Demonstrator # 11

Studying Circular Motion

TEACHER NOTES

Activity title:
STUDYING CIRCULAR MOTION

Subject:
Physics - Class XI

Student age:
16-18 years

Estimated duration:
2x50 minutes (50 minutes, for data collecting, 50 minutes for data processing)

Science content
- The Principles of Newtonian dynamics;
- The mechanical laws concerning: motion, speed, the acceleration of harmonic oscillations;
- The InLOT System;
- The elastic pendulum.

Learning objectives

Lesson is valuable because creatively exploit knowledge like kinematics, trigonometry, practical skills through non-formal learning contexts applicability, such as sport.

SPECIFIC COMPETENCIES: At the end of this lesson students will be able to:
- to apply the laws of circular motion and to strengthen their understanding
- to understand dependencies between different physical quantities specific circular motion by mathematical modelling of this process
- to capitalize the knowledge of trigonometry
- to use creatively INLOT system in applied contexts
- to explore the physical reality testing AM handy devices in circular

Inquiry-based character

The student will enhance their work skills specific scientific investigation and discovery activities geared for this type of learning:

1. Identify Questions for Scientific Investigations

- Identify testable questions
- Refine/refocus ill-defined questions
- Formulate hypotheses

2 Design Scientific Investigations

- Design investigations to test a hypothesis
- Identify independent variables, dependent variables, and variables that need to be controlled
- Operationally define variables based on observable characteristics
- Identify flaws in investigative design
- Utilize safe procedures
- Conduct multiple trials

3 Use Tools and Techniques to Gather Data

- Gather data by using appropriate tools and techniques
- Measure using standardized units of measure
- Compare, group, and/or order objects by characteristics
- Construct and/or use classification systems
- Use consistency and precision in data collection
- Describe an object in relation to another object (e.g., its position, motion, direction, symmetry, spatial arrangement, or shape)

4 Analyze and Describe Data

- Differentiate explanation from description
- Construct and use graphical representations
- Identify patterns and relationships of variables in data
- Use mathematic skills to analyze and/or interpret data

5 Explain Results and Draw Conclusions

- Differentiate observation from inference
- Propose an explanation based on observation
- Use evidence to make inferences and/or predict trends
- Form a logical explanation about the cause-and-effect relationships in data from an experiment

6 Recognize Alternative Explanations and Predictions

- Consider alternate explanations
- Identify faulty reasoning not supported by data

7 Communicate Scientific Procedures and Explanations

- Communicate experimental and/or research methods and procedures
- Use evidence and observations to explain and communicate results
- Communicate knowledge gained from an investigation orally and through written reports, incorporating drawings, diagrams, or graphs where appropriate

Applied technology (if any)

In order to do so the KLiC project uses an innovative sensor data collection tool, namely the InLOT system (www.inlot.eu) that consists of the following modules:

• ***SensVest*** - a vest, equipped with various sensors, designed to carry components that measure and transmit physiological data to the base station.

• ***Leg and Arm Accelerometer*** - small devices attached to the leg and/or arm that enable the 3-D measurement of the acceleration for the leg and/or arm.
Ball Accelerometer - a ball that has embedded an accelerometer measuring three dimensions and a communication unit that enables the transmission of data packets to the base.
• ***Base Station*** - responsible for the collection of all transmitted data
• ***User Interface Software*** - user friendly interface, designed with a pedagogical frame of mind, that enables the process of data and actions such as plotting data on a graph or creating a mathematical model to fit the data.
User details can be found in Annex 2.1.

Materials needed

- InLOT system
- PC
- Physical kit: *circular motion*
- Worksheet (Annexes 6.1, 6.2 and 6.3)

Discussion guide

Anticipation: Unit summary: *The kinematics of the circular motion*

Essential Question: *How physics helps us to better understand the sorrounding world?*

Before a project approach

Before using a project approach, the high school students will review the principles of Newtonian dynamics, will discuss techniques for working with INLOT system, then write an essay about the use of physical knowledge in sports. Essays will be between three and five pages and will be noted. Essays will be evaluated in terms of Newtonian dynamics harnessing knowledge about techniques for working with INLOT system discussed above.

After a project approach

After the scenario proposed sequence no. 6 has been completed, indicated that students apply the theme and new skills to the situations described by their essays. Students will be invited to explore the questions: a) *How physics helps us to better understand the surrounding world?* and *b) How that gives us the performance perspective?*. Students will analyze how science and technology in performance are mutually supportive and not just athletes

Building knowledge

Teaching strategy

- The teacher monitors and advises business groups, provides support points, support students in their approach.
- Use project method
- Integrate knowledge and skills achieved an adequate framework for reflection.

Reflection / Consolidation

Evaluation method: gallery tour

Assessment

- ✓ Summative
- ✓ formative

Annex 6.1

Using **accelerometer**

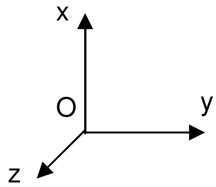


Photo accelerometer

Reference directions of accelerometer

What accelerometer (AM) measures?

- The frames of reference in which the experiments are conducted are non-inertial, so it is necessary to simplify the model; therefore we encourage the selection of appropriate experimental contexts secondary level approach.
- It appears that AM measures, momentary, relative acceleration in non-inertial frames of reference. Generally, according to kinematics in non-inertial frames of reference:

$$\vec{a}_{rel} = \vec{a}_{abs} - (\vec{a}_{cor} + \vec{a}_{transp}) \qquad (0.1.)$$

$$m \cdot \vec{a}_{rel} = m \cdot \vec{a}_{abs} - m \cdot (\vec{a}_{cor} + \vec{a}_{transp}) \qquad (0.2.)$$

$$m \cdot \vec{a}_{rel} = \vec{F} + \vec{F}_c \text{ [1]} \qquad (0.3.)$$

-Accelerometer (AM) measures the difference between the momentary gravitational component (reference direction Ox of AM), plus centrifugal momentary acceleration (if a change of direction of motion) and momentary acceleration of movement of AM in that direction.

$$a_x = g_x + a_{cfx} - a_{mx} \qquad (0.4.)$$

Where: - a_x is the value measured on test direction (relative acceleration)

- g_x is the component of gravity acceleration on test direction

---

1. where $\vec{F}_c$ is supplementary forces.

Particularly, there are situations (eg, a ball suspended at rest relative to the earth, but relative to a man sitting on a rotating wheel, the ball appears to be in rotation), where it may happen that the body viewed from S does not any force, but still to see him moving accelerated relative to S' due to supplementary force, $\vec{F}_c$:

$$a_{abs} = 0 \Rightarrow \vec{F} = 0 \rightarrow \vec{F}_c = m \cdot \vec{a}_{rel} \qquad (0.5.)$$

An important class of reference frames is the object's own frame or frame-related rigid object moving uniformly force from their frame (eg the man and the object (= S') are resting on the rotating disc, and the object is caught in a spring). In such frames the object is evident in the rest ($\vec{a}_{rel} = 0$), although there is a real force $\vec{F}$. In this case: $\vec{F} + \vec{F}_c = 0 \rightarrow \vec{F}_c = m \cdot \vec{a}_{rel}$. That supplementary force is equal but opposite to the real force, so it is equivalent to the Newtonian inertial force.

Supplementary forces are fictitious forces that should be added to the real forces to ensure the validity of the IInd principle of Newtonian mechanics in non-inertial frames. These are not forces of interaction, we can show the body that produces them, so it doesn't applies the IIIrd principle of Newtonian mechanics.

- a_{cfx} is the component of centrifugal acceleration on test direction
- a_{mx} is the acceleration of movement (accelerometer and body together) on test direction (acceleration of transport).

$$a_y = g_y + a_{cfy} - a_{my} \tag{0.6.}$$

$$a_z = g_z + a_{cfz} - a_{mz} \tag{0.7.}$$

If the motion is made on certain direction, relatively to the reference directions of AM, then the previous relations are wrote on each component of the acceleration measured by accelerometer (≠0).

All measured values are fractions of g (gravity acceleration), expressed relative to the value of g for which was calibrated AM.

Cases:

I. $a_{mx} = 0$ (AM is at rest, set on the object whose motion is studied, or in rectilinear and uniform motion on test axis, chosen as the OX axis)

$$\Rightarrow a_x = g_x + a_{cfx} \tag{0.8.}$$

- More if $a_{cfx} = 0$

$$\Rightarrow a_x = g_x \tag{0.9.}$$

II. $g_x = 0$ (the test axis is in a perpendicular plane on vertical)

$$\Rightarrow a_x = a_{cfx} - a_{mx} . \tag{0.10.}$$

- In addition if $a_{cfx} = 0$

$$\Rightarrow a_x = -a_{mx} \tag{0.11.}$$

This is the method of determining the acceleration of motion of AM/the object bounded on AM.

What we can measure with the accelerometer in the laboratory / practical applications?

- *Angles*: AM in resting, sat alongside a surface makes an angle α with the vertical;

$$a_x = g \cdot \sin\alpha \Rightarrow \alpha = \arcsin\frac{a_x}{g} \tag{0.12.}$$

- Acceleration of translational motion on:
    - Axis in the horizontal plane regardless of the gravity component
    - Axis of the other plane, but taking into account the gravity component
- Acceleration of complex motion (rotation and translation)

ASSESSMENT TOOLS

Scores for project evaluation

1 = Criterion is not fulfilled	3 = Criterion is fulfilled in good measure
2 = Criterion is met only slightly	4 = The criterion is fully met

1. All team members undertake collaborative activities by completing the steps in processing aid given to them and collect data for one of the roles within the team

   1 2 3 4

2. Each member fulfills the role it has in the team. Team members' work together to achieve a quality presentation

   1 2 3 4

3. Presentation made meet the recommended structure.

   1 2 3 4

4. Explanation contained in the presentation is enlightening to the public

   1 2 3 4

5. Project presentation is eloquent and enlightening for the audience participating.

   1 2 3 4

6. The manner of presentation is attractive and involving public

   1 2 3 4

7. Team members are open to public questions and formulate answers all questions pertinent to public

   1 2 3 4

8. Introducing the team roles demonstrates that members are knowledgeable in all fields covered by the project.

   1 2 3 4

9. Team members speak out loud, communicates a very clear presentation of content, and establish eye contact with audience.

   1 2 3 4

10. Team members provide additional explanations to the public request, using the flip chart

    1 2 3 4

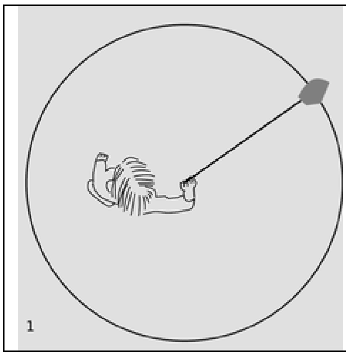
Completion:

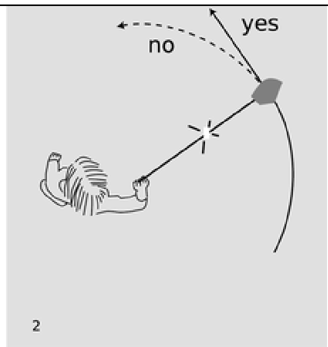
Note: The lesson is built valuing prior knowledge acquired in different learning contexts and integrates communication skills, collaboration skills, investigation, practical skills, but also interpersonal and social skills, artistic skills and expression.

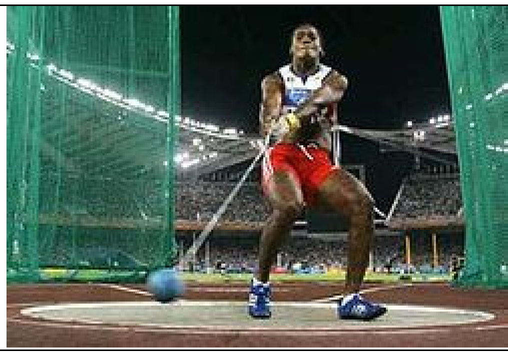
Annex 6.3

AUXILIARY FOR TEACHING

6.I. Kicking life into Classroom: Studying circular motion







6.II. Into Lab with InLOT – Studying circular motion

Modelling physical phenomena: The circular motion	**Principle method**

A. The uniform circular motion

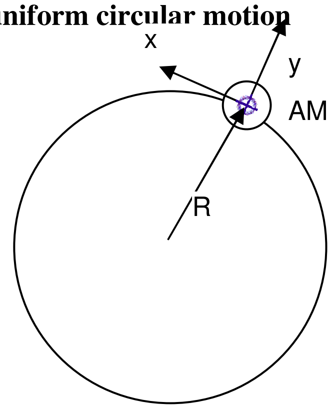


fig.6. The circular motion

The simplest and most important curvilinear motion is circular motion, moving the material point trajectory is a circle. We will use the accelerometer and InLOT system to make specific determinations circular motion.
Circular motion is uniform, if the mobile velocity is a vector with constant module, ie handset describe equal arcs in equal time intervals.
Uniform circular motion is a periodic motion because after going through all repeats the same circle, at time intervals equal.

Characteristic physical quantities:
T = the **period of one rotation** of the uniform circular motion is the time where the body through the circumference of the circle. The period is measured in seconds.

- <u>Knew R case</u>

6.II.A. The calculation of the angular velocity

$$a_y(t) = \omega(t)^2 R \qquad 6.14$$

$$\omega(t) = \sqrt{\frac{a_y(t)}{R}} \qquad 6.15$$

This is the angular velocity at the t moment, if the circular motion is variable. If the circular motion is uniform circular motion, then ω = const.

6.II.B. The calculation of the period of circular motion

This calculation comes from:

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{R}{a_y}} \qquad 6.16$$

6.II.C. The calculation of the angular acceleration in uniform variable circular motion

Returning to the case circular movement and considering various values measured of AM in the direction Ox, we can determine the angular acceleration. First of all:

$$a_x(t) = \varepsilon(t)\cdot R \qquad 6.17$$

$$\varepsilon(t) = \frac{a_x(t)}{R} \qquad 6.18.$$

- <u>Knew T case</u>

ν= rate/frequency of rotation, or speed, the number of full rotations made per unit time (rate / s). Frequency is measured in s^{-1} or $\frac{1}{s}$.

The angle θ swept out in a time *t* is named **curvilinear coordinate**.
v = **linear or tangential velocity** (speed) is given by the curvilinear coordinate changes while mobile. Speed is measured in m/s.
ω = **angular velocity** is the angle/unit time from the center described by the radius vector.

$$\omega = \frac{\Delta\theta}{\Delta t} \quad (6.1.)$$

The angular velocity ω units are radians/second (rad/s). For an rotation of Δθ = 2π, Δt=T, then:

$$\omega = \frac{2\pi}{T} = \frac{vT}{RT} = \frac{v}{R} \quad (6.2.)$$

$$v = \omega R \quad (6.3.)$$

this is the mathematical dependence between angular velocity and linear velocity (speed).
a_{cp} = **the centripetal acceleration** – or inward acceleration – is due to variation of the direction of linear velocity vector, direction which is tangent to the trajectory of motion.

$$a_{cp} = a_n = \frac{|\Delta \vec{v}|}{\Delta t} = \frac{v^2}{R} = \omega^2 R \quad (6.4.)$$

$$\vec{a_{cp}} = \omega^2 \vec{R} \quad (6.5.)$$

The centripetal acceleration is measured in m/s^2.
According with the second law of Newtonian dynamics is F_{cp} = ***the centripetal force***.

$$F_{cp} = ma_{cp} = ma_n = \frac{mv^2}{R} = m\omega^2 R \quad (6.6.)$$

$$\vec{F_{cp}} = m\vec{a_{cp}} = -m\omega^2 \vec{R} \quad (6.7.)$$

B. The uniform variable circular motion - is the circular motion with constant **angular acceleration**, means:

$$\varepsilon = \text{const.} \quad (6.8.)$$

The relation (6.8) is the angular acceleration law for uniform variable circular motion.
Distinguish two cases:
1. $\omega_1 > \omega_2$ for $t_2 > t_1$; $\varepsilon > 0$ – uniform accelerated circular motion.
2. $\omega_2 < \omega_1$ for $t_2 > t_1$; $\varepsilon < 0$ – uniform decelerated circular motion.

$$\omega = \omega_0 + \varepsilon t \quad (6.9.)$$

This is the angular velocity law in uniform variable circular motion, with initial angular velocity ω_0.

$$\alpha = \alpha_0 + \omega_0 t + \varepsilon \frac{t^2}{2} \quad (6.10.)$$

6.II.D. The calculation of the angular acceleration in uniform variable circular motion

$$a_y = \omega^2 \cdot R \quad 6.19$$

$$R = \frac{a_y T^2}{4\pi^2} \quad 6.20.$$

$$a_x = \varepsilon \cdot R, \quad \varepsilon = \frac{a_x}{R} \quad 6.21.$$

$$\varepsilon = \frac{a_x}{a_y} \cdot \frac{4\pi^2}{T^2} \quad 6.22.$$

and this is the motion law in uniform variable circular motion. Cases: 1. $\alpha_0 = 0$, $\alpha = \omega_0 t + \varepsilon \frac{t^2}{2}$ (6.11.) 2. $\omega_0 = 0$, $\alpha = \alpha_0 + \varepsilon \frac{t^2}{2}$ (6.12.) 3. $\alpha_0 = 0$, $\omega_0 = 0$, $\alpha = \varepsilon \frac{t^2}{2}$ (6.13.)	

STUDENT WORKSHEET

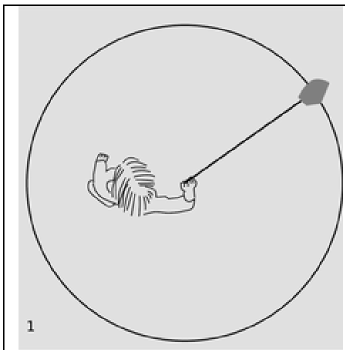
Activity title:
STUDYING CIRCULAR MOTION

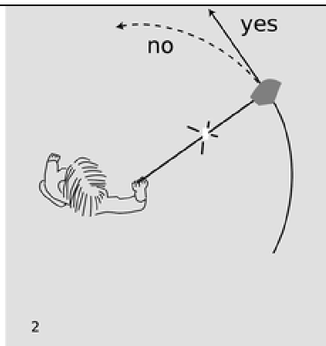
Introduction

Curriculum-Framing Questions
Essential Question
How would the universe appear without regular phenomena?
Unit Questions.
At what extent the laws of mechanics which are already known can be applied to periodic phenomena?
What immediate applications do you see for the study of periodic phenomena in nature?
Questions of content
What periodical mechanical phenomena can we identify in the nature? What physical quantities are characteristic for the oscillatory movement? How can we represent harmonic oscillator motion laws? What happens to energy in motion harmonic oscillator? Under the action of which type of force a harmonic oscillatory motion is present? What is the difference between the damped oscillation and the ideal one?

Thinking about the question

6.I. Kicking life into Classroom: Studying circular motion





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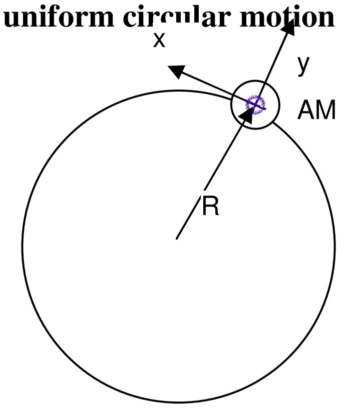

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Principle method

- <u>Knew R case</u>

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ω = **angular velocity** is the angle/unit time from the center described by the radius vector. $$\omega = \frac{\Delta\theta}{\Delta t} \qquad (6.1.)$$ The angular velocity ω units are radians/second (rad/s). For an rotation of $\Delta\theta = 2\pi$, $\Delta t = T$, then: $$\omega = \frac{2\pi}{T} = \frac{vT}{RT} = \frac{v}{R} \qquad (6.2.)$$ $$v = \omega R \qquad (6.3.)$$ this is the mathematical dependence between angular velocity and linear velocity (speed). $\boldsymbol{a_{cp}}$ **= the centripetal acceleration** – or inward acceleration – is due to variation of the direction of linear velocity vector, direction which is tangent to the trajectory of motion. $$a_{cp} = a_n = \frac{\lvert\Delta \vec{v}\rvert}{\Delta t} = \frac{v^2}{R} = \omega^2 R \qquad (6.4.)$$ $$\vec{a_{cp}} = -\omega^2 \vec{R} \qquad (6.5.)$$ The centripetal acceleration is measured in m/s^2. According with the second law of Newtonian dynamics is $\boldsymbol{F_{cp}}$ ***= the centripetal force***. $$F_{cp} = ma_{cp} = ma_n = \frac{mv^2}{R} = m\omega^2 R \qquad (6.6.)$$ $$\vec{F_{cp}} = m\vec{a_{cp}} = -m\omega^2 \vec{R} \qquad (6.7.)$$ **B. The uniform variable circular motion** - is the circular motion with constant **angular acceleration**, means: $$\varepsilon = const. \qquad (6.8.)$$ The relation (6.8) is the angular acceleration law for uniform variable circular motion. Distinguish two cases: 1. $\omega_1 > \omega_2$ for $t_2 > t_1$; $\varepsilon > 0$ – uniform accelerated circular motion. 2. $\omega_2 < \omega_1$ for $t_2 > t_1$; $\varepsilon < 0$ – uniform decelerated circular motion. $$\omega = \omega_0 + \varepsilon t \qquad (6.9.)$$ This is the angular velocity law in uniform variable circular motion, with initial angular velocity ω_0. $$\alpha = \alpha_0 + \omega_0 t + \varepsilon \frac{t^2}{2} \qquad (6.10.)$$	

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Materials needed

- InLOT system
- PC
- kit physics: circular motion
- Worksheet

Safety

Follow the rules of labor protection in the physics laboratory.

Investigation

Name and surname of the participants:1.____________,2.____________, 3. _______________,
4.____________, 5. ____________
Category □ student; □ teacher; □ athlet; □ other
Age: ___________, gender: □ M, □ F

Experimental determinations	**Action plan:**
6.II.A. The calculation of the angular velocity The angular velocity is: ω = ______________ rad/s **6.II.B. The calculation of the period of uniform circular motion** T = _______ s **6.II.C. The calculation of the angular acceleration in uniform variable circular motion** ε = ___________ rad/s^2	Use InLOT platform for collecting data: **6.II.A. The calculation of the angular velocity** 1. Accelerometer is attached rigidly rotating disk moving so Oy reference axis is pointing in the direction of AM radius circular trajectory and the Ox axis in the direction perpendicular to the axis of rotation. 2. From values recorded with InLOT platform for a_y, and considering R known and using equation (6.15), we can calculate the angular velocity. **6.II.B. The calculation of the period of uniform circular motion** 1. Accelerometer is attached rigidly rotating disk moving so Oy reference axis is pointing in the direction of AM radius circular trajectory and the Ox axis in the direction perpendicular to the axis

6.II.D. The calculation of the angular acceleration in uniform variable circular motion, with knew T, ε = ____________ rad/s^2	of rotation. 2. From values recorded with InLOT platform for a_y, and considering R known and using equation (6.16.) we can calculate the period of the uniform circular motion. **6.II.C. The calculation of the angular acceleration in uniform variable circular motion** 1. Accelerometer is attached rigidly rotating disk moving so Oy reference axis is pointing in the direction of AM radius circular trajectory and the Ox axis in the direction perpendicular to the axis of rotation. 2. From values recorded with InLOT platform for a_y, and considering R known and using equation (6.17), we can calculate the angular acceleration. 3. We can study also: a. the uniform accelerated circular motion, b. the uniform circular motion, c. the uniform decelerated circular motion. 4. Represent the chart of dependence angular acceleration - time. **6.II.D. The calculation of the angular acceleration in uniform variable circular motion, with knew T,** 1. Accelerometer is attached rigidly rotating disk moving so Oy reference axis is pointing in the direction of AM radius circular trajectory and the Ox axis in the direction perpendicular to the axis of rotation. 2. From values recorded with InLOT platform for a_x, a_y, with knew T and using equation (6.22) we can find angular velocity in uniform variable circular motion.

Analysis

Analyze the causes of friction and what impact they had on the outcome of the experiment.

Further investigation

1. **Relevance.** Students will reflect and find answers identifying possible practical role of the work done, the benefits of science and technology on life in general, the place of science in society, the social role of researcher.
2. **Connection with the real world.** Students will reflect on the practical character of their project, they will understand the importance of experimental data and the practical benefits of using the results .

Assessment

Gallery Tour: Students will prepare oral presentations to appropriate audiences, which are accompanied by multimedia presentations, brochures and websites. These products must identify current community needs and resources and provide acceptable solutions. Thus, the task turns into a learning project in support of the community, creating an authentic purpose and making a connection with the real world through community.

Evaluation criterion:

1. All team members undertake collaborative activities by completing the steps in processing aid given to them and collect data for one of the roles within the team
2. Each member fulfills the role it has in the team. Team members' work together to achieve a quality presentation
3. Presentation made meet the recommended structure.
4. Explanation contained in the presentation is enlightening to the public
5. Project presentation is eloquent and enlightening for the audience participating.
6. The manner of presentation is attractive and involving public
7. Team members are open to public questions and formulate answers all questions pertinent to public
8. Introducing the team roles demonstrates that members are knowledgeable in all fields covered by the project.
9. Team members speak out loud, communicates a very clear presentation of content, and establish eye contact with audience.
10. Team members provide additional explanations to the public request, using the flip chart