# The physics of Gravitram: “Leisure or outdoor learning?”

N Suprapto[1], H Mubarok[2]
{nadisuprapto@unesa.ac.id[1], husnimubarok254@gmail.com[2]}

Physics Department, Universitas Negeri Surabaya, Indonesia[1,2]

**Abstract.** Through a research project of exploring the physics concept in Techno Park, this study was manifested. The authors specified the discussion into “Gravitram". It is a complex system in which an electric motor lifts metal balls to the top of the system, so each ball experience the law of conservation of energy. Rationally, the authors adopted the qualitative thematic paradigm in the research methodology. Documentation study including 92 pre-service physics teachers in Surabaya as participatory action research through photo-elicitation, video analysis, and content analysis of electronic resources were used in the data collection. For a clear explanation, the findings and discussion are started from the history of the gravitram system, gravitram in the world, and the physics analysis of the system itself. The discussion is also exploring further the role of this system as a part of physics leisure, outdoor learning, or both of them.

**Keywords:** Gravitram, Physics Concept, Outdoor Learning, Techno Park

## 1 Introduction

In the 19th century, New York had shown performances of kinetic motion art, which were made of metal, wood or plastic that featured small interlocked pieces that could produce a large number of track configurations. More complicated add-ons, such as “jumps, trampolines, xylophone ramps, loops, and electronic triggers are also typical with more complex sets” [1]. With iron balls are moving in an orderly motion and passing through a beautiful configuration track, which calls “rolling ball”.

Not only in New York but Hong Kong also did not want to lose, they created “the highest rolling ball statue in the world, as high as 22 meters (72 feet), called the Energy Machine, which is located in the Hong Kong Science Museum in Hong Kong” [2]. In its context, a museum is a special place for visitors to add insight into history and exhibitions. What if the device is placed in a tourist area where the majority of visitors are just to refresh their brains as a vehicle for entertainment?. Can the rolling ball attract the attention of visitors? This is a question that serves as a benchmark for the ability of science and visitors' interest in matters relating to science and kinetic motion art attractions.

Another case with a roller coaster, some visitors enjoy this vehicle just pitted their adrenaline, how much courage the visitors to enjoy the roller coaster ride. This type of amusement rides uses the form of high railway lines, which are designed with fast turns, steep slopes, sometimes inversions, and people drive roller coaster trains in the open lane. This vehicle is often found in the parks throughout the world [3], **Figure 1** is one of the example of roller coaster. In the context of a student, very few visitors observe the science concepts used in

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designing this vehicle, how the system works, how big the role and application of the concepts of kinetic motion and mechanical energy (energy balance).

**Fig. 1.** Roller coaster [4].

Based on the purpose and concept of the construction of a tourist park and amusement park, it cannot be separated from science, but how capable the visitors, employees, and owners are to observe, understand and comprehend the science content in the park. Especially, in the Techno Park, which mostly highlights the concept of science to visitors, in line with other countries, Indonesia has developed Techno Park; the concept of Techno Park has been widely used, especially in Java.

East Java Park has contributed to the insight of visitors in understanding the science concepts inside. The roller coaster is already in the 'Jatim Park' and rolling ball with a complicated track and a beautiful configuration are existing too. By observations, visitors are more interested in rolling ball in understanding physics concepts. The physics concept is very basic in this vehicle. Another name for the rolling ball is kinetic sculpture or *gravitram*. It is "a complex system in which an electric motor lifts metal balls to the top of the system, so each ball gains potential or stored energy" [5]. When a ball is released, its potential energy is converted into kinetic energy and the ball is moving. Additionally, as the ball collides with other balls or parts of the system, energy is released through friction and sound. Therefore, researchers are interested in examining deeper about gravitram, with the following purposes (1) To what extent do the existences of *gravitram* as a medium for outdoor learning (2) To what extent do the physics concepts behind the *gravitram*?.

## 2 Method

This study uses a qualitative thematic paradigm. The documentation study includes 92 pre-service physics teachers in Surabaya as participatory action research (PAR). Photo-elicitation, video analysis, and content analysis of electronic resources were used in the data collection. Data sourced from primary and secondary data. Primary data come from surveys and direct observations by researchers and PAR in the location of gravitram in Indonesia. The PAR joined the program namely 'Field Trip of Physics Techno Park' in East Java Indonesia. While secondary data comes from relevant websites, YouTube, and social media. We use thematic analysis to gain knowledge and insight into data collected [6], [7], [8]. This method allows researchers to develop designs and deeper concepts of physics using thematic analysis to fix data; researchers control wide-ranging patterns that will allow them to carry out a more detailed

research and analysis [6]. This is very inductive: themes emerge from data collected and are not forced or determined in advance by researchers.

# 3 Analysis

## 3.1 History of gravitram

*Gravitram* was first made by Shab Levy and his colleague, George Hohnstein in 1973. The word *gravitram* is "a combination of two-words 'gravity' and 'tramway'," [9]. Gravity is "a force that tries to pull two objects towards each other" [9]. The bigger an object, have a stronger gravitational pull. Earth's gravity is what keeps objects on the ground and what causes them to fall [9], [10]. A tramway is a path for moving objects, such as trains, cars, bus or other objects [11]. Levy created more *gravitram* together with his son for the last, completed in 2010. One of them was "*gravitram* commissioned by the Weitzmann Institute of Science, in Rehovot, Israel" as shown in **Figure 2**.[12].

The creation of *gravitram* is not far from the idea of the rolling ball and Galileo's experiments. Galileo's contributions to physics assisted connect the heavens to the Earth. He made a significant involvement to the next researchers in the understanding of the laws of physics as universal laws. In various methods, Galileo contrasted with the Aristotelian sight of the universe. Galileo assumed that objects experienced uniform acceleration because of gravity. He designed an experiment concerning spheres rolled on an inclined plane to investigate his theory. Galileo's experimental tools were humble; it consisted of wooden paths with hollows cut into it and bronze balls.

"The bronze ball will roll down the groove, and it can track its movements due to gravity. The angle at which the incline is positioned will reduce the acceleration of gravity that is seen in such a way that it can make accurate measurements. By observing this phenomenon accurately on a small scale at various tilt angles, then he can make statements about free fall objects in the force of gravity" [13].

*Gravitram* is a spectacular design, displaying accuracy and in-depth physics concepts. The combination of ball motion, the sound it's making, complicated paths indicate the level of skill of its creator. One of the most significant and most complex *gravitrams* made by Shab levy was at the Brazilian museum in 1995. It is about 15' and 12' tall and controlled by visitors through a computer console that allows various gates and tricks to operate according to visitor input [12] another kind of *gravitgram* can also be found at Kentucky, Louiseville in the Museum of Science and Industry as shown in **Figure 3**.

## 3.2 *Gravitram* in the world

Iron ball movements that follow the rules of potential energy have spread across the globe, including in Australia, America, Louisville, Massachusetts and many other cities and countries that already have *gravitram* or rolling ball. Each path on *gravitram* consists of "a series of simple mechanisms, including Archimedian screws, chain lifters, and chainsaws" [5]. This is what is at "Questacon (the national science and technology center)", Australia. The questacon science park is "located in King Edward Terrace, Parkes, in Canberra, Australian Capital Territory, Australia". A part of the government that manages this park is the department of industry, innovation, and science. Through Questacon, the government strives to understand and make

people aware of more excellent technology and technology in the community and is committed to making it fun, interactive, and relevant. People of all ages will engage with science in extraordinary ways with more than 200 live exhibitions in interactive galleries, as well as outdoor and indoor science park experiences.

**Fig. 2.** The gravitram kinetic sculptures of Shab Levy [12].


**Fig. 3.** Gravitram 4 in "Museum of science and industry, Kentucky, Louisville" [14].

his *gravitram* design marks the departure of the 1 "steel ball used in the previous sculpture 3. Now a larger and bolder ball is introduced, requiring a rethinking of many structural engineering challenges. Here, for the first time, a 2 "plastic hardball is used, and a familiar bowl is lost. *Gravitram* 4 also introduces many additional features not seen in other *gravitram*. The most important of these is the chaotic pendulum supported by a moving ball and visible still in the left image and partial motion in the stereo image on the right-side [14].

At the Family Museum, Bettendorf, there is "a Fox Hollow Kinetic Sculpture in a Rolling Ball Sculpture that spoils visitors to the greatness of the rolling ball design" as shown in **Figure 4** Children of all ages and even adults would be facilitated by "the Hollow Fox Ball Kinetic Statue at the Family Museum in Bettendorf" [15]. In other places, the Wentz *Gravitram* as shown in **Figure 5** is "inside the Exploration Place Science Centre in Wichita, Kansas" [16]. The system has five balls that keep moving, there are bottle openers and bicycle chains to lift the balls, and then gravity takes them down through a wire tunnel at all angles [16]. The latest *gravitram* in this series was made by the Shab and Ariel Levy father-son team. This system is "the 14th in the series and was made 37 years after the first on this page". "The basic size is 4'x 4' and the height is 8', it uses ball bearing and features several new, other tricks that not found in the previous sculpture" [16].

"George Rhoads Rolling Ball Sculpture, Toronto Canada" as shown in **Figure 6** has a different design, appearing wider and large making children more easily observe the motion of the ball. This is an exciting conglomerate of moving parts, clinks, and it makes kids who are frenzied stunned. This moving statue works, repeatedly, without a doubt. At six points around it, children can insert the ball into the machine, but regardless of whether the center of the equipment is still functioning. This is "a huge Rube Goldbergian toy", a toy that activates both separately from, and interactively with, children who admire it [17].

In addition to those mentioned above, there are several *gravitrams* scattered throughout the world, namely at "the Singapore Science Centre: The *Gravitram"*[18], "Imagination Station Rolling Ball Sculpture, Toledo", "Exercise in Fugality by George Rhoads, Logan International Airport Terminal E – Boston", "Oklahoma Science Museum", in Rolling Ball Sculpture [19] and others.

**Fig. 4.** Fox Hollow Kinetic Sculpture, Family Museum [15].

**Fig. 5.** "Wentz gravitram, exploration place, Wichita, Kansas" [16].

**Fig. 6.** "George Rhoads rolling ball sculpture, Toronto" [17].

### 3.3 Specific *gravitram* from Techno Park in Indonesia

Indonesia has many amusement rides from small scale to large scale, one of which is in the East Java Park Group. Various variations of amusement are displayed, ranging from animals, plants, simple technopark until spot that challenge adrenaline. One of the most common is the roller coaster. In almost every large-scale amusement vehicle, we will meet the roller coaster, several entertainment venues likely Jatim Park 1 (JP 1), Trans Studio Bandung, Ancol, Makassar Trans Studio, and others. The roller coaster uses the principle of conservation of energy in its movement across rails that have been designed in such a way as to achieve equilibrium. On a small scale that is no less interesting is *gravitram* or rolling ball.

*Gravitram* or rolling ball uses the principle of energy conservation in the principle of motion. This vehicle is not commonly found in entertainment venues in Indonesia. Tourist attractions that present *gravitram* in Science Park is JP 1 as shown in **Figure 7** that also comes with an instruction banner shown in **Figure 8**. The elements of relationship and education are the main attraction for visitors to observe the system that works on *gravitram*.

**Fig. 7.** Gravitram in JP 1, East Java Indonesia [PAR's documentation].


**Fig. 8.** The instruction banner of gravitram [PAR's documentation].

Complex and unique paths are characteristic of these science spots, the motion of the ball through the designed track and the momentum experienced by the ball with the ball or other

gravitram components resulting in an interesting tone and rhythm with good timing being the center of attention of this technopark. Gravitram in JP 1 is equipped with a brief description board about the understanding and simple concepts of the gravitram system. This is very suitable if it associated with outdoor learning and place-based education (PBE) [20], which can be integrated with the 2013 curriculum in Indonesia.

### 3.4 Physics concept of *gravitram*

*Gravitram* is part of the technopark that applies the main principle to is the conservation of energy. The mechanical energy in each position is the same, the change of potential energy into kinetic energy, sound, and heat. Electric motors lift the ball to the top of *Gravitram*, so that each ball has potential energy. "When the ball is released, the potential energy is converted into kinetic or moving energy". Also, "when the ball collides with the ball or other parts of *gravitram*, energy is released through sound and friction" [5]. Based on the name '*gravitram'* the tight concept it has is "the concept of gravity which gives potential energy to any object at a certain height" [21].

Each path on *gravitram* consists of a series of simple mechanisms, including "Archimedian screws, chain lifters, and chainsaws" [5]. However, with good design and timing, *gravitram* becomes a center of attention. The movement of the ball rolling causes friction. "The effect of static friction on a rolling object is to reduce the linear velocity of the object and to increase the rotational speed; the net work done by the frictional force becomes zero. On the other hand, a ball that rolls without slipping on a horizontal or tilted surface can roll to a halt, because energy is dissipated as a result of compression and expansion of objects in the contact area" [22].

There is the main difference between rolling on an inclined plane and rolling on a horizontal surface. In the case of a horizontal surface, internal friction will eliminate the kinetic energy of the ball, it gives impact to the ball will slow down. In the inclined plane, "one can assume that the kinetic energy is conserved if the hardball rolls without slipping and without flaws, despite the relatively large frictional force on the ball" [23]. In both cases, the static frictional force acts on the ball because the contact area or point on the ball is immediately stationary when the ball is rolling without slipping. Therefore both conditions are comparable, even though the ball accelerates on a slope and slows down on a horizontal surface [23].as shown in **Figure 9** both frictions on the plane surface stand up mainly from compression and expansion of the sphere or surface in the contact area, which acts to dissolve energy in an equal way as the ball loses energy when bouncing. In the inclined plane, the same rolling friction is existing, but apart from that, there is much greater static friction that arises from the gravitational pull on the ball under the incline. The final force acts to convert "the spherical translational energy into rotational kinetic energy without wasting energy" [23].

The change of potential energy to sound is caused by collisions between the balls or parts of the *gravitram* component. The energy change from the collision process provides a characteristic sound rhythm. This is closely related to the law of conservation of energy which states that energy cannot be created or demolished, energy changes from one form to another, from kinetic energy to sound energy. The same concept applies to momentum. "The total momentum of the system before and after the collision is the same, well-known as the conservation law of Linear Momentum" [21]. This spread over to all collisions as long as the net external force acting on the system is zero. The force system is formed by contacting the ball with the ball, as shown in **Figure 10**.

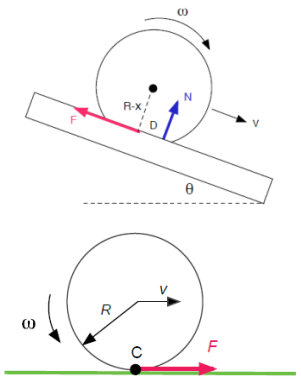


**Fig. 9.** The incline and horizon surface.

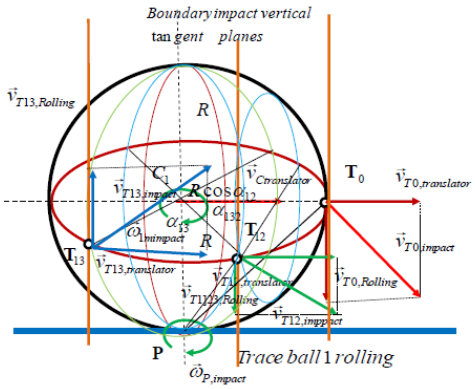


**Fig. 10.** "Plan of component impact velocities of impact points of a ball for the different types of collisions two equal rolling balls" [24].

To sum up, in Gravitram, to address the question, why do these balls roll?. The answer is due to the influence of gravity, an object in the shape of a ball will roll down when placed on an inclined plane. The energy possessed by the object to move is usually called gravitational potential energy which then turns into kinetic energy when the object is moving.

## 4 Conclusion

*Gravitram* is part of a technopark that has an appeal. A unique and complicated system is the hallmark of this sports science. The concept of physics used is conservative energy with its main center being gravitational or potential energy that turns into other energy. *Gravitram* is very suitable for use as a media for outdoor learning, especially science or physics subject with a place-based education model that can be integrated with the 2013 Indonesian curriculum. Thus, the existence of *gravitram* seems close to outdoor physics learning rather than physics leisure after seeing the history, the system in the world, and the physics analysis of the system itself.

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