## III. Pedagogy for Science

Webster's defines pedagogy as: "1. the function or work of the teacher; teaching, 2. the art or science of teaching; education: instructional methods."

### A. Instruction, Learning Transfer, Inquiry

By the time students enter high school, they are required to shift from a middle school science focus on experiential based thinking to more abstract hypothetical thinking required by the High School Content standards and the Investigation and Experimentation (I&E) Standards described in the Science Framework for California Public Schools. For instance, in grade six the I&E Standards call for students to "develop a hypothesis" and "construct appropriate graphs from data and develop qualitative statements about the relationships between variables." This emphasis is consistent with the increased cognitive demand in middle school mathematics: "By the end of grade seven, students are adept at manipulating numbers and equations and understand the general principles at work…They graph linear functions and understand the idea of slope and its relationship to ratio." (Mathematics Framework for California Public Schools). By providing multiple opportunities for students to learn the science content by designing experiments, generating hypotheses, collecting and organizing data, representing data in tables and graphs, analyzing the results and communicating the findings, students are developing and applying mathematical concepts in multiple contexts. This process facilitates the development of students' hypothetical thinking operations and provides the foundation for transfer of learning not only between mathematics and science but also to other disciplines and creates the need to use these mathematical and scientific tools in the students' everyday lives.

In learning the science content standards in grade eight, as well as in grades six and seven, students will need multiple opportunities to "plan and conduct a scientific investigation to test a hypothesis… construct appropriate graphs from data and develop quantitative statements about the relationships between variables,…apply simple mathematic relationships to determine a missing quantity in a mathematic expression, given the two remaining terms…Distinguish between linear and nonlinear relationships on a graph of data" as described in the Standards. Focusing instruction on the acquisition of these mathematical and scientific tools will ensure that "Students…are prepared to undertake the study of algebra… in grade eight… and will be on the pathway for success in high school science." (Science Framework for California Public Schools)

To ensure that students are prepared for the quantitative and abstract nature of high school science, there should be a continued emphasis on the inquiry-based instructional model. This model includes many common elements or phases described in the research literature on how students best learn science concepts. The research clearly points out that inquiry involves asking a question, making observations related to that question, planning an investigation, collecting relevant data, reflecting on the need to collect additional data, analyzing the data to construct plausible explanations, and then communicating findings to others.

Such a process is at the heart of the immersion units (extended inquiry) described in both the elementary and secondary instructional guides. To help science teachers plan and organize their immersion and other inquiry-based units the following process can serve as a guide:

- Phase 1. Students are engaged by a scientific question, event, or phenomenon. A connection is made to what they already know. Questions are posed in ways that motivate students to learn more.
- Phase 2. Students explore ideas through direct, hands-on investigations that emphasize observation, solve problems, formulate and test explanations, and create and discuss explanations for what they have observed.
- Phase 3. Students analyze and interpret data they have collected, synthesize their ideas, and build concepts and new models with the support of their teacher. The

interaction between teachers and students and the use of other sources of scientific knowledge allows learners to clarify concepts and explain that have been developed.

- Phase 4. Students apply their new understanding to new settings including real life situations to elaborate on their new knowledge.
- Phase 5. Students, with their teachers, review and assess what they have learned, and evaluate their understanding.

There are many factors that should be included in such instructional models to ensure the transfer of learning to new settings[1]. One such factor that affects transfer of learning is the degree of mastery of initial learning. Initial learning is influenced by the degree to which students learn with understanding rather than memorizing a set of facts or procedures. Students must be provided with enough time for them to process information. Attempts to cover too many topics too quickly may inhibit later transfer because students only remember isolated facts or are introduced to organizing concepts they cannot grasp because they do not have enough specific information related to what they are learning.

Motivation is a factor that affects the amount of time students are willing to spend on science learning. Students who have “choice and voice” in investigations they are conducting, who engage in novel experiences, and who encounter unexpected outcomes usually develop the intrinsic motivation associated with long-term, sustainable intellectual growth that characterizes effective learning transfer. Knowing that one is contributing something meaningful to others (in cooperative groups) is particularly motivating. Learners are also motivated when they are able to see the usefulness of learning and when they can use what they have learned to do something that has an impact on others. Examples include tutoring or helping younger students learn science or participatory science nights for parents, community members and other students. Seeing real life application of what students have learned creates the so-called “Aha” response when they fit concepts learned to actual situations. Such transfer can be very motivating to students[1].

A crucial element of learning transfer is related to the context of learning. Knowledge or concepts that are taught in a single context are less likely to support transfer than is knowledge that is taught and experienced in multiple contexts. Students exposed to several contexts are more likely to abstract and intuit common features of experience and by so doing develop a more flexible representation of knowledge. To accomplish all of this, teachers of science:[2]

- Plan an inquiry-based science program for their students
- Guide and facilitate learning
- Use standards aligned texts and supplemental materials
- Engage in ongoing assessment of both their teaching and student learning
- Design and manage learning environments that provide students with the time, space, and resources needed for learning science
- Develop communities of science learners that reflect the intellectual rigor of science inquiry and the attitudes and social values conducive to science learning
- Actively participate in the ongoing planning and development of the school science program

The following chart provides a way to gauge instructional transfer by monitoring student behavior or by using possible teacher strategies. The chart is adapted with permission from BSCS (Biological Science Curriculum Study) and is intended to be used to assess units of study rather than individual lessons:

[1] How People Learn, Expanded Edition; Bransford, John D; Chapter 3, Learning and Transfer; National Academy Press; Washington D.C.; 2000

[2] National Science Education Standards; Chapter 3, Science Teaching Standards; National Academy Press, Washington D.C.; 1996

## The Learning Cycle

| Stage of Inquiry in an Inquiry-Based Science Program | Possible Student Behavior | Possible Teacher Strategy |
|---|---|---|
| **Engage** | Asks questions such as, Why did this happen? What do I already know about this? What can I find out about this? How can I solve this problem? Shows interest in the topic. | Creates interest. Generates curiosity. Raises questions and problems. Elicits responses that uncover student knowledge about the concept/topic. |
| **Explore** | Thinks creatively within the limits of the activity. Tests predictions and hypotheses. Forms new predictions and hypotheses. Tries alternatives to solve a problem and discusses them with others. Records observations and ideas. Suspends judgment. Tests idea | Encourages students to work together without direct instruction from the teacher. Observes and listens to students as they interact. Asks probing questions to redirect students' investigations when necessary. Provides time for students to puzzle through problems. Acts as a consultant for students. |
| **Explain** | Explains their thinking, ideas and possible solutions or answers to other students. Listens critically to other students' explanations. Questions other students' explanations. Listens to and tries to comprehend explanations offered by the teacher. Refers to previous activities. Uses recorded data in explanations. | Encourages students to explain concepts and definitions in their own words. Asks for justification (evidence) and clarification from students. Formally provides definitions, explanations, and new vocabulary. Uses students' previous experiences as the basis for explaining concepts. |
| **Elaborate** | Applies scientific concepts, labels, definitions, explanations, and skills in new, but similar situations. Uses previous information to ask questions, propose solutions, make decisions, design experiments. Draws reasonable conclusions from evidence. Records observations and explanations | Expects students to use vocabulary, definitions, and explanations provided previously in new context. Encourages students to apply the concepts and skills in new situations. Reminds students of alternative explanations. Refers students to alternative explanations. |
| **Evaluate** | Checks for understanding among peers. Answers open-ended questions by using observations, evidence, and previously accepted explanations. Demonstrates an understanding or knowledge of the concept or skill. Evaluates his or her own progress and knowledge. Asks related questions that would encourage future investigations. | Refers students to existing data and evidence and asks, What do you know? Why do you think...? Observes students as they apply new concepts and skills. Assesses students' knowledge and/or skills. Looks for evidence that students have changed their thinking. Allows students to assess their learning and group process skills. Asks open-ended questions such as, Why do you think...? What evidence do you have? What do you know about the problem? How would you answer the question? |

Chart 1 - The 5 E Model (R. Bybee)