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Physics of Gulli – Danda

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Abstract

Using traditional games as instructional tools to understand physics concepts is a good idea and can play a vital role in developing activity based physics curriculum. Learners are able to relate with such tools more easily thus helping them develop pre-knowledge, logical reasoning, strategy making, concentration and nurture their inquiry-based scientific temperament epistemologically. Gulli – Danda[†], a native game in many parts of the world, is used here as an instructional tool to formalize metacognitive aspects of physics terms evolved during the demonstration of the game. A vast range of kinematic terms are involved with the demonstration of Gulli – Danda which are studied in the present paper in detail. Different forms of energy associated with specific movements of the game have also been discussed thoroughly which strongly supports the use of Gulli – Danda as a potential tool to understand physics terms associated with it.

Furthermore its use in explaining momentum conservation, trajectories of projectile motion, center of mass, moment of inertia, and elastic as well as inelastic collision has been demonstrated. We suggest that such traditional games and models, which are easily available the learner, can be effectively used as low cost pedagogical tools to develop instructional strategies in physics education. It was also observed that learners were able to make a connection with the seen and unseen world through demonstration of Gulli – Danda, which provides powerful evidence for a strong connection between the neuroscience of brain chemistry and play and joy. It also advocates using traditional native games as props and 'play' as the basic component of enquiry. An analysis of the post test results of different sets of audiences at different places revealed that no learner scored less than fifty percent marks on these tests. This is a clear indication of achieving average gain in conceptual understanding of learners towards physics concepts by using Gulli – Danda.

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Key Words: Traditional native games, brain compatible pedagogical approach, low cost demonstration tool, physics of Gulli-Danda.

† *It is a popular traditional game of India and is the national game of Nepal and is played in rural areas and small towns of India as well as Pakistan, especially in Punjab. In the United States, a similar game is called Pee-wee. It is also known as Tipcat in English, Dandi - Biyo in Nepali, Alak - Doulak in Persian and Kon - ko in Khmer (the Cambodian language).*

1. Introduction:

Physics, from its genesis, has been the branch of science that attempts to use the language of mathematics to describe how nature functions. Its scope of study encompasses not only the behavior of objects under the action of given forces, but the theories that provide us with some of our deepest notions of space, time, matter and energy. Its ultimate objective is the formulation of a few comprehensive principles that bring together and explain all such disparate phenomena. It also deals with describing why and how certain real-world phenomena occur and enables us to envisage what may transpire in certain circumstances. At its core, physics establishes itself as a comprehensible and an intriguing subject that demands a logical and systematic approach.

It is a fair assumption that the majority of students concur that physics proves to be a very strenuous and difficult subject studied at school. Student difficulties stem from physics concepts, the way in which a physics course is taught, and physics problems which are sometimes very vague. Perhaps it is the general lack of interpretation of what physics is, combined with the subject's inherent difficulty and reliance on mathematics, which tends to discourage a student from studying physics. Students find physics difficult because they have to contend with different aspects such as experiments, formulas and calculations, graphs and conceptual explanations at the same time. Thus, physics as a discipline requires learners to employ a variety of methods of understanding [1 – 3]. This makes learning physics particularly difficult for many students, and there are bound to be many hindrances before the students get a good grasp of the subject.

The purpose of this study is to measure the effectiveness of employing one of the Indian traditional games (Gulli – Danda) as a demonstration instrument to verify if it helps in drawing learners' attention and enhancing their conceptual understanding of physics. The participants for this study were drawn from middle and high school students, teachers and researchers both from India as well as the United States. This study presents a new pedagogical approach [4] which uses potential of traditional games [5 – 8], as tools, to motivate learners and help teacher tailor instructions [9, 10] to individual learners' needs and interest. For this I have used 'Gulli – Danda' (name of the game in Hindi, an Indian native language) as a demonstration tool for my presentations [4] to different sets of audiences at different places in the United States and India.

Section 2 of the paper is devoted to the familiarity and understanding of Gulli – Danda whereas section 3 demonstrates the physics associated with it, which is drawn from the established kinematic terms and I have tried to present a connectedness between these terms with the different movements of Gulli – Danda. Section 4 exhibits the use of Gulli – Danda as a tool, which I did with the different sets of audiences at physics education research groups and schools in the United States to test its effectiveness [4]. Physics terms and ideas evolved during the demonstrations are also given in this section with the observations during the conduction of the activities. In addition, questions framed by the participants are discussed along with the comparison of post test results at different places.

2. Familiarity and understanding of demonstration tool used (Gulli – Danda):

It is a popular traditional game in India and is the national game of Nepal [11]. It is played in rural areas and small towns in India as well as Pakistan, especially in the Punjab area. Its origin in India is found dated back to the "Maurya Dynasty". It is a four plus player game. In the United States, a similar game is called Pee-wee. It is also known as Tipcat in English, Dandi-Biyo in Nepali, Alak - doulak in Persian and Kon - ko in Khmer (the Cambodian language) [11].

The Gulli is a cylindrical wooden piece tapered at both ends, usually 4 to 5 inches in length and approximately 1 to 1.5 inches in diameter in the middle. The Gulli's ends are blunt. A Danda is a straight cylindrical stick usually between 15 and 18 inches in length and around 1.5 inches in diameter.

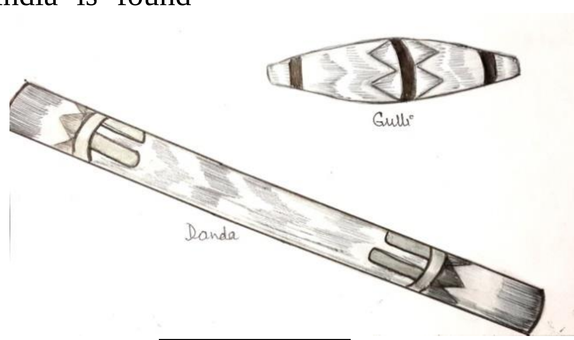


Diagram (1)

At a conceptual level, we can liken the Danda and Gulli to a bat and a ball, in the sense that a Danda is used as a bat to hit the Gulli. As this is a rural, native game with no recognition from any local or international sports bodies, there are no standards on sizes, shapes or type of materials to be used for the Gulli and Danda. People use whatever is convenient and available within their reach and do not really care about exact length, diameter and weight as long as the equipment serves its purpose. For that matter, there are no standard rules for the game as such, as each region, province and state follows its' own rules. Thus we have different variations of Gulli - Danda being played across different regions. However, certain general rules that are commonly followed while playing Gulli – Danda are as follows: First we need two teams with not less than four players on each team. After a coin toss, the winning team starts batting (or fielding, whatever they choose). A circle is drawn at one corner of the ground where the batsman will bat. This circle will have a small pit (groove) dug in the center for the Gulli to be placed in.

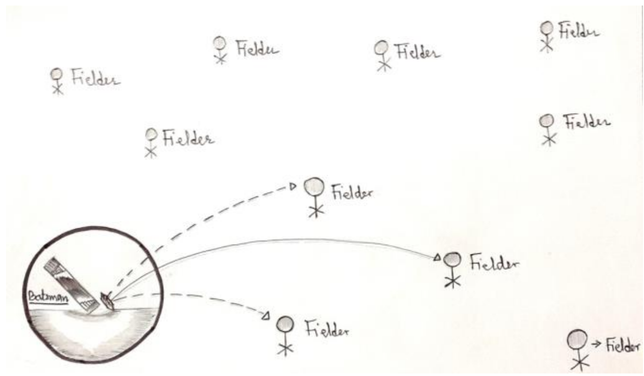


Diagram (2)

The first player from the batting team will use the Danda to bat, while the fielding team is spread out across the ground to field. The batsman gently hits the Gulli across one of the tapered ends with the Danda, and quickly strikes it hard as soon as it is lifted off its groove and when it is still in the air. It is a double motion strike from the batsman – somewhat like a "tip and whack". The idea behind the "tip" being gentle is to ensure that it lifts the Gulli off the ground to a reasonable height and reach for the batsman to hit it hard once again ("whack") while it is in the air. The Gulli remains airborne if the batsman strikes the Gulli with the Danda during the whack. If the batsman is unable to strike the Gulli in three continuous chances, the batsman is out. This is similar to a strikeout in Baseball.

If the batsman strikes the Gulli, and no fielder is able to catch it before it lands, the Danda is used to measure the distance from the center of the circle (from the batsman's batting spot) to the spot where the Gulli landed. Each Danda length adds one point to the batting team. If the batsman strikes the Gulli and a fielder catches it before it touches the ground, the batsman is out and then the next player of his team comes to bat. There is one other way that the batsman could be out. Once the batsmen hits the Gulli and no fielder catches it before it touches the ground, the batsman places the Danda within the small circle from where he was batting, horizontally on the ground, with its length facing the fielding team.

The fielding team picks up the Gulli from the ground and throws it at the Danda (after measuring the distance). If the Gulli strikes the Danda, the batsman is out. If it does not hit the Danda, the batsman does the "tip and whack" once again from the point where the Gulli has landed after the fielding team's throw at the Danda. In the event that the Gulli landed behind (beyond) the small circle, the start point for the batsman would be his original batting spot. The batsman repeats the same process of hitting the Gulli again until he is out. Repeat the above steps until all players of the batting team are out. The sum of all the points scored by the batting team becomes the target for the other team to beat. Now the fielding team will bat and the batting team will field. Repeat all above steps for the new batting team. The team with the highest score wins the match.

3. **Physics of Gulli – Danda:** The Gulli, which has conical ends, is initially at rest and the Danda, when raised to a height (h), contains potential energy given as,

$$U_D = Mgh.$$

Where M is the mass of the Danda and h is the height to which it is raised.

When the batsman brings the Danda down to h = 0, with velocity (V) to hit the Gulli, the energy stored in the Danda in the form of potential energy (U_D) gets converted into kinetic energy (KD) as the Danda loses the potential energy (neglecting air drag).

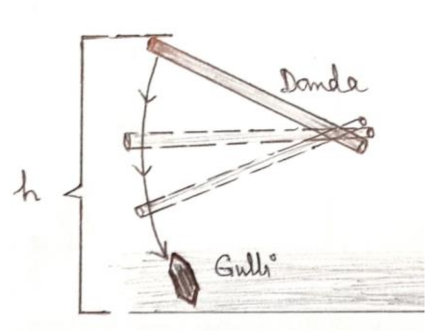


Diagram (3)

Since, the lost potential energy is used to impart velocity to the Gulli, according to conservation of energy,

$$U_D = K_D,$$

$$Mgh = \frac{1}{2}\ MV^2. \qquad \ldots(1)$$

The velocity associated with the Danda is given as:

$$V = \sqrt{2gh}. \qquad \ldots(2)$$

In eq. (1) Mgh is the gravitational potential energy acquired by the Gulli and also the work done by the gravitational force expressed as,

Work done by the conservative force = – (change in potential energy).

The momentum in the horizontal direction will be conserved since there is no net external force in the horizontal direction.

Now,

$$MV = mu\ Cos\,\theta\ , \qquad \ldots(3)$$

where m is the mass of the Gulli and u is the velocity with which it is projected. θ is the angle made by the Gulli with the horizontal, known as angle of projection and is shown as,

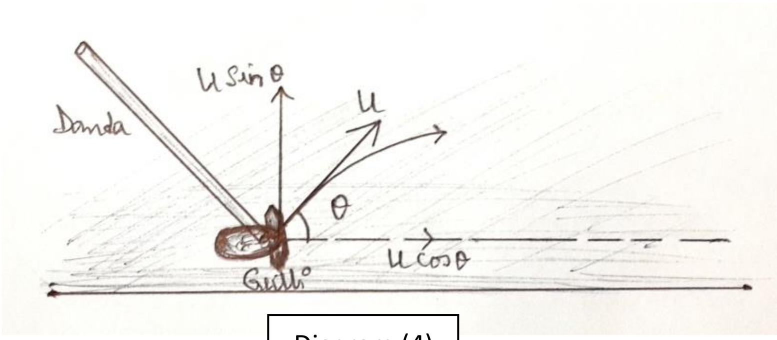


Diagram (4)

Let the batsman provide an impulse 'I' which makes the Gulli attain a velocity v at a height 'h'. The impulse imparted is given as,

$$I = mv - mu = change\ in\ momentum. \quad \ldots(4)$$

The path followed by the Gulli under the gravitational force is given by the equation,

$$y = x\tan\theta - \frac{gx^2}{u^2 Cos^2\theta}. \quad \ldots(5)$$

Where x and y are the distances travelled by the Gulli with the velocity components in the X and Y axis respectively.

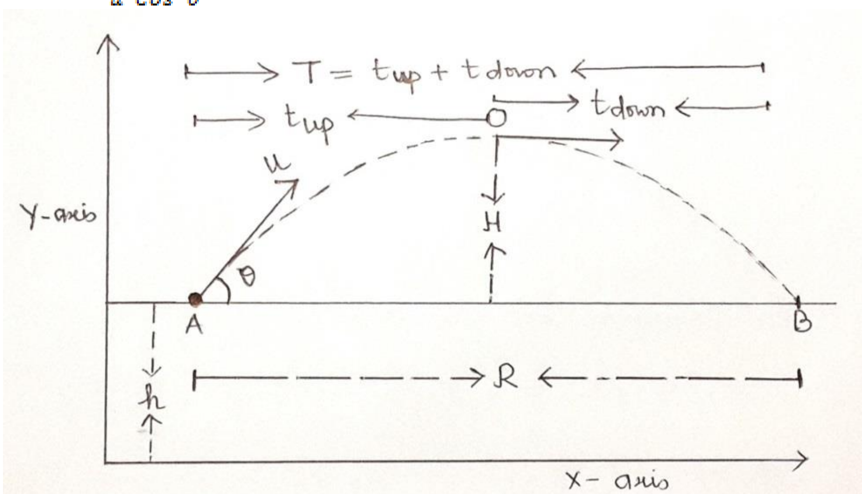


Diagram (5)

Equation (5) clearly shows that the trajectory followed by the Gulli is parabolic in nature. The center of mass of the Gulli also follows the same trajectory as that of the Gulli. To find out the center of mass of Gulli and Danda, we shall assume shapes of both the Gulli and the Danda as completely cylindrical and will be shown by the diagram:

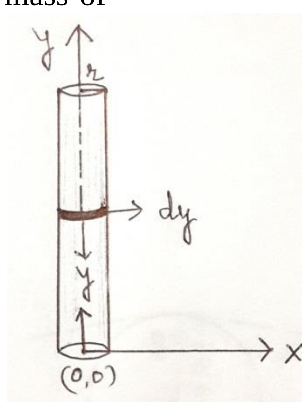


Diagram (6)

The position vector of the center of mass of the Gulli is given as,

$$\vec{r}_{CM} = \frac{\int \vec{r}\, dm}{\int dm},$$

where dm is the mass of a small segment of the Gulli. On putting the values of individual components in this equation, we get,

$$\vec{r}_{CM} = \frac{\int y\hat{j}\frac{m}{h}dy}{\int dm} = \frac{\frac{m}{h}\int_0^h y\hat{j}\,dy}{\int dm} = \frac{h}{2}\hat{j}. \quad \ldots(6)$$

The motion of the Gulli is best described as a combination of rotation and translation which gives the complete rotational aspect of the motion shown by the diagram as follows:

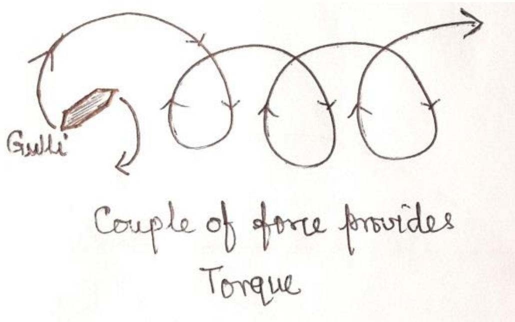


Diagram (7)

Kinetic energy of rotation of the system is given as,

$$K_{rotational} = \frac{1}{2}I_{CM}\omega^2. \quad \ldots(7)$$

Where I_{CM} is the moment of inertia of the Gulli about an axis (of rotation) passing through the center of mass and ω is its angular velocity.

Angular momentum about the axis of rotation =

$$m(\vec{v}\times\vec{r}) + I_{CM}\omega = [\vec{L}_{orbital} + \vec{L}_{spin}]. \quad \ldots(8)$$

Just after the Gulli is hit, the power transferred to the Gulli by the Danda is given as,

$$P_g = \frac{\vec{F}.\overrightarrow{ds}}{dt} = mg.u\,Cos(90+\theta) = -umg\,Sin\theta. \quad \ldots(9)$$

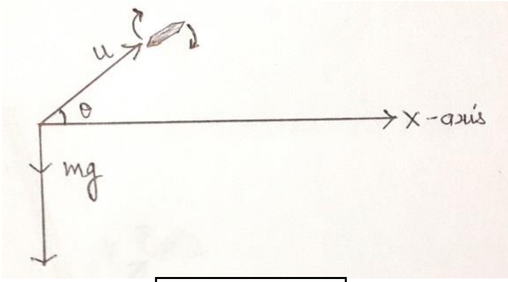


Diagram (8)

The radius of curvature just after the hit is shown as,

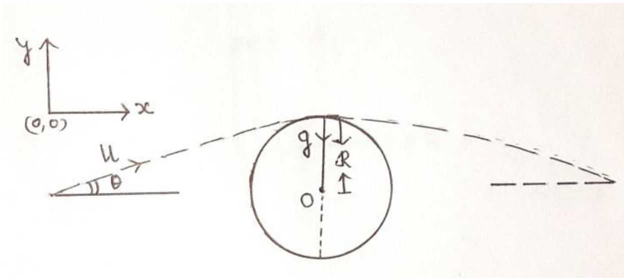


Diagram (9)

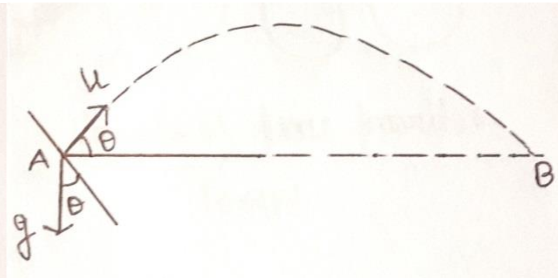


Diagram (10)

and is given as,

$$g\ Cos\ \theta = \frac{u^2}{R} \Longrightarrow R\ = \frac{u^2}{g\ Cos\ \theta}. \qquad \ldots(10)$$

If we analyze the motion in two dimensions, we get,

$$u_x = \ u\ Cos\ \theta, a_x = 0$$
$$u_y = \ u\ Sin\ \theta, a_y = -g$$

Time of flight can be expressed as,

$$T = \frac{2u\ Sin\theta}{g}. \qquad \ldots(11)$$

The distance travelled by the Gulli along the horizontal direction is the range of travel and is given as,

$$Range = u_x \times T = \frac{u^2\ (2Sin\theta\ Cos\theta)}{g} = \frac{u^2\ (Sin2\theta)}{g}. \qquad \ldots(12)$$

Since velocity u makes an angle θ with the horizontal, it takes the Gulli to the maximum height, after getting hit by the Danda, so the maximum height achieved by the Gulli during its motion in air is given as,

$$H = \frac{u^2\,Sin^2\theta}{2g}. \qquad \ldots(13)$$

The collision of Danda and Gulli will be perfectly inelastic, therefore the coefficient of restitution cannot be one, and it will have the value,

$$e = \frac{u}{v\ Cos\theta}. \qquad \ldots(14)$$

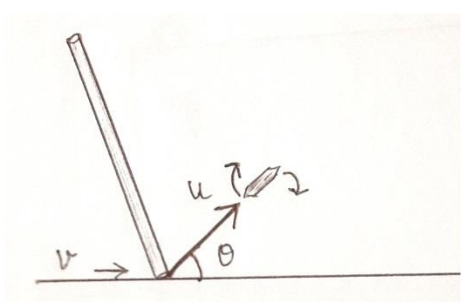


Diagram (11)

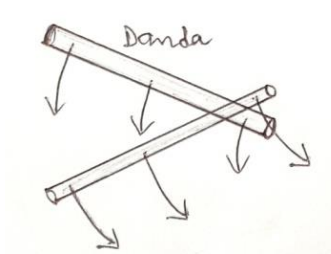


Diagram (12)

While hitting the Gulli, the motion of the Danda may be transitional because the trajectory followed by all the points of the Danda is the same.

4. Using Gulli – Danda as a demonstration tool:

Gulli - Danda was demonstrated to different sets of audiences at physics education research groups [4] and schools in the United States to test its effectiveness (without telling them about physics terms involved with the game). Presentations were focused on the use of traditional games as demonstration tools and their effectiveness to create active learning environments in the classrooms.

A video was also played with an illustration of 'How to play' Gulli - Danda (http://www.youtube.com/watch?v=JFtU9JnFVkU). After the video and demonstration, participants recorded their observations and responses in the form of physics terms and the ideas that evolved followed by discussion.

4.1 Physics terms / ideas evolved during the demonstration / presentation:

Force and effort, cylindrical shaped playing material, conical edges on the Gulli, angle of hitting, laws of motion, momentum conservation, speed, thrust, angle of projection, impulse, rotation, torque, elastic potential energy, gravity, superposition, linear and angular momentum, rotational motion, moment of inertia, acceleration, projectile motion, conservation of energy, vectors, center of mass, maximum horizontal range, friction, trajectory followed by the Gulli, gravity, displacement, action – reaction, angular velocity, free fall, angle of collision, momentum transfer, power, extended body vs. particle, air resistance, 2D kinematics, centripetal force, rotational energy, rotational vs. translation motion, elastic and inelastic collision, translation kinetic energy, fulcrum and elevation.

It is clear from this activity that learners come out with ideas and terms that they have come across in real life. They try to relate these terms with a particular activity or demonstration. The idea is that when an instructor demonstrates a particular game in class, he/she could take any term of the learners' choice forward to explain the concept further. Discussion could be taken to the next logical level subsequent to establishing the motivation and interest that learners would have developed during the initial part of the interaction. Once learners get the initial thrust of interest and motivation, the same could be used further by the teacher to develop and maintain learners' confidence throughout the interaction and also through the difficult topics.

Participants were given the opportunity to play Gulli-Danda to experience it first-hand. The activity was conducted at different places and results that were recorded from each of these places were very encouraging. Some of the observations are:

(i) Enough stimulation was seen amongst the participants because they were engaged in the activity.

(ii) Participants were encouraged to think independently. They were discussing different kinds of motion followed by the Gulli and predicting different forces used on the Danda to hit the Gulli. This motivated the learners to develop and design new models which nurtured capacity building and a scientific temperament in them.

(iii) There was no requirement of hi-tech machines to record the outcomes (it was all about evolving ideas).

(iv) A few physics ideas were picked for further deep study and detailed discussion (the instructor could choose any of the ideas or physics terms of the students' choice).

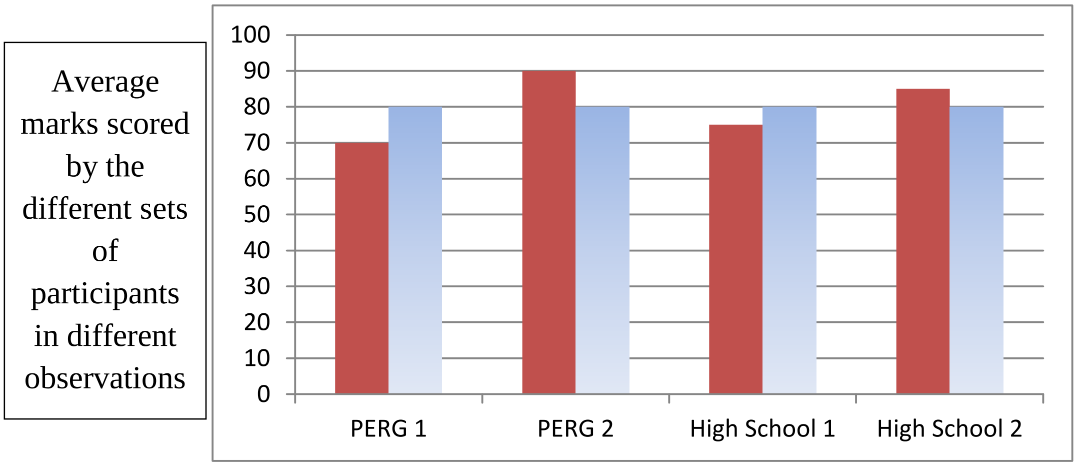
4.2 Questions framed by the participants:

1. How hard and where should you hit for the Gulli to pop up?
2. Why does the Gulli pop up when you hit it down? What force makes it go up?
3. How does wind influence the flight of the Gulli or what is the role of air resistance to minimize or maximize the range?
4. What would change if you modify the shape or weight of the Gulli or how does the different size of the Gulli affect the outcome of the game?
5. What about the energy, when it is at the ground and when it is in the air?
6. Which is the best place and best angle to hit the Gulli in order to reach the desired range?
7. What is the best timing to hit the Gulli when it is in the air in order to reach the maximum range?
8. Why is there horizontal translational motion sometimes?
9. How does the angle (or value) of applied force affect the trajectory followed by the Gulli?
10. Why does the Gulli rotate after being struck?
11. What is the relationship between force and location of impact?
12. How does the player judge when to hit it?
13. What will happen if you hit the Gulli at different locations?
14. How much force should be applied to the Gulli in order to get 3m? Is it possible to set the parameters like this?
15. Which degree of rotation is most useful when looking for the greatest distance?
16. Is there a certain angle measurement where the player hits the Gulli to make it spin or travel faster?
17. How is the orientation affected by air-resistance? Is this significant for the distance to be travelled by the Gulli?
18. How does the curvature of the ends affect the rotational and translational energy imparted?
19. How does the nature of the ground affect the initial upwards motion or how does the hardness of the ground affect the force needed to launch at a certain maximum height?
20. Why was there a small pit dug at the place of blowing the Gulli (in the video)?

It is very clear from the questions asked by various participants, each from a different place and a different setting, that there is a set range of questions for every activity or demonstration. Questions asked for a particular demonstration using a particular game revolved around a few concepts or queries. This indicates that props and models based on games can be developed and used in the curriculum which addresses specific concepts in science, particularly in physics.

4.3 Comparison of post – test results at different places:

An identical time based post – test was given to the participants after each demonstration at different places, (to physics education research groups (PER) and high school students) in the US. The average scores of all attempts and their comparison with the overall average is shown through the graphs as follows:



Comparison of average marks of individual observation with the overall average

The graph depicts that average scores achieved by the participants at physics education research group seminars (shown as PERG 1 and 2 in the graph) are 70% and 90% whereas the average marks scored by the participants at different high schools (shown as High school 1 and 2 in the graph) are 75% and 85%. Overall average score*of all these attempts is 80%.

(*Average score = Sum of the average scores of different attempts / Total number of attempts).

What emerged here is that strategies on 'using games as demonstration tools in the classrooms' worked well as participants were able to predict, infer, use previous knowledge, summarize and ask questions.

5. Discussion and outcomes:

This study discusses responses of learners towards an instructional method and its effectiveness over different class settings for detailed understanding of developing awareness of everyday thinking and learning. Everyday learning depends upon a number of factors like students' interest areas, surrounding environment, involvement of teacher and the taught, motivation to learn, challenges in learning and fear of failure. If the learning environment is made so comfortable for a learner such that learners get motivated as active participants in the learning process, I think half of the job is done. A similar attempt is made through study results reported in the presented article. Using Gulli – Danda as demonstration tool, to introduce physics ideas and to motivate learners to think independently, was acclaimed as a great idea at different places when it was presented. Such demonstrations were able to draw participants' attention and were able to engage them actively in hands on as well. Using games as low cost demonstration tools can be one of the methods to overcome traditional method of teaching.

Physics of Gulli – Danda is demonstrated comprehensively in section 3 which covers all key aspects of the motion involved with Gulli – Danda. Equation (2) gives the velocity achieved by the Danda which has been developed through the potential associated with it and then later converted into its kinetic energy. Equation (5) illustrates that the Gulli follows a parabolic trajectory and performs translational and rotational motion both depending on the nature of force and angle provided at the time of the hit. This equation is related to schematic diagrams 4 and 5. Position vector of center of mass of Gulli is given by eq. (6) and the power transformed by the Danda is shown in eq. (9). The radius of curvature, time of flight, horizontal range and maximum height attained along-with the coefficient of restitution are given in the successive equations and shown through the respective diagrams. How Gulli - Danda was used as demonstration tool with different sets of audiences at physics education research groups and schools in the United States has been explained in section 4. Evidence of providing opportunities for learners to think independently is also well discussed in this section. It is also established that this method nurtures an inquiry based scientific temperament in learners since framing questions after the demonstration is a key feature of the method.

Through this method, learners were able to learn to appreciate the culture and values associated with the game, which increases their awareness of a particular culture. A specific set of physics ideas were evolved during the demonstrations which are given in section 4.1. Questions framed by the participants are discussed in section 4.2 which clearly shows that learners were able to make connections with the seen and unseen world through demonstrations of Gulli – Danda which provides powerful evidence for a strong connection between the neuroscience of brain chemistry and play and joy. It advocates using traditional native games as props and ‘play’ as the basic component of enquiry and also shows that these games can be used to develop low cost pedagogical tools to address specific concepts which may possibly play a major role in designing an activity based physics curriculum. A comparison of post test results of different sets of audiences at different places is presented in section 4.3, which shows that no learner scored less than fifty percent marks in these tests. This is a clear indication of achieving average gain in conceptual understanding of learners towards physics concepts through using Gulli – Danda.

In totality, this paper addresses all the research questions focusing on pedagogical approaches used for developing activity based science curriculum. Furthermore, I plan to develop brain compatible animations, videos and video games explaining scientific principles using traditional games as low cost pedagogical tools (to connect classroom teaching to real life experiences) in science teaching which will disseminate use of these demonstration tools worldwide as reflective innovative practices resulting in sustainable changes for blended learning and flipping classrooms leveraging the power of technology.

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