

Teaching STEM effectively with the Learning Cycle Approach

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The main challenges for teachers with regard to STEM-oriented instruction are: 1) How to integrate science, technology, engineering and mathematics in such a way that students see the interconnectedness and interdependence between these disciplines; and 2) How to help students realize that solutions to real world problems or issues involve the combined use of knowledge, processes and practices from all of these disciplines. In order to teach STEM effectively, these two challenges must be met, but how? Teachers need pedagogical approaches or models that can address these challenges effectively. Given that the STEM definition adopted by IPST includes *"the application of knowledge to real-life problem solving"*, it follows that effective STEM-oriented instruction must involve a pedagogy that is centered around real-life issues, concerns, problems or questions and offers students the opportunity to employ two or more of the STEM disciplines in an integrated manner to address the questions.

The "Learning Cycle" offers just such a pedagogical approach in which instruction is organized in a manner that establishes the purpose and usefulness of lesson content early in the lesson with real-life contexts, involves students actively in the learning process, provides opportunities for connecting lesson content to real life applications, and gets students to "experience" science the way real scientists do and problem-solving the way real engineers do. The Learning Cycle approach is a "continuous" instructional process but for the sake of understanding it better, we will consider it in terms of 5 specific phases described below. Table 1 indicates the alignment between these phases of the Learning Cycle and the Scientific and Engineering Practices deemed essential in *A Framework for K-12 Science Education* (2012), which form the foundation for STEM-oriented instruction.

Table 1: Alignment between the phases of the Learning Cycle and Scientific & Engineering Practices

Phases of the 5E Model of Learning Cycle	Essential Scientific & Engineering Practices (Based on <i>A Framework for K-12 Science Education</i>)
ENGAGEMENT	• Asking Questions • Defining Problems
EXPLORATION	• Developing & Using Models • Devising Testable Hypotheses • Planning & Carrying out Investigations • Collecting, Analyzing and Interpreting Data • Using Mathematics & Computational Thinking
EXPLANATION	• Analyzing and Interpreting Data • Constructing Explanations and Critiquing Arguments based on Evidence • Designing Solutions • Communicating and Interpreting Scientific Information
ELABORATION	• Applying and Using STEM Knowledge
EVALUATION	• Applying and Using STEM Knowledge

The ENGAGEMENT Phase:

This is the beginning of the lesson. The goal in this phase is to *engage* students' minds in the learning process; to get them to start thinking about the topic of the lesson; to generate curiosity, interest and, perhaps, even suspense about the topic. Such engagement "hooks" students in ways that answer the question, "Why should we learn this stuff?" early in the lesson and provides motivation for students to pursue learning. This is not accomplished by announcing to the class, "Today we are going to learn about Density in Chapter 5." Rather, it is accomplished by involving students in one or more of the following activities (not an exhaustive list but just a few suggestions) as lesson starters.

- **Demonstration** of a phenomenon that raises curiosity and generates specific questions, which provide meaning, purpose and focus for the rest of the lesson activities.

- **Media Clip** of an event connected to the topic of the lesson (such as an earthquake), which can generate questions to be pursued during the rest of the lesson.
- **Report** (either print or video) of a recent discovery or unusual finding (such as the large scale death of frogs in various parts of the world) that is related to one or more concepts involved in the lesson. This report can be used to generate questions that students can pursue further.
- **Hypothetical Story or Scenario** (such as "This class has been invited by the Victory Toy Company to develop a toy that will..."), which can involve students in performing specific tasks or solving specific problems that will lead to an understanding of particular science concepts.
- **Open-ended Question/Brainstorming** (such as "What comes to your mind when you hear the word 'population?'"), from which specific questions, problems, or issues can be generated.

The choice of which Engagement activity to use depends largely on the topic/content of the lesson and how you want to connect it to real life contexts at the very beginning of the lesson.

For example, in a lesson on Population Growth, I start by asking students the population of the town they live in, then the country they live in, and ultimately ask if they know how many people are in the world. Finally, I show a video clip of world population growth and invite students to raise questions that come to their minds after viewing the video. Discussion of their questions distills down to the following major "lingering" question: "What factors influence human population growth?"

Things to Keep in Mind regarding the Engagement Phase:

- Do not use technical vocabulary terms that have not yet been learned in your class. Instead, discuss ideas or problems in common everyday language.
- Do not provide answers, definitions, explanations, etc. Instead, ask students to predict and raise questions.
- Promote higher order thinking and establishment of specific questions, problems or issues.

The ultimate goal of the engagement phase is to generate what may be called "lingering questions" to be answered, or to identify specific problems for which specific solutions need to be designed or engineered, or to present specific issues that need to be addressed or dealt with. Once these are established, students are to be involved in activities that answer the "lingering questions", design/engineer solutions to the specific problems, or address the identified issues. How we go about doing that takes us to the next phase of the Learning Cycle.

The EXPLORATION Phase:

This phase follows the Engagement phase and is designed to get students actively involved in "exploring" so that the lingering questions can be answered, solutions to problems can be designed/engineered and tested, or issues can be addressed using scientific information. Exploration can be done in a variety of ways such as designing and conducting experiments; participating in laboratory activities; building and examining

models; running simulations of natural phenomena; conducting “virtual” (online) experiments or simulations; gathering information from print resources (including the textbook), online resources, or human resources; performing specific tasks, etc. The goal of the exploration phase is to collect or generate as much data and/or information as possible, related to the lingering questions, problems or issues. The exploration activities should be designed, chosen or determined in such a way that allows for active student involvement (both **hands-on** and **minds-on**) rather than passive following of directions provided by the teacher. In other words, students should be given opportunities to come up with their own design for experiments or models, engineer their own solutions, and determine what technological applications would be the most appropriate/useful in their investigations. As indicated in Table 1, the Explanation Phase offers ample opportunity for students to engage in scientific and engineering practices and integrate knowledge from various STEM disciplines.

For example, while the topic of population growth and the factors involved in population growth are essentially biological (science), the way I go about having students “explore” them involves mathematics. Students are provided with information regarding a number of hypothetical families and questions to answer based on those families. As evident in this task description, provided as Appendix A, there are a number of mathematical procedures that are involved in answering these questions. Thus, the lesson effectively integrates the S and the M of STEM in learning about the real world issue of human population growth.

The Important Points about the Exploration Phase:

- The purpose for the exploration activities is provided by the lingering questions, problems or issues. In other words, the exploration activities are not random, “stand alone” instructional events but are chosen strategically to address the questions, problems or issues presented/generated during the Engagement phase.
- Several exploration activities can be done within the same lesson. Either all students participate in all activities or different student groups perform different activities, depending on the nature of questions, problems, or issues being pursued.
- The focus during the exploration phase should be on gathering or generating data/information and testing ideas and models, rather than composing explanations or formulating answers.

After generating information, designing and testing models, or completing mathematical computations during Exploration activities, we are ready to make sense of it all in the next phase of the Learning Cycle.

The EXPLANATION Phase:

This is the phase during which all the data/information gathered or generated through “exploration” is used to make sense of the phenomena being explored; synthesize scientific concepts and principles; introduce new scientific vocabulary; develop definitions; generate explanations; and formulate answers to lingering questions, solutions to problems, or ways to scientifically address specific issues. Most often, this is the phase where the teacher may use interactive lectures and discussions to help students understand the topics intended in the lesson, see their connections to real life, and appreciate the

interconnectedness as well as interdependence of the STEM disciplines in addressing these real life issues.

For example, in the lesson on population growth, during the Explanation phase, I have students share their answers to the questions described in the task (see Appendix A). As they share their answers, we discuss how they arrived at the answers. They were supposed to have graphed the growth of their assigned families. We discuss the patterns of growth represented in the graphs and try to figure out the factors influencing growth from those patterns and the information provided about the families in the task description. Connections between the factors (biological) and the growth pattern (mathematical) become evident during these discussions.

Important Points about Explanation Phase:

- All of the lecture/discussion must take into account and flow from what the students did during exploration. In other words, this is not the time for the teacher to simply go through a previously prepared power point lecture on a specific topic. Rather, it is the time to work through the information that students gathered during Exploration and use it to arrive at concepts that the lesson is supposed to teach.
- Have students first present or share what they discovered/observed/gathered during Exploration. Ask them questions that will make them think about the information they have generated.
- Maintain an interactive, negotiating kind of environment in which students are actively involved in making meaning of the information being dealt with, rather than passively receiving information being dispensed by the teacher.

The goal of the Explanation phase is to develop an understanding of topics that the lesson was designed to teach, in the context of lingering questions, problems, or issues relevant to real life. Once this understanding is developed, students can then be invited to apply or use this understanding to a new situation or solve a new (but related) problem. This takes the lesson into the Elaboration phase.

The ELABORATION or EXTENSION Phase:

This is the phase in which students apply the knowledge gained in the lesson to new situations. They can be asked to answer new questions, solve new problems, or address new issues that are based on the concepts learned in a given lesson. A new research project, designing a new experiment, engineering a new model, or identifying real life examples of situations where the learned concepts can be applied, are all examples of how this phase can be conducted. In some situations, activities or assignments used in this phase can actually serve as EVALUATION of student learning.

For example, in my lesson on population growth, after learning the factors that influence human population growth, I ask students to pick various geographical regions of the world, research population growth patterns in their chosen regions and explain those patterns by relating them to the factors we studied. All of this is done as separate research projects.

The example of the research project described above for my population growth lesson can easily serve to evaluate student learning because they have to first investigate population growth patterns in some specific part of the world and then explain them using the knowledge of the influencing factors we learned in this lesson.

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graph TD; Engagement[Engagement Phase] --> Elaboration[Elaboration Phase]; Elaboration --> Evaluation[Evaluation Phase]; Evaluation --> Explanation[Explanation Phase]; Explanation --> Exploration[Exploration Phase]; Exploration --> Engagement;
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Engagement Phase
Generating student interest, curiosity, motivation to learn; resulting in one or more 'explorable' lingering questions, problems, issues, or tasks related to real life.

Elaboration Phase
Applying the newly gained knowledge to new situations, solve new problems, engineer new solutions, or generate new questions, to reinforce and ensure a sound understanding of the concepts involved.

Evaluation Phase
Assessing student learning using authentic assessment approaches.

Explanation Phase
Analyzing the data/information gathered during exploration phase; making sense of the results to synthesize scientific concepts, principles, laws, etc.; introducing appropriate scientific vocabulary; assessing the effectiveness of proposed solutions, and addressing the lingering questions, problems, issues, etc.

Exploration Phase
Exploratory activities conducted by students to gather data/information useful for addressing the lingering questions, or designing/engineering and testing solutions to specific problems.

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Appendix A: Exploration Task for Population Growth Lesson

My Family in 100 Years

(Adapted from ***Biology: A Community Context***, by W. H. Leonard & J. E. Penick, 1998, South-Western Educational Publishing)

The Task

This inquiry is designed to explore the factors that may contribute to population growth in human societies. You will calculate and illustrate, through a graph, the number of children in each generation for each of the following hypothetical families for the generation interval nearest to 100 years (make a separate graph for each family).

In order to simplify population growth calculations, population biologists often only take into account the females in the family. Therefore, for this inquiry, assume that all children born are females and all complete their full reproductive potential. Start each family with one female at time ZERO and calculate their descendants for as many generations as possible during the next 100 years. The number of descendants in the final generation nearest to the 100th year will represent the contribution of that family to population growth of their society. After calculating and graphing your results, please answer the questions that follow the family descriptions.

The Family Descriptions

Kunchai:

The Kunchai family lives in the suburbs (outer parts of big cities) and averages two children per generation. The women have their first child at age 25.

Corrigan:

The Corrigan family lives in a metropolitan city and averages one child per generation. The women have their first and only child at age 35.

Salazar:

The Salazar family lives in a large city and averages three children per generation. The women have their first child at age 15.

Chow:

The Chow family lives in a village (rural setting) and averages three children per generation. The women always have their first child at age 20.

Narula:

The Narula family lives in a small town and averages two children per generation. The women have their first child at 20.

The Questions

1. Which family seems to contribute most to population growth over a period of 100 years?
2. Which family seems to contribute least to population growth over a period of 100 years?
3. Based on the family descriptions provided, what factors may influence a family's contribution to population growth?

Figure out (and describe how you did it) which, if any, of the factors you identified in question 3 above, have the greatest impact on population growth as modeled by these hypothetical families.