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ISLE in your class: planning of one cycle

The *ISLE* system has been used in large classes (over 500 students) and in smaller classes. The format for the instruction depends on the format of the course. Use the following materials to help implement ISLE philosophy:

The College Physics textbook published by Pearson (Etkina, Gentile and Van Heuvelen, 2014)

Physics Active Learning Guide (with Activities for the students) *and Instructor Guide*, which provides reasoning behind different activities and pedagogical approaches, cues on where to use particular activities and hints for instructors.

For example, in one large class, a two-week unit starts with students observing phenomena in the first lecture (we will call lectures "large-room meetings", as the students participate actively during these periods). These phenomena are lecture demonstrations selected according to the criterion of simplicity – the pattern that we want the students to see should be clear. The students work in groups of two/three to record their observations, look for patterns in these observations, and analyze the experiments in various ways to help produce qualitative explanations that account for their observations. Here the instructor helps them by suggesting what representation to use for their analysis. Students then use the different explanations to make predictions about a testing experiment proposed by the professor or they suggest their own testing experiments. This is done through interactions with representatives of the groups, voting, or an electronic response system. The testing experiments are used to discriminate among the different explanations.

The main difference between the observational experiments at the beginning and the testing experiments that come later is that students do not make predictions about the outcomes of the observational experiments but they do make predictions for testing experiments based on the explanations that they are testing. In this first large room meeting or in a second one, students identify relevant physical quantities.

Students look for patterns in experimental data that relate these quantities—to devise a relationship between them – called a "rule". These "rules" are then subjected to experimental testing again. Sometimes students analyze data that is collected for them during a demonstration or often they observe the experiment from which the data can be collected but use the table of prepared data for their analysis. Then, students use the qualitative explanations and the quantitative rules to reason about new processes, to represent them in multiple ways, and to solve problems of easy to moderate difficulty. All this happens in an interactive format using a peer instruction approach.

During one or more recitations in this first week of the development for a particular unit or early in the second week, students work in groups on problems—qualitative problems, multiple representation activities, and often on more complex multi-part problems. They also evaluate solutions to the problems devised by other students. The lab related to this conceptual area occurs during the second week and involves more complex quantitative testing experiments and experiment problems. Students design their own experiments to test a concept or to solve a problem. They practice hypothetico-deductive reasoning (if, then, but, therefore) to make predictions and to assess the results of the experiment. In lectures during this second week, a new cycle starts. As stated earlier, different formats are used depending on the size of the class and the class time available for each part of the course—lecture, recitation, and laboratory.

Students go through the same cycle for many concepts. The most difficult part of the cycle is to provide challenging questions that are based on real life examples so that the students can see that the explanation that they invented "works" or "makes sense" for the real world and addresses the ideas that they had before. This sequence allows the students to answer the question "how do I know this?" at every step of the cycle.

The rationale for different elements of *Investigative Science Learning Environment* (Fig. 1) and the practical implementation comes from several different areas: workplace studies, studies of the nature of science and scientific reasoning, brain studies, studies of students' learning of science, and studies of cognitive apprenticeship.

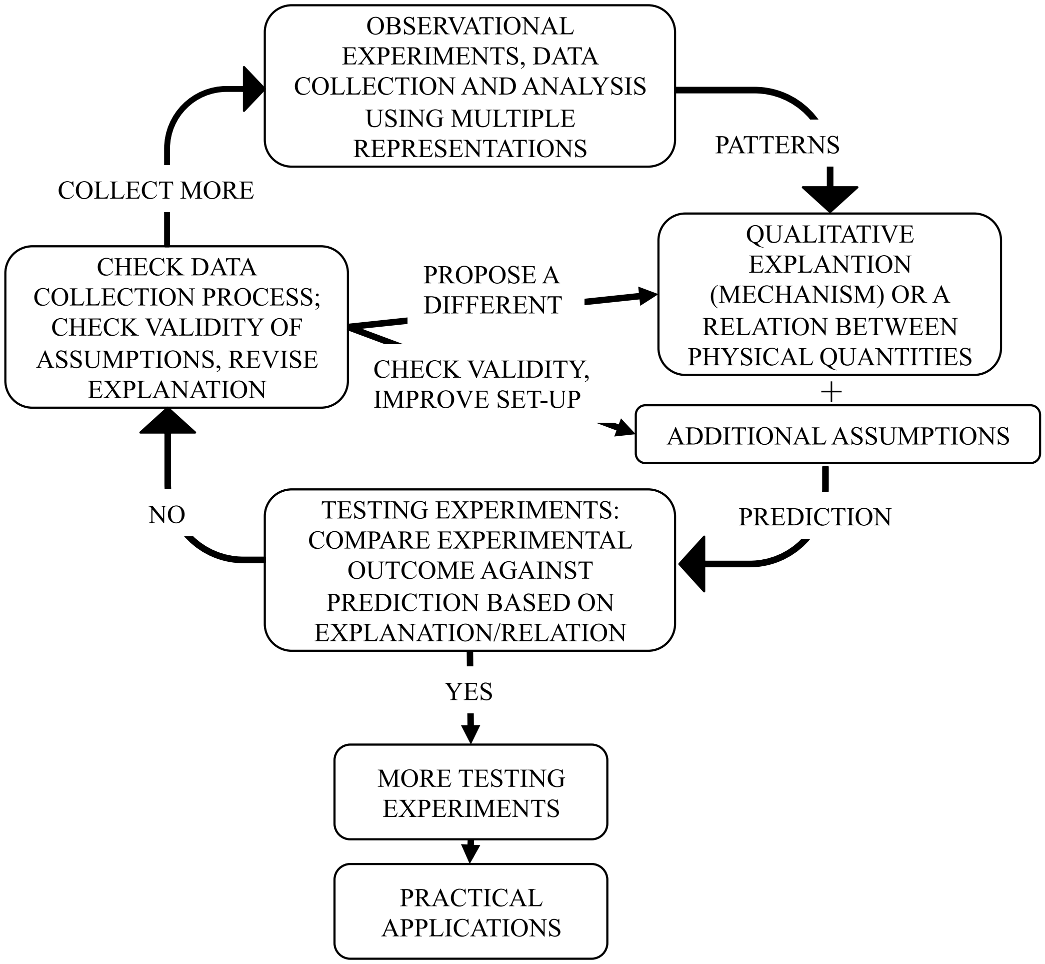


Figure 1. ISLE cycle

An example of how ISLE works in one unit: circular motion

Sample activities for large room meetings, recitation, and laboratory for one unit: We will outline the routine for a unit on circular motion for a large enrollment algebra-based college physics course (the mathematical level can be decreased for a high school course). We assume that there are two large room meetings during the week, followed by one recitation and one laboratory the following week. This unit comes after students learned linear kinematics and dynamics. All of the activities used in the description below can be found in *The Physics Active Learning Guide* (Etkina, Gentile, Van Heuvelen, 2014).

Large Room Meeting 1

Observation Experiments: The first large room meeting starts with several demonstration experiments or videotaped experiments of objects moving in a circle at constant speed [the videos are available at http://paer.rutgers.edu/pt3/experimentindex.php?topicid=58cycleid=9]: a person hits a rolling bowling ball with a mallet so that the ball moves in a circle, a rollerblader initially skating straight holds a rope whose other end is held by another person. The rollerblader then moves in a circle around this other person. Students are asked to identify objects interacting with the object of interest and then to make front view free-body diagrams (as seen in the plane of the circle as the object approaches). They then look for patterns in the motion and in the diagrams that can be the basis for a provisional rule for a circular motion at constant speed. After drawing the diagrams they find that the net force exerted on the moving object is always horizontal and points to the center of the circle.

The above observational experiments are examples of experiments from which students can clearly see a pattern. This does not mean that they let go of their original ideas. In the case of circular motion there are two alternative ideas that students have: there must be a force in the direction of motion, and there is a force outward. Both of these ideas are based on everyday experience.

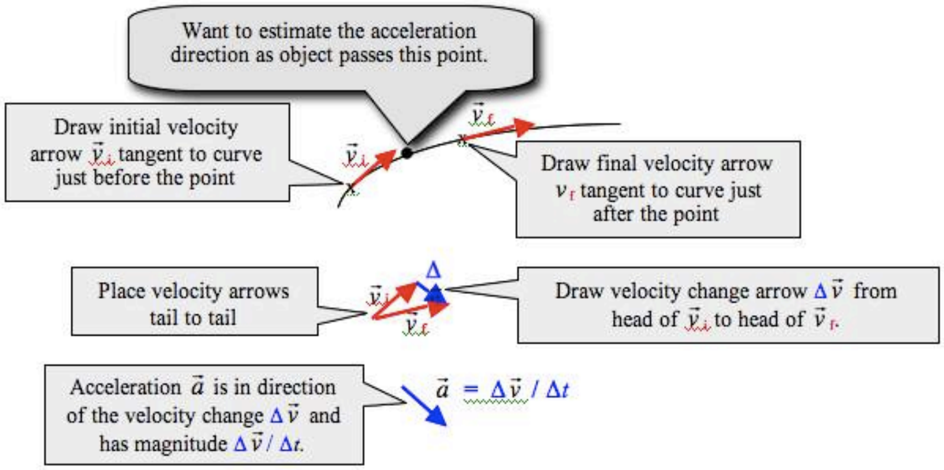
Provisional rule(s): Students devise a provisional rule: it appears that when an object moves at constant speed in a circle, a net force is horizontal and points toward the center of the circle (rule 1). At this point some of them still think that when an object moves in a circle there is an outward pushing force (rule 2) or a force in the direction of motion (rule 3). Thus if some of the students suggest that such forces should be present, the instructor accepts these rules as provisional rules.

Testing Experiment (s): Now students need to use the invented rule or rules to predict what will happen if a person rolls a small ball inside a ring. Students draw free-body diagrams and see that there is a net force exerted on the ball - the normal force of the ring on the ball which points toward the center. Thus, according to rule 1, the ball, if it is already in motion, should move in a circle inside the ring. According to rule 3 (force in the direction of motion) the ball should not move in a circle, as there is no force exerted on it along the circle. Students test their prediction by observing the experiment. As they observe the ball rolling inside the ring, the second prediction is not supported, and rule 3 is rejected. The next prediction is about what happens if part of the ring is removed. When students use rule 1, they say that if the ring is removed, there will be no net force exerted on the ball, thus it should move in a straight line according to Newton's first law. If they use rule 2, then the ball should fly outward. Then they perform the experiment or watch it. The ball moves in a straight line, and rule 2 is rejected. After this experiment the instructor might ask them why do we feel that we are thrown outward when in a car that is making a turn if there is no outward force exerted on us? This exercise allows students to connect new knowledge to the ideas they had before without decreasing their confidence.

The third testing experiment involves a prediction about the tension force exerted by a string on a ball swinging like a pendulum bob. Is this force smaller, the same or more than when the ball hangs at rest? (A spring scale supports the top end of the string). This is a more complicated situation than students encountered before – the speed of the motion changes. But if you focus students' attention only on the lowest point of the swing, they can make the prediction using a free-body diagram. There are two objects that exert forces on the bob – the Earth and the string. Students predict that if the net force points towards the center of the circle, the point of the pendulum's support, then the force of the string should be greater than the downward force of the Earth on the ball – greater than the tension when the ball was at rest. This is a counterintuitive prediction that is based on the rule that students invented; thus they are really excited to see the outcome of a testing experiment that can be easily performed in a lecture or a lab setting.

Qualitative kinematics of circular motion: Fred Reif and Joan Heller developed a concrete diagrammatic method for helping students gain a qualitative understanding of acceleration during two-dimensional motion. It helps students develop a "feel for" centripetal acceleration instead of seeing it as just v^2/r. We first introduce this method (Fig. 2), and then students apply it to the motion of an object moving in a circle at constant speed and discover that at different points the acceleration points toward the center of the circle.

Figure 2.



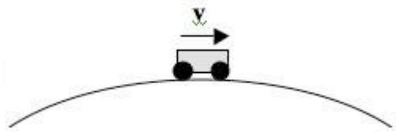
Large Room Meeting 2

Newton's second law qualitative concept building and representing: In the first circular dynamics large room meeting, students learned that: (a) the net force that other objects exert on an object moving at constant speed in a circle points toward the center of the circle; and (b) the direction of the acceleration of this circling object also points toward the center of the circle (based on the use of the graphical velocity subtraction technique). Based on these observations, students realize that the familiar Newton's second law also applies to two-dimensional circular motion.

Qualitative circular motion reasoning with Newton's second law: A very important aspect of *ISLE* is reasoning with multiple representations. An example of such a multiple representation reasoning activity is given in Fig. 3.

Figure 3.

Representing and reasoning: A battery powered toy car moves at constant speed across the top of an almost frictionless circular hump, as shown at the right.



(a) Use the graphical velocity subtraction technique to decide if the car is accelerating when passing across the top of the hump and, if it is accelerating, to estimate the direction of the acceleration.

(b) Construct a free-body diagram for the car when passing across the top of the hump. Make the force arrows the correct relative lengths.

(c) Use Newton's second law to qualitatively compare the results of parts (a) and (b) to be sure they are consistent. If not, revise your work on one part or the other.

When performing these activities, students do not look for a numerical answer. They work in groups of two during class and then the instructor discusses possible correct and incorrect answers. A follow up activity can be a multiple-choice question which students answer via a personal response system.

Quantitative centripetal acceleration: We use the graphical velocity subtraction method to help students determine how the magnitude of the centripetal acceleration depends on the speed of an object moving in a circle and on the radius of the circle. Students, guided by the instructor, perform two activities that lead them to the understanding of how the acceleration is related to the speed of the object and the radius of the circle.

Quantitative testing experiment for Newton's second law as applied to circular motion: Students now have Newton's second law in component form (from their study of translational dynamics) and a quantitative expression for centripetal acceleration. They can now use these concepts to make predictions about the outcomes of several testing experiments. One of them involves objects of different mass and the same surface placed on a rotating platform at the same distance form the center. Students need to use Newton's second law and their knowledge of circular motion to predict which object will fly away first. It is very important here that students actually draw free body diagrams and reason quantitatively before they make the prediction. As before, the prediction is counterintuitive – all objects should fly off at the same time, and students often do not think that the experiment will work. However, the success of the experiment makes them feel confident about their ideas.

Recitation

Now, the emphasis is on problem solving—applying the concepts and strategies that were learned earlier. Below we provide examples of several non-traditional activities. In recitations students work in groups on a set of problems from the *The Physics Active Learning Guide* (***ALG***).

Representing processes in multiple ways: These activities ask students to represent a situation in different ways, including free-body diagrams, mathematics, etc. They do not solve problems to find a numerical answer. See Fig. 4.

Figure 4

Represent a process in multiple ways: For each roller coaster car situation below, determine the car's acceleration direction, construct a free-body diagram for the car (make the force arrows the correct relative lengths), check for consistency of the net force and the acceleration direction, apply the radial component form of Newton's law for the car, and check for consistency of the free-body diagram and the equation.

Words and Sketch	*Words and Sketch*	*Words and Sketch*
The roller coaster car glides at constant speed along a frictionless level track. Choose a system. 	The roller coaster car moves along a frictionless circular dip in the track. Choose a system. 	The roller coaster car moves inverted past the top of a frictionless loop-the-loop. Choose a system. 
Direction of $\vec{a}$	**Direction of** $\vec{a}$	**Direction of** $\vec{a}$
Free-body diagram	**Free-body diagram**	**Free-body diagram**
Apply $\Sigma F_{radial} = m\,a_c$	**Apply** $\Sigma F_{radial} = m\,a_c$	**Apply** $\Sigma F_{radial} = m\,a_c$

The students are relating the abstract mathematical representation to more concrete sketches and diagrams.

Equation Jeopardy Problems: Students are given a mathematical description of a circular motion process and are asked to construct a description in words and in a sketch that is consistent with the word description (Fig. 5). They are learning to read the mathematical language of physics with understanding.

Figure 5.

Equation Jeopardy: Write in words a problem and construct a sketch for a situation involving circular motion that is described mathematically below (there is more than one possibility). Provide all the details for this situation.

$$200\text{ N} + (50\text{ kg})(9.8\text{ m/s}^2) = (50\text{ kg})\,v^2/(12\text{ m})$$

Evaluation Problems: Students are given the solution to a problem. The solution has mistakes, which they need to identify and correct (Fig. 6). This helps develop the very important science process ability of evaluation.

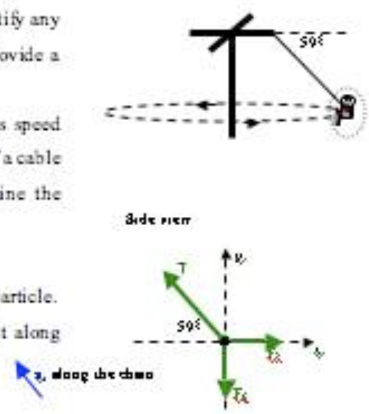
Figure 6.

Evaluation problem—amusement park ride: (a) Identify any errors in the solution to the following problem. (b) Provide a corrected solution if there are errors.

The problem: 80-kg Samuel rides at a constant 6.0-m/s speed in a horizontal 6.0-m radius circle in a seat at the end of a cable that makes a 59° angle with the horizontal. Determine the tension in the cable. Assume that g = 10 N/kg

Proposed solution: The situation is pictured above.

We simplify by assuming that Samuel, the system, is a particle. A free-body diagram for Samuel is shown at the right along with the acceleration direction.

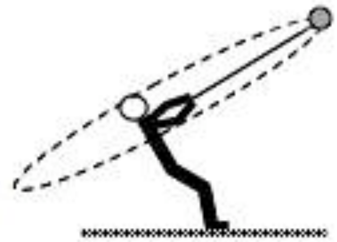


Represent mathematically and solve:

$$F_c = m(v^2/r)$$
$$= (80\text{ kg})(6.0\text{ m/s})^2/(6.0\text{ m}) = \underline{480\text{ N}}.$$

Posing problems: Students are provided with a picture of a situation and need to devise a problem based on the situation (Fig. 7).

Figure 7.
Problem posing—hammer throw: An Olympic throw for a 7-kg hammer (the ball connected to the wire) is a little less than 90 m. Invent two problems for this situation and use the principles of physics to solve these problems about the hammer throwing situation depicted at the right.



Laboratory

In the laboratory students work on the following experiment;

Design two independent methods to determine the net force exerted on the bob of a conical pendulum by other objects as the bob moves at a constant speed in a circle of a chosen radius.

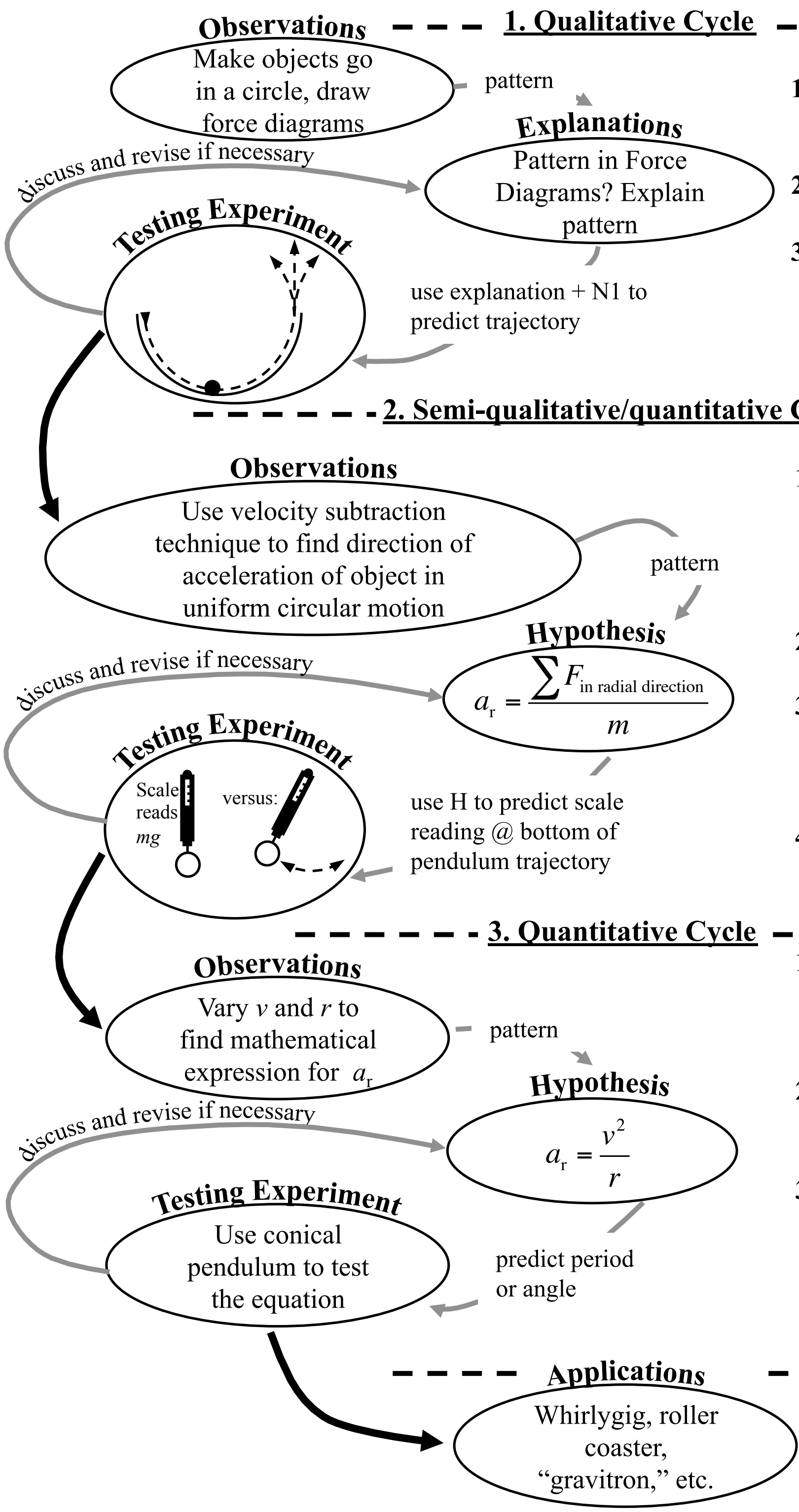
Equipment: A conical pendulum with a long string, a ring stand, a watch with a second hand and a large piece of paper.

For each method include: a) a complete description with a labeled diagram; b) a free-body diagram if needed; c) the quantities that you will measure and the quantities that you will calculate; d) the mathematical procedure that you will use to determine the net force; e) additional assumptions that you make, and f) sources of experimental uncertainty and ways to minimize them. Then perform the experiment, record data in an appropriate way and find the value of the net force. Decide if the results of the two methods agree with each other.

A variation of the above schedule is summarized in the diagram below.

Activity numbers are from the Active Learning Guide (2014) by Etkina, Gentile and Van Heuvelen.

Circular Motion



1. Qualitative Cycle

1. **Obs & Pattern:** ALG 4.1.1 + 4.1.2 can be done as lab experiment.
2. **Explanation:** ALG 4.1.3
3. **Test:** ALG 4.1.4 video in LRM, or do in lab with video or real equipment.

2. Semi-qualitative/quantitative Cycle

1. **Develop representational skill**: velocity subtraction Textbook section 4.1, Figure 4.2
2. **Obs & Pattern:** ALG 4.2.1 + 4.2.2
3. **Hypothesis:** Present to students or let them discuss and propose themselves
4. **Test:** ALG 4.2.4 & 4.2.5

3. Quantitative Cycle

1. **Obs & Pattern:** ALG 4.3.1 + 4.3.1. This is an experiment done on paper.
2. **Hypothesis:** Equation emerges from discussion.
3. **Test:** Best done in lab: Ask students to design experiment to test the full relationship:
$$\frac{v^2}{r} = \frac{\sum F_{\text{in radial direction}}}{m}$$