Exploring the intersection of Torajan hanging graves and physics concepts in ethnoscience education

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Abstract

This qualitative, ethnographic study aims to identify, analyze, and reconstruct the physics principles embedded in the Hanging Grave tradition of Tana Toraja, specifically focusing on the *erong* (coffin), body, and hanging structures into contextual learning materials. Conducted in Kesu District, Toraja Regency, data were gathered via triangulation (observations, interviews, and documentation) utilizing purposive sampling. Four key informants participated: a traditional chief, a coffin manufacturer, a cemetery caretaker, and a community member. Data were processed through reduction, display, and verification. The study reveals three major socio-cultural physics applications that are (1) Static Equilibrium, The *erong* support system on the cliff wall functions as a cantilever beam. The static load is sustained by a pinch moment at the beam's base, satisfying static equilibrium criteria to prevent rotation or collapse. (2) Kinematics and Dynamics, The *Ma'Popengkalo Alang* (body transportation) ritual involves mechanical work (*W = F.s)* and energy transformations. The minimum force required to move the mass vertically is heavily dictated by the cliff's angular slope. (3) Thermodynamics**,** The degradation of *erong* wood follows thermodynamic and thermal expansion principles. Periodic ambient temperature fluctuations induce thermal stress, accelerating weathering. This is culturally mitigated through physical conservation during the *Ma'nenek* ceremony. Ultimately, this indigenous science reconstruction successfully transforms complex cultural engineering into structured, contextual physics concepts ready for curriculum integration.

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1. Introduction

Physics is not limited to equations and theories; its application is essential to enhancing the quality of life. However, in schools, students commonly think of physics as an abstract subject instead of a tool to improve their lives (Hidaayatullaah et al., 2020; Özkan et al., 2024; Sunarti et al., 2025; Suprapto & Nandyansah, 2021). For example, when students are asked basic physics questions such as, "What is the relationship between wind and boat speed?" or "How can you efficiently lift a fishing net?" Students cannot solve these problems (Martawijaya et al., 2023). The results of PISA 2022 show this at the national level in Indon/esia. Science literacy has declined by 13.2 points in the last four years, with the latest score of 383 still below the OECD average (≈485). This suggests that most students can only answer fundamental science questions but struggle with complex real-world problems (OECD, 2023).

This happens because classroom instruction merely provides information without immediately relating it to students' real-life experiences (Roth et al., 1997). Physics is fundamentally tentative as a science, which means it was built on scientific truths. As a result, pupils must be trained to seek scientific truth. Obtaining scientific truth must incorporate procedures such as observation, experimentation, and reasoning, rather than just rote data memorization (Hogan & O'Flaherty,

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2022). On the other side, students' ideas of science are frequently limited to its technological applications, such as automobiles, electrical appliances, and spacecraft. This restricted perspective can lead students trained in non-science and non-engineering fields to regard science as useless to their education (Kim & Park, 2024; Park & Song, 2009). According to research, about half of middle and high school pupils surveyed said that learning science was superfluous. Students should be encouraged to pay attention to their environment, including culture, to grasp science's purpose and application (Park & Song, 2009).

Culture-based science learning, or ethnoscience, can bridge physics concepts and everyday life phenomena. Ethnoscience is science learning linked to culture by exploring students' indigenous cultural perspectives and translating them into concepts, principles, and/or laws (Atmojo et al., 2019). It not only transfers culture and cultural manifestations but also uses culture to enable students to create meaning, break through the boundaries of imagination, and be creative in achieving a deep understanding of physics. (Winarto et al., 2021). Through ethnoscience, students learn about physical phenomena relevant to their lives, such as local cultures and regional values.

Culture-based, holistic, and local learning has a significant beneficial impact on science education (Pang et al., 2021; Marcellino et al., 2022; Wang et al., 2021). Students can realize that science is not just abstract theory but something relevant to their daily lives and culture. Integrating local wisdom also helps students understand science more deeply through real-world experiences and develop critical thinking by comparing traditional knowledge and modern science. Furthermore, they can appreciate cultural heritage while understanding the scientific principles underlying local practices (Chamidah & Rohmawati, 2022; Mulyono et al., 2024; Yuliana et al., 2021). Moreover, this integration will enhance student learning excellence and equity in rural areas. This can be achieved by valuing physics within their culture; thus, science curricula need to be reformed considering the culture and perspectives of minority groups (Isa et al., 2022).

Cultural research in science education has increased significantly over the past 50 years, with research peaking in 2013 based on searches in Scopus. Most studies were conducted in developed countries, with the United States, the United Kingdom, and Germany being the most represented. The study's findings suggest further exploration of the influence of students' cultural backgrounds on their attitudes and engagement in science learning, as well as ways to integrate this into the curriculum and teaching. Educators must develop culturally responsive approaches to reduce social and cultural barriers in science education (Zheltukhina et al., 2023).

Hanging funerals and the framework of physics education have not been systematically connected in any prior research. Few studies examine the scientific aspects of Toraja culture, especially physics, even though there are studies on the subject. Due to their distinctive cultures, the Toraja people could be employed as an ethnoscientific research subject. Because of how they commemorate and bury their family, this tribe is regarded as the most distinctive in the world (Adams, 2003; Baan et al., 2022). A series of expensive funeral ceremonies (Rambu Solo) and cave tombs on high cliffs can be found in Toraja (Hidayah, 2018). One of Toraja's most in-demand burial places is in Ke'te Kesu', Kesu' District, North Toraja Regency (Nur et al., 2021). The Toraja tribe believes that the high placement of the tomb will accelerate the journey of the spirit to its destination (Hidayah, 2018).

The Hanging Grave in Tana Toraja is a popular tourist attraction with visitors. It contains thick religious, social, and cultural values to become an ethnoscience object. The hanging grave in Tana Toraja is a cemetery on rocky cliffs that forms shelves containing corpses (Patarai et al., 2021). The teachings of burial in stone were brought by Aluk Todolo or Puang Matoa (Bulu', 2016). There are three reasons why the Toraja tribe maintains a hanging grave, or burial of a corpse in stone. The first reason is to continue the teachings of their ancestors, their ancestors who lived in the Stone Age and used caves as graves. The second reason is that the ancestors of the Toraja tribe thought that humans would continue to develop in the future, so that the land could only be used as agricultural land. As an alternative, a cave could be used as a graveyard. The third reason is to make it easier for families to make a pilgrimage to the tomb because they can see firsthand the condition of the coffin (erong). If the coffin is damaged, the family will replace it with a new coffin (Lanta, 2019).

The Hanging Grave on the Tana Toraja Cliff consists of hangers and erong. Erong is a container formed as a secondary burial container equipped with a lid (Bernadeta, 1998; Noviani et al., 2024). The second burial is carried out when the ceremony is ready; the corpse, made into a skeleton, is taken, cleaned, and then wrapped to be buried in the erong (Somba, 1999). Erong di Toraja is a family graveyard, so in one erong can be placed several corpses from one family. Each Erong can accommodate up to 20 corpses (Bernadeta, 1998).

The Toraja tribe puts erong as high as possible. The higher the number of people who died, the higher the placement of erong (Lanta, 2019). The Toraja tribe believes the deceased bring their property (Hidayah, 2018). The placement of a high erong accelerates the journey of the spirit to its destination (Lanta, 2019). This form of belief is the ancestral heritage of the Toraja tribe (Bulu', 2016). In the past, the Toraja people kept corpses in tongkonan houses; the length of time to store corpses was a maximum of thirty-six nights for noble families. At the same time, the other groups are less than that, or even not kept at all, because the ceremony is very short. Finally, storing or burying corpses in stones has become a tradition among the Toraja people (Hidayah, 2018).

The funeral of the Toraja tribe is seen from the social or caste status of a person who has died. There are three caste levels: the upper caste, the middle caste, and the lower caste. The position of the erong is determined based on caste because it is not just about laying or burying in stone. The top caste are the descendants of nobles who hold a solo sign ceremony by cutting 24 or more buffaloes and laying the topmost erong. The middle caste is the descendants of nobles who cut fewer than 24 buffaloes and put the middle part of the erong in the middle. The lowest caste is ordinary people, or people, and the placement of the lower Erong (Lanta, 2019).

This research aims to explore the concept of physics on the Hanging Tomb on the cliff of Tana Toraja as a formal effort in integrating local wisdom into contextual physics learning, while preserving Indonesia's cultural richness. Substantially, this study advances the corpus of physics education research (PER). Furthermore, this research makes a significant contribution to the global discourse on the decolonization of science curriculum, as well as setting a conceptual benchmark for future researchers seeking to integrate indigenous knowledge systems into the formal academic realm.

The study also serves as a catalyst for cultural preservation by providing empirical validation of the traditional structures and architecture of indigenous peoples. By elevating ancestral traditions to the realm of scientific validation, this research is able to foster communal cultural pride and support sustainable heritage conservation. For physics educators, this study provides an operational blueprint for implementing Culturally Responsive Science Education. Meanwhile, for students, the cultivation of the laws of physics in a familiar socio-cultural ecosystem will be effective in reducing cognitive alienation, broadening the perception of the usefulness of physics, and encouraging high-level science process skills that are essential to reverse the decline in local scientific literacy.

2. Method

2.1. Research Approach

Qualitative research methods are used to explore physics concepts at the Hanging Tombs on the Tana Toraja Cliffs. This exploration requires an in-depth description and analysis of the culture surrounding the Tana Toraja Cliff Hanging Tombs, making an ethnographic approach appropriate for this study. The ethnographic approach emphasizes a deep understanding of social behavior from the actors' perspective. This approach can provide a "thick description" or a rich narrative that deeply reflects social reality, but it is susceptible to subjectivity (Fansury & Rampeng, 2023; Gold, 1997).

2.2. Research Participants

In this study, informants were selected using the purposive sampling technique. Purposive sampling is a technique for selecting informants based on criteria consistent with the research's characteristics and aims. This study's informants include Layuk Sarungallo, the traditional leader of Ke'te Kesu, North Toraja Regency; Tinting, the traditional leader's sister and a former erong maker; Sandi, the cemetery caretaker; and Baso, a resident of Ke'te Kesu, Tana Toraja.

2.3. Research Instruments

The main instrument in qualitative research is the researcher himself. The researcher used interview guidelines and observation sheets as instruments to help researchers follow the grid of interview and observation guidelines used. Interview guidelines can be seen in Table 1 and observation sheet grid can be seen in Table 2.

Table 1. Interview Guidelines

Aspects	Variable	Indicator	Question
Hanging Graves on the Tana Toraja Cliffs	Components of Hanging Graves on the Tana Toraja Cliff	Various components that make up the Hanging Grave on the Tana Toraja Cliff	1-2
		The philosophy and history of the Hanging Grave on the Tana Toraja Cliff, especially its components	3-5
	Physics Concepts	Shape of the Hanging Grave Component on the Tana Toraja Cliff	6-7
		Component Size of the Hanging Grave on the Tana Toraja Cliff	8-9
		The process of compiling the components of the Hanging Grave on the Tana Toraja Cliff	10

Table 2. Observation Sheet Grid

No	Observed indicators
A.	Various components that make up the Hanging Grave on the Tana Toraja Cliff
1	Erong consists of a lid and a body.
2	Buffer
3.	Other components
B.	Shape of the Hanging Grave Component on the Tana Toraja Cliff
1	Erong shaped like a boat, pig, buffalo.
2	Some of the buffer fortifications
3	Other forms
C.	Component Size of the Hanging Grave on the Tana Toraja Cliff
1	Erong has a length of 2 meters.
2	Supports follow the size of the erong

2.4. Data Collection

This study uses data triangulation, integrating documentation, interviewing, and observational methods to gather reliable data while avoiding the subjectivity of the players. The observation technique was used to create a picture of the tangible ideas in the Hanging Tombs on the Tana Toraja Cliffs, which involved direct and indirect observation and information recording. Two people were interviewed to share ideas and information through question-and-answer sessions, which allowed for the creation of meaning around a particular subject. The interview aims to learn more about how participants comprehend the events and circumstances, especially concerning the importance of local knowledge in the Tana Toraja Hanging Tombs. To preserve data in the form of pictures or photographs that will be used as information during observation and online documentation searches, technical documentation is completed.

2.5. Data Analysis

Miles and Huberman (1992) describe the analysis technique used to grasp the physics principles at the Hanging Tombs at Tana Toraja Cliffs, which includes data reduction, data display, and conclusion drawing/verification. (1) Data Reduction: Data collected through interviews, documentation, and observations is reduced by the existing problem formulation. (2) Data Display: Data reduction results are presented in the form of charts and relationships between categories, allowing for drawing conclusions and implementing actions. (3) Conclusion drawing and verification are ongoing in the field, although the conclusions remain provisional. These findings were then validated by rethinking while writing, reviewing field notes, and consulting with the team. When the problem is discovered, the data analysis cycle ends. (2) Data Display: Data reduction results are presented in charts and relationships between categories, allowing for conclusions and actions to be taken. (3) Conclusion drawing and verification are carried out continuously in the field, but the conclusions are still preliminary. These conclusions were then verified by rethinking during writing, reviewing field notes, and discussing with the team. The data analysis cycle is stopped when the problem has found a satisfactory answer.

3. Results and Discussion

This research explores physics concepts in the Hanging Grave on the Tana Toraja Cliff. It requires a deep understanding of the philosophy, history, shape, size, and process of making the hanging grave.

3.1. Philosophy and History

A hanging grave is a place to store the body on a rock cliff. The Toraja people used to believe in Aluk Todolo, or Animism. The community believes their ancestors are from China and brought development and teachings to Toraja. According to Layuk Sarungallo, 1100 years ago, the Toraja people were tested for their loyalty by placing the body of their family in their house when they died; the Toraja people could not leave the body even if it decomposed. After the Toraja people can weave pineapple fibers, and the body is then wrapped in pineapple fiber. After the development occurred, the Toraja people thought of a way to prevent the body from rotting at home, so the Toraja people made an erong, and a ceremony was carried out to move it on the Batu Slope.

Meanwhile, according to resource person T, 60 generations ago, the Toraja people lived in caves; after being able to cultivate crops, huts were made from the roof of rumbia as a place to live and die. After the development of the Toraja people, they made a grave place that contained family clumps by utilizing large wood from the cempaka and sandalwood types. Before moving to the erong, the body of the Toraja people was buried in a traditional house, waiting for all their problems, such as debts and receivables, to be finished, until their harsh words were finished. In the process of waiting for the solution to the problem, the body automatically decays at home. So that the body that decomposes at home does not transmit disease, the fluid in the body is accommodated in a bamboo placed in a cave. The body is embalmed with traditional medicines, including betel lime, areca nut, and betel leaf, so that germs in the dead do not move to the living. After everything is finished, a ceremony is carried out to put the body into the erong. The balm smeared on the body is believed to move to the erong and preserve the erong. Each cemetery began to deteriorate, and the supports began to be damaged; the grandmother's event was carried out to repair the grave.

Erong is the first cemetery in Toraja. Erong is a tomb that accommodates a minimum of 2 or 5 people, and seven people, so erong is also called a tomb because it can accommodate more than one person. Erong is placed on a rock cliff because the Toraja people know that the Toraja exist in the mountains or highlands, so the existing land is used as a place to live and a source of life, such as raising buffaloes, cultivating crops, etc. Erong is placed on a rocky hill because the Toraja people think that rocks are not helpful for life, so the land and rice fields are used for plantations, and rocks are used as graves.

The distinctive feature of the hanging grave on the cliff of the Tana Toraja lies in its ceremony. People included in the Erong must follow traditional formal ceremonies and not step over customary norms. So that the erong is only for the echelons or nobles, while the bodies of ordinary people are only wrapped and placed in caves. When the echelon dies, all people who have a celebration are having ceremonies and delivering the body to the cemetery, but all who have celebrations as a tribute to the echelon. For example, the traditional formal ceremony in question is cutting a 24-day buffalo that lasts 7 days; otherwise, the body should not be put into the *erong*, and the community ceremony wears formal clothes. The ceremony is called the solo sign.

3.2. Parts that make up the hanging tomb

Erong parts of the Tana Toraja cliff can be seen in Figure 1.

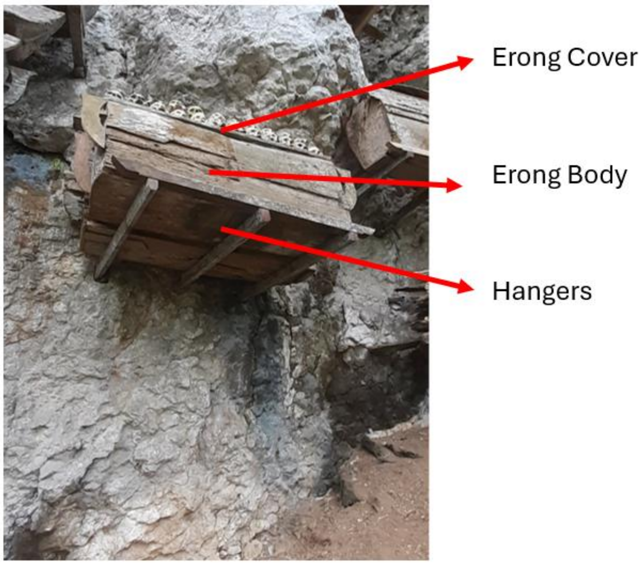


Figure 1. Erong Parts of the Tana Toraja Cliff

The parts and sizes of the Hanging Graves on the Tana Toraja cliff are

a. Cover and Body Erong

The size of the erong is small and large; there are two types of erong. Some have high horns for men and short horns for women, following the shape of the genitals (Interview/L/129-142). Erong is made closed to protect it from animal disturbances, one of which is dogs; it is feared that bones from ancestors are taken by dogs (Interview/T/152-166). There are small and large sizes for families, small for families with one father, one mother, and child, and large for families with many siblings (Interview/T/145-149). The length of the erong is 2.5 meters, about 180–2meters following the average body shape of the Toraja (Interview / T/155-157). The observation results showed that the size of the erong has a length of 193 cm, a lid of more than 20 cm, a width of 45 cm, and a diagonal length of 73 cm for the boat type, while for the pig type it has a length of 178 cm, a more close of 32 cm, a width of 52 cm, and a roof of 140 cm.

b. Hangers

The erong is hung so that the erong and its body are not eaten by termites or worms and other animals; the Toraja people take great care of the bodies of deceased family members. Supports are made only to strengthen and secure so that the erong does not fall to the ground (Interview/L/207-211). The support design is made to be strong and use instinct. Hanging grave makers sculpt stones to be used as support pegs. The erong must be hung to be safe from dog nuisance; therefore, a buffer is needed to hang the erong. Forms of Hanging Graves can be seen in Figure 2.

(a)

(b)

(c)

Figure 2. Erong with (a) Boat, (b) Pig, (c) Buffalo

According to Tinting, the philosophy of the erong form according to *the toparenge* (noble people) says that he will sail to Nirvana. Vehicles can be boats, pigs, and buffalo for the unmarried. The shapes of the graves are arranged close together, meaning that he is a close relative. The various forms of *erong* are:

a. Boat

The boat's shape means the body is in one clump within one big family. The boat's shape is for those with a family or are married. The Toraja people say that the tongkonan house is a boat from South Asia and is used as a house; if the Toraja people die, they also make a boat to return to their origin. An erong in the shape of a boat with carvings is an erong for the Toraja people, who are considered saints who still bless their community, or in the Toraja language, it is called tommeng balli. Erong, in the shape of a boat, is also interpreted as a rich person.

b. Buffalo

The shape of the buffalo means that during the life of the deceased person, they were a person who was good at fighting and keeping buffalo. The form of buffalo is for those who have never had a family/are not married but have a good economy. Erong, in the shape of a buffalo, is also interpreted as a man.

c. Pig

The shape of the pig signifies the woman who raises the pig. The Pig form is for those who have never had a family, are unmarried, and have a low income.

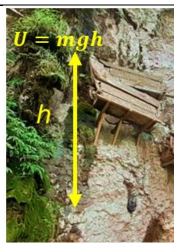
3.3. Making Hanging Grave Erong

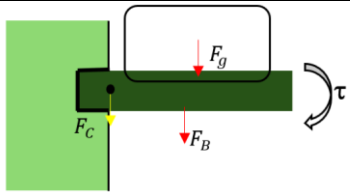
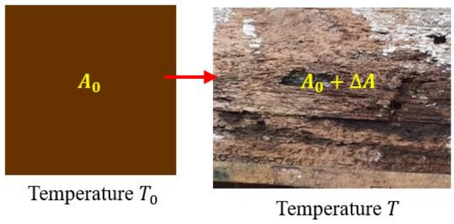
Erong comes from one large wood (Interview/T/286-292). It is made by carving plain wood without carving with a long chisel (Interview/L/244-251 and Interview/T/490-497). The chisel size is long to make it easier to make the scraped erong. The work took about six months and was done by three people. Another person who works for another guide is called Panre Nunu, who might be an architect if the world today were an architect (Interview/T/539-546).

3.4. Analysis of the Physics Concept in Hanging Graves

Physics concepts in stone graves on tana toraja cliffs can be seen in Table 3.

Table 3. Physics Concepts in Stone Graves on Tana Toraja Cliffs

Science Culture	Community Knowledge	Physics Concepts
A Solo Wedding Ceremony	 The distinctive feature of hanging graves on the Tana Toraja cliff lies in the echelons, or nobles, who died and performed expensive traditional ceremonies or solo signs that should not exceed customary norms. One of the processions from the solo sign is Ma'Popengkalo Alang, which is a procession of parading or carrying bodies wrapped to a stone grave on the Tana Toraja cliff to be buried. The ceremony was carried out in harmony and solemnity as a tribute to the echelon. To preserve the echelon bodies of animals such as dogs, termites, and worms, the erong is placed on the rock cliff and hung to form shelves. The higher the erong is hung, the safer the body will be from animal interference.	 When performing one of the solo signage ceremonial processions, namely Ma'Popengkalo Alang or delivering the body to a hanging grave on the cliff, the community voluntarily makes an effort. It expends greater energy for the deceased echelon as a final tribute. In physics, the higher the erong is placed on the cliff, the greater the effort and energy expended to deliver the body.

Science Culture	Community Knowledge	Physics Concepts
Pendant shape design by Panre nunu	 It is not a hanging grave when there are no hangers. This Grave Hanger is designed by Panre Nunu. The hanger is designed to be strong and use instinct. Hanging grave makers sculpt stones so that they can be used as support pegs. The erong must be hung to be safe from dog nuisance; therefore, a buffer is needed to hang the erong.	 Illustrations of pegs (rock cliffs) and erong supports can be seen above. The support rod is in a horizontal position. In the physics of such a rod, it is called a cantilever beam. Due to the force caused by the weight of the beam (F_B) and the force acting due to the load of the erong (F_g), then when the rod does not rotate, the normal force between the supporting rod and the rocks will be pointing upwards. When the rod tends to rotate (Presence of Style Moments τ), the normal force due to the support rods and rocks will lead downwards, symbolized by cap F sub cap C, So this force prevents the stem from moving and rotating.
Grandma's Event	 The community knew that the cemetery would be weathered. When the cemetery began to deteriorate and the supports began to be damaged, a grandmother's event was held to repair the grave.	 In physics, weathering occurs due to expansion. During the day, the air temperature rises, causing expansion in the grave, and at night or when it rains, the temperature decreases; this happens repeatedly, causing the wood to rot.

The Hanging Grave in Tana Toraja is an *erong* that is arranged hanging on the cliff of Tana Toraja; this result is in accordance with (Patarai et al., 2021) who stated that on the rock cliffs, a kind of shelf is made as a place to place coffins (*erong*) containing corpses called hanging graves. Three main components make up a hanging grave on the Tana Toraja Cliff, namely *the erong* body, the erong *lid*, and the support or hanger. According to the cemetery consists of a hanger and a second burial container (erong body) equipped with a lid. Each component forms a system that contains the concept of physics that can be used as a physics lesson as follows:

a. Work and Energy

Based on the interview results, the characteristic of hanging graves on the Tana Toraja cliff lies in the echelons of nobles who died and performed traditional formal ceremonies or solo signs, which were expensive and should not step over customary norms. The traditional Rambu Solo ceremony is a death ceremony organized by the Toraja people. One of the processions from the solo sign is Ma'Popengkalo Alang, which is a procession of parading or carrying bodies wrapped in a barn to be buried. The process is carried out in harmony in a funeral ceremony that shows the respect of the Toraja people for their deceased ancestors (Patarai et al., 2021).

Researchers found the concept of business and energy in the procession of Ma'Popengkalo Alang. Effort means something that is realized when the force works on an object and the object moves a certain distance as a result (Douglas C, 2014). Mathematically, it can be written as follows in Equation 1.

$$W = F_{||}\, d, \tag{1}$$

Where W is the effort made by an object, $F_{||}$ the force is parallel to the displacement d, and d is the object's displacement. An example of an effort in physics related to the effort made by the introduction of the erong is shown in Figure 3.

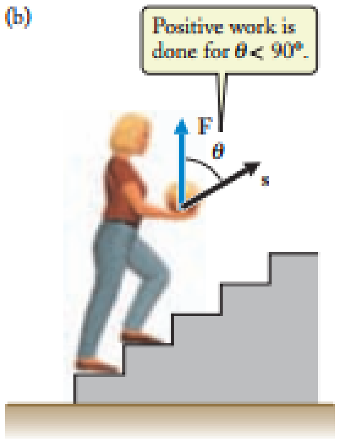


Figure 3. The woman who is lifting a ball and climbing the stairs
Source: (C. Ohanian & T. Markert, 2007)

Figure 1 shows a woman moving a ball up a ladder. According to Ohanian & Markert (2007), the effort made by women can be counted by Equation 2 or Equation 3.

$$W = F\ d\ cos\ \theta \quad (2)$$

Or

$$W = F_x d_x + F_y d_y + F_z d_z \quad (3)$$

Similar to the example above, when delivering the body to a hanging grave on the cliff, the community voluntarily makes an effort, namely bringing the erong up the cliff of Tana Toraja. This is the same as equations, where W is the effort made by the erong usher, F is the force of the erong to lift the erong up the cliff, and d is the movement of the erong from the bottom of the cliff to the top of the cliff. The work or effort made to move an object from the initial position to the final position equals the difference between the initial and final potential energy (Abdullah, 2016). According to Halliday et al (2013), the relationship between effort and potential energy, written as Equation 4.

$$W = U_2 - U_1 \quad (4)$$

U_2 is the potential enerErong erong when it is on the cliff and U_1 is the potential energy of Eong before it is brought to the cliff. Potential energy is the energy produced by forces depending on the position of an object environment; environment, the most common potential energy is the gravitational potential energy expressed by the following Equation 5.

$$U = mgy \quad (5)$$

Where U is the potential energy, m is the mass, and y is the height of the object above (Giancoli, 2023). If it is assumed that the initial height of the erong is equal to zero (Equation 6), the final height of the erong is equal to y (Equation 7).

$$U_1 = mg(0)$$

$$U_1 = 0 \quad (6)$$

So,

$$W = U_2 - U_1$$

$$W = U_2 - 0$$

$$W = U_2 \quad (7)$$

So, based on the equation, the introduction of the erong makes the same effort with the potential energy of the erong when it is on the cliff. The community voluntarily made an effort and expended greater energy for the deceased echelon as a final tribute. The higher the erong is placed on the cliff, the greater the potential energy of the erong and the greater the effort made by the erong to deliver the body.

b. Rigid Object Equilibrium

Researchers found that hanging graves on the Tana Toraja Cliff can be attributed to the balance material of rigid objects. According to Giancoli the cause of the motion of an object is force. In rotational motion, something that causes an object to rotate or rotate is called a moment of force or torque(Giancoli, 2023). The moment of force is defined as the result of the time between the force and the distance from the point to the action line of the force in a perpendicular direction (Equation 8).

$$\Sigma\vec{\tau} = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + \cdots \quad (8)$$

The direction of the moment of the style meets the rule of the right hand. The finger grip acts as the direction of rotation, and the thumb as the force moment. The torsion arm is the perpendicular distance between the line along which the force is acting and the axis of rotation. Torque is a vector quantity, so it has a value and direction. Torque has a positive value, so the object rotates counterclockwise, and a negative value means that the object rotates in the direction of clockwise rotation.

An object that not move due zeroo a moment of force ($\sum \tau = 0$) which acts on a system equal to zero and the net force ($\sum F_x = 0$, $\sum F_y = 0$, dan $\sum F_z = 0$) which works also equal to zero then the object can be said to be in equilibrium. Equilibrium, which means equal or balanced power. Rigid Object Equilibrium according to Giancoli (2023). An Example of Rigid Object Equilibrium recliff is shown in the Hanging Grave System on the Tana Toraja cliff as Figure 4.

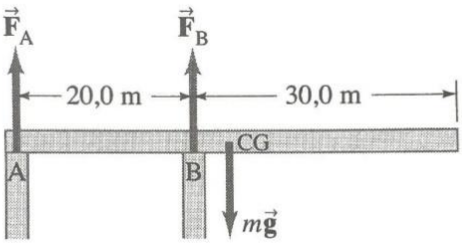


Figure 4. Beams and their supports Source: (Giancoli, 2023)

Figure 4 shows the forces acting on a homogeneous beam that overhangs beyond its support; such a beam is called a cantilever. The forces consist of the force exerted on the two supporting legs and the gravitational force acting on the CG beam. The weight of the beam acting on the CG will rotate the beam facing the fulcrum point B. When the beam is not moving or in a balanced state, it should be poAng downwards, so that $F_A F_B F_A$ can be seen in Equation 9 and Equation 10.

$$\sum \tau = r_1 F_A - r_2 mg = 0 \quad (9)$$

$$\sum F = F_A - F_B - mg = 0 \quad (10)$$

Meanwhile, the illustration of the stake place (stone cliff) and the support of the rock cemetery on the Tana Toraja cliff can be seen as shown in Figure 5.

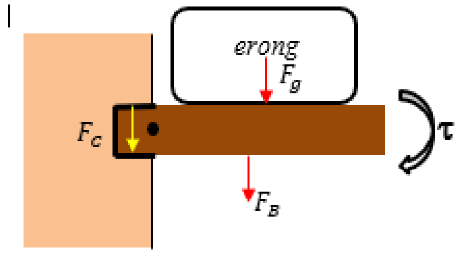


Figure 5. Diagram of the Hanging Grave on the Tana Toraja Cliff

The support rod is horizontal and overhangs beyond the support, so it is called a cantilever rod or beam. It is assumed that the fulcrum is at the end of the block tucked in the rocks (O). Due to the force caused by the weight of the beam (F_B) and the force acting due to the load of the erong (F_g), then when the rod does not rotate, the normal force between the supporting rod and the rocks will be pointing upwards. When the rod has a tendency to rotate (Presence of Style Moments τ) Then the normal force due to the support rod and the rocks will point downwards which is symbolized by F_C so that this force prevents the rod from moving and rotating.

c. Expansion of Substances

Meanwhile, the illustration of expansion of substances can be seen as shown in Figure 6.

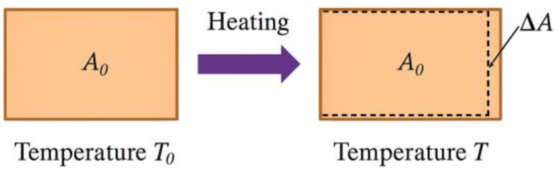


Figure 6. Expansion of Substances

Researchers found that hanging graves on the Tana Toraja Cliff can be attributed to substance expansion. All objects shrink if they experience an increase in temperature, and vice versa; objects shrink if the temperature decreases (Abdullah, 2016). There is no exception to the hanging tomb made of wood. During the day, the air temperature will rise, causing the hanging grave's expansion; at night or when it rains, the temperature will decrease. This happens repeatedly, causing the wood to become weathered.

The results ofthis research prove that the hanging grave on the cliff of Tana Toraja is capable of becoming a physics laboratory. These findings explicitly reveal three key physics concepts embedded in these practices. First, the procession of transporting the body (Ma'Popengkalo Alang) shows the principle of work and potential energy. Secondly, the Erong support system acts as a cantilever beam, which describes the balance of rigid objects regulated by normal torque and force. Third, the physical weathering of the wooden tomb that was culturally muted by the Ma'nenek ceremony shows the concept of thermodynamics of thermal expansion and contraction caused by extreme temperature fluctuations.

The results of this research are also in line with the curriculum objectives in Physics Subjects in Indonesia. Pedagogically, the socio-cultural and physical dimensions of the Tana Toraja hanging grave can be institutionalized seamlessly into Phase F of the High School Physics Curriculum (specifically targeting students aged 16–18 years). Within this framework, the conceptual physics extracted from ethnographic sites directly addresses the mandatory core competencies (Learning Outcomes) in the independent curriculum, which require students to evaluate force-motion dynamics, fluid mechanics, and thermodynamic systems in real-world engineering and natural phenomena. By leveraging these local artifacts, educators can transform rigid academic standards into a dynamic and culturally responsive physics curriculum.

Furthermore, integrating hanging graves in this physics subject operates investigation-based science process skills (Process Skills) that have been determined in high school physics education. The structural complexity of the cliff tomb is inherently with the achievement of process proficiency in the independent curriculum that consists of (1) empirical observation of cultural structure, (2) hypothetical formulation of mechanical stability, (3) investigative planning, (4) analytical data processing of structural loads, and (5) collaborative communication of socio-scientific results. Instead of carrying out abstract laboratory routines, students engage in authentic scientific inquiry by deconstructing the physics underlying their own cultural heritage. In addition, by using the Tana Toraja Hanging Tomb as a living laboratory, students are trained to use physical reasoning (such as the laws of mechanics and static equilibrium) to solve real structural problems. It is a scientific interpretation skill that is precisely tested in global competency standards.

Third, the study fundamentally improves the perception of the use value of physics in the eyes of students by empirically demonstrating its functional operation in local cultural heritage. The educational psychology literature often warns that high school students develop cognitive alienation from physics due to the pervasive Eurocentric bias that frames this discipline almost exclusively around high-tech innovation and industrialization. This research succeeded in dismantling these elitist barriers by validating the complex classical mechanics embedded in the survival and burial structures of Tana Toraja ancestors. By showing that the laws of abstract physics are inherently functional in their own heritage, this study provides a concrete and local response to the global call for the decolonization of science curricula and the integration of indigenous knowledge systems. Further, this approach offers a strategic framework to mitigate the decline in local scientific literacy such as the downward trend observed in the recent PISA report by transforming physics education into a culturally responsive place-based learning experience that stimulates deep intrinsic engagement.

3.5. Limitation

This research is limited only to hanging graves on the Tana Toraja Cliff, namely on the body of the erong, the lid of the erong, and the hanger, especially in Kesu District, Toraja Regency. There are many other hanging graves in Tana Toraja. Interviews with respondents and observations at other hanging grave sites have the potential to show variations in data that can expand the scope of the study's findings. Many cultures in Tana Toraja have not been explored. A more in-depth study of other cultures is still needed. Then, this research is limited to providing materials and data related to the concept of physics in the Tana Toraja hanging grave; educators and researchers can further develop this material into teaching materials tailored to the characteristics of students and schools. Another limitation is that it only uses quantitative methods. Further research can use other methods, such as quantitative methods, to measure the effectiveness or impact of this learning.

4. Conclusion

Based on the results of the research, it is known that the hanging grave on the Tana Toraja Cliff contains a physical concept, namely (1) The characteristic of the hanging grave on the cliff of the land of Toraja is the echelon who died and performed the solo sign ceremony, when doing one of the solo sign ceremony processions, namely Ma'Popengkalo Alang or delivering the body to the hanging grave on the cliff, the community voluntarily made an effort and expended greater energy as a form of respect finally (2) Panre nunu' designed Erong to be hung to be safe from dog disturbances, the suspension beam of the hanging grave in physics is called a cantilever beam, the support still prevents the movement and rotation movement of the beam so that the hanging grave system remains in equilibrium (3) The community realizes that the cemetery will be weathered so that a ma' nenek event is made; in physics, weathering occurs due to temperature changes that cause expansion.

Author Contributions

Nurul Arsyi : Conceptualization, Investigation, Data Curation, Writing – Original Draft Preparation, and Visualization. Muh. Mahfud : Conceptualization, Formal Analysis, Investigation, and Data Curation, Writing–Review & Editing. Nurul Hidayah : Conceptualization and Project administration. Mutahharah Hasyim : Methodology dan Supervision. Herwin : Supervision.

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