.31, SD=15.07), as shown in Figure 2. This was quite surprising since it is usually considered that male students always have more positive attitudes towards studying science rather than their female counterparts. The findings of this research, however, showed a different result.

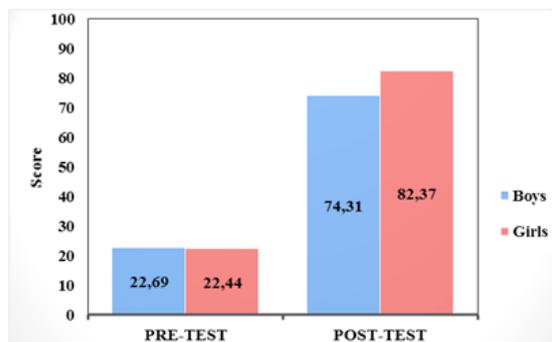


Figure 2. Conceptual Understanding; Boys' VS Girls' Pre/Posttest Scores Result

CONCLUSION

The findings from the three-weeks program revealed that there was a statistically significant improvement in students' conceptual understanding of the general relativity theory with a very sizeable effect. Apart from the fact that most general relativity related concepts are new to students. Hence, all students achieved very low scores before the program. High improvements in

students' scores happened after being exposed to the program. Convincingly, it indicates the effectiveness of implementing activity based learning using models and analogies to present abstract concepts of the theory of general relativity in a way that students can tangibly grasp.

The findings of this research revealed that activity based learning using models and analogies could potentially help the Indonesian year 10 students to comprehend general relativity-related concepts. It was showed by the statistically significant improvements in students' conceptual understanding before and after the program. Their mean score improved from 23% on the pretest to 78% on the posttest, with a sizable effect size (0.86).

Our results of this program indicate that further research can be conducted with a larger number of students and in a longer period. Thus, it provides a promising prospect for future research in Indonesia.

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APPENDIX

Conceptual Understanding Questionnaire

EINSTEINIAN PHYSICS CONCEPTS

Pre/Post-Program Quiz

1. What is a straight line?
2. How can you tell if a straight line is really straight? Why?
3. Can parallel lines ever meet? Circle Yes or No. Please give reasons for your answer.
4. Can the sum of the angles in a triangle be different from 180° ? Circle Yes or No. Please give reasons for your answer.
5. Can the velocity of an object influence its mass? Circle Yes or No. Please give reasons for your answer!
6. Suppose you read on Facebook a story titled, "Scientists have made an aircraft which flies at the speed of light". Would you believe this story if it sounded plausible? Yes or No? Please explain the reasons for your answer.
7. In the absence of air resistance (say in a huge vacuum tank or on the surface of the moon), if we drop a hammer and a feather, which one of the following is true?
 - a. The hammer will reach the ground first
 - b. The feather will reach the ground first
 - c. Both hammer and feather will reach the ground at the same time
 - d. The hammer will initially go faster than the feather, but they will finally reach the ground at the same time
 - e. Not sure
8. A pendulum on earth swings with the period 3 s. If the pendulum was put in the rocket in deep space (free from the influence of gravity) and the rocket was accelerating at 9.8 m/s^2 (the acceleration of an object when it falls on earth). What would be the period of the swinging pendulum in the rocket? Please explain your reason in one sentence.
9. Does the flow of time measured by a clock on the top of Mount Jaya Wijaya flow differently from the flow of time measured by a clock at sea level? Circle Yes or No. Please give reasons for your answer.
10. Can a massive object, like a star, change the direction of a passing light beam? Circle Yes or No. Please give reasons for your answer.
11. There are places in the universe where gravity is so strong that light cannot escape. Such regions are called
12. On February 2016, scientists announced that they have detected ripples that came to earth in the form of waves travelling at the speed of light. The ripples are called