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7. MIND YOUR P'S AND E'S

Developing Creativity in the Science Classroom

INTRODUCTION

In its report, "Preparing the Next Generation of STEM Innovators: Identifying and Developing our Nation's Human Capital", the National Science Board (2010) of the National Science Foundation clearly states that "the U.S. education system too frequently fails to identify and develop our most talented and motivated students who will become the next generation of innovators" (p. 2). Too often, students with tremendous potential and high levels of creativity and talent go unrecognized and undeveloped because they lack the opportunities needed to develop their untapped potential. There are many successful programs focused on advanced learners in which today's top scientists have participated. Students who are encouraged to develop their abilities and who participate in activities related to science during their youth generate significant numbers of patents, win more Nobel Prizes, and are more likely to hold tenured academic faculty positions at top universities (Lubinski & Benbow, 2006).

Creativity is one of the required cognitive attributes for success in the 21st century, according to Howard Gardner, stating that "Everything that can become automated, will be", (Sparks, 2011, p. 1). The question of creativity as a domain-specific skill is a hotly contested one. While it would appear that there are some general skills that are "creative" (Mayer, 2010), it cannot be assumed that by promoting arts education, for example, that students will transfer those skills over to the domain of science. Research has found that "[t]hese transfer claims have been posited without any particular mechanism; there's a lot of magical thinking going on," states Ellen Winner, a long-time creativity researcher (Sparks, 2011, p. 3). If one wants to develop creativity in science, it is critically important to do so within the field of science, and not assume that such skills in other content areas will transfer.

Creativity is highly dependent upon the context. A study, done by Mumford et al. in 2010, found differences in how creativity is demonstrated between scientific fields irrespective of experience within the field. Health scientists demonstrated stronger performance at problem definition and solution appraisal, while biological scientists were stronger at information gathering and idea generation. Social scientists were found to be stronger in idea generation and conceptual combinations. Such differences found across expertise levels appear to be more related to the structure of the discipline, rather than expertise in the related skills.

M. K. Demetrikopoulos & J. L. Pecore (Eds.), Interplay of Creativity and Giftedness in Science, 107–126.

Because of its dependence on expression within the structure of a discipline, creativity is a construct that many claim to recognize, and yet few can define. In addition, there are cultural differences of the understanding of creativity, with East Asians being more likely to view creativity as an outside demand or experience but one with internal rewards, and Americans more likely to perceive creativity as an internal personality trait that results in innovative external products (Lubart, 2011; Paletz, Peng, & Li, 2011). There are also heated debates about how to measure creativity, whether it is rare or common, and how to study it. The tension between defining creativity as a "property of people, products, or processes" (Mayer, 2010, p. 450) is one that is not resolved in this chapter, nor is the concept of creativity as an individualistic characteristic or a result of social and cultural environments. For the sake of this chapter, which focuses on practitioners within a science educational environment, we leave most of the theoretical arguments to researchers and will focus on multiple ways of developing creativity within the science classroom. To develop creativity in a practical, content-based manner, we will examine the integration of the four elements of creativity, known as the 4Ps, in conjunction with the content-focused process of the 5Es, as the organizing method.

Creativity is often described as the 4Ps, or the combination of people, products, and processes that occurs within a given place (Mayer, 2010, Kozbelt, Beghetto, & Runco, 2011). Given this four-sided aspect of creativity, it is worthwhile to explore these aspects as separate components to be developed and nurtured within a classroom.

Table 1. 4Ps of creativity and teacher actions

Element of Creativity	*Teacher Responsibilities*
Place	Establish context, support and underlying classroom culture; identify materials and resources
Person	Support personal creative qualities; encourage lack of conformity and questioning
Process	Link explorations to concepts; support innovative combinations and experimentation; provide models of divergent thinking
Product	Evaluate the usefulness of a product; determine quality of end result

Likewise, in science education, there is an organizing method or process to teach inquiry and discovery of most concepts. Science education has similar goals and objectives to fostering creativity as an inquiry-based approach that recognizes individualized elements of discovery and critical problem solving. Although, probably not recognized on a grand scale as novel products or processes, the outcomes in a true inquiry-based approach to science education do foster creative elements because the findings or discoveries are original to the student and authentic learning has taken place. Most science educators recognize that the learning cycle is an effective approach to an inquiry-based classroom. The learning cycle was developed in the 1960's by Karplus and Their (1967) and had three distinct phases of instruction: (1) Exploration, (2) Concept Introduction, and (3) Concept Application. Since the introduction of the original learning cycle, many revisions and alterations have taken place, but the most popular and widely recognized version now is the 5E model: Engagement, Exploration, Explanation, Elaboration, and Evaluation (Bybee, 1997). The 5E model incorporates the original three phases of the learning cycle but adds two critical elements: Engagement and Evaluation.

The 5E model and its subsequent impact on student achievement has been extensively evaluated and its appropriate use has resulted in greater student academic achievement in science, higher retention rates of scientific concepts and improved reasoning ability and process skills (Hanuscin & Lee, 2008). As a process for planning and executing instruction the 5E model allows teachers to sequence and organize a range of activities and applications and avoid randomness and lack of connection to the curriculum. The table below depicts the each of the 5E phases and subsequent teacher responsibilities as adapted from Abell and Volkmann, 2006 along with an additional E phase.

Table 2. 6E (5E+1) Process and teacher actions (adapted from Abell and Volkmann, 2006)

Phase of Instruction	*Teacher Responsibilities*
Engagement	Establish context; motivate; identify misconceptions
Exploration	Provide common experiences; determine student conceptual understanding
Explanation	Link explorations to concepts; introduce formal content
Elaboration	Expand or apply student knowledge; provide extension activities
Evaluation	Assess student understanding of formal content; determine revisions
Experience	Provide context and preparation; model play and creativity

In the subsequent sections each of the standard 5 phases are more thoroughly explained and placed within context of the 4P's. In addition, a sixth "E" is proposed. "Experience" provides context and preparation for the entire encounter of a science-based lesson that fosters creativity and intertwines the two research-based strategies found separately in science and gifted/creativity investigations. "Experience" as a step in lesson design is meant in both the noun and the verb form; teachers themselves have to model "play" and "experience" creativity themselves in order to teach it (Starko, 2005), and they have to plan for the experience by preparing an array of materials and resources that may be only indirectly related to the nature of the problem, but that promote curiosity- which directly leads to the next “E” of “Engagement”.

P’S AND E’S INSTRUCTIONAL MODEL

It is worthwhile pursuing a model of instruction that combines the process of creativity development with the inquiry-based process of science instruction. Such a model provides a “road map” for teachers to explore the development of creativity and science talent. Such development cannot be left up to talented and gifted programs alone. According to Kim, Cramond, and VanTassel-Baska, (2010), there is a high level of correlation between creativity and intelligence scores, up to an IQ score of 120. However, above 120, there does not appear to be any relationship. Thus, the most creative individuals may be merely bright, whereas the most academically gifted students may not be highly creative. It is important to recognize that developing creativity in science is not an activity reserved only for gifted students or gifted programs, and in fact, may be very appropriate for students with learning differences, who often think “outside of the box” (Hughes-Lynch, 2010). Teachers must plan to incorporate the process of creativity within the process of science instruction for all students.

Experience

It is essential that the science teacher purposefully plans and prepares the experience of the classroom in order to develop creativity (Egan, 2005). A teacher cannot merely take a set of educational standards and hope that preparing a strong science lesson will consequently produce creative scientists. Creativity has to be a separate goal; one that is supported and fostered, despite the innate tensions and challenges that emerge as a result. Technical scientific knowledge is not the goal; creative “messes” using the tools of science are, and the teacher has to be prepared to establish that experience.

Place. The teacher has to focus on the classroom, and even the school, as an environment that promotes and encourages creativity. Therefore, the teacher has to plan the experience as one that is promoting, rewarding and encouraging continued development of creative outputs. Csiksentmihalyi (1999), for example, stated that a “set of rules must be transmitted from the domain to the individual, the individual must then produce a novel variation in the context of the domain… and then variation must then be selected by the field for inclusion in the domain” (p. 315). The classroom has to have materials, space and time that encourage “messing around”, rather than specific, content-based, goal-oriented opportunities.

Table 3. Ps and Es instructional model

	Place	*Person*	*Process*	*Product*
Experience	Knowing the rules of the field; selecting which areas to explore; providing openness of experience within limits of content	Risk taking and ability issues; classroom management and discipline	Thinking skills; questions to develop open-ended responses	Teacher knowledge of content; understanding of what constitutes originality
Engage	Devising an activity and materials that will generate questions	Facilitating question-asking, rather than answer-providing	Providing challenging, interesting and relevant questions to solve; allowing time for processing	Asking for a non-predetermined product that solves a relevant and interesting problem.
Explore	Providing materials, time, and problems for open discovery and exploration	Encouraging risk taking and opportunities for mistakes	Noticing obscure information and shifting, dynamic problems	Individualized and varied outcomes or products
Explain	Develop an open forum for student explanation with facilitation of formal content	Reinforcing honesty and ethical behavior; not rushing to judgment; comfort with lack of closure	Guided didactic conversation of formal content	General student understanding of formal content; evolving criteria
Elaborate	Provide a place to expand and apply basic conceptual knowledge	Facilitate approaches that go into deeper detail and deeper thought	Allowing students to elaborate and revise hypotheses	General and refined outcomes or products of formal content
Evaluate	Determine where evaluation data will be collected	Decide level of data (individual or group)	Formative/ Summative or both	Real time data that can be used to reform future lessons.; Quantity and originality of ideas

Person. The teacher must establish a tone of risk-taking within the classroom; a tone that often is difficult to maintain. In an interview with renowned psychologist Robert Sternberg, he noted that university students who took more risks got higher marks for creativity in a drawing contest. But when they took controversial stands in other content areas, the raters often scored them down. He stated that "the raters were saying 'I want you to be creative, and be sure you agree with me'" (Sparks, 2010, p. 6). Classroom management of behavior is a necessary element; a classroom culture that encourages respect without close-mindedness; questioning without anarchy. The teacher can provide modeling for this behavior by keeping the intellectual curiosity on the subject matter and away from the interpersonal.

Process. There are a number of commercially available programs to develop creativity. These began with Osborn's "brainstorming" techniques in the 1940's, (Lehrer, 2012), and evolved to include Gordon's "synectics" (1961) Edward de Bono's "Six Thinking Hats" (1999), von Oech's Roles and "Whacks" (1998), and Cameron's "The Artist's Way" (2002). Despite lack of research in their effectiveness, and even some research that shows that they may inhibit creativity (Lehrer, 2012), these programs have been amazingly popular. As the teacher prepares to develop creativity, it would be worthwhile to examine some of these programs and think about how to incorporate brainstorming coupled with individual time for pondering; to think about new combinations of materials while maintaining integrity of previous scientific knowledge.

Product. A teacher's effectiveness hinges on an understanding of both content and the learning process. In order to be highly effective a teacher needs to have a rich, coherent conceptual map of their discipline; an understanding of why a subject is important; and an understanding of how to communicate knowledge of that subject to others (Darling-Hammond & Baratz-Snowden, 2005). It is not enough for a teacher to know the content. An effective teacher can draw relevant connections and provide real world examples within their subject area. A teacher of creativity can recognize and appreciate creative responses from a solid understanding of what constitutes originality within a subject.

In planning the experience, it is important that teacher prepare for, understand, and appreciate both the field in which they are teaching and the creative process. Prior research has explored whether teachers' knowledge and ability are associated with student learning in the classroom. In short, major studies have found that students learn more from mathematics teachers who majored (earned a four-year degree) in mathematics than from teachers who did not (Goldhaber & Brewer, 1997). Similarly, students learned at higher levels from mathematics and science teachers (with a major) who studied teaching methods in the subject they teach than from those who did not (Monk, 1994). In summation, in the established experience, it is important that teachers have a strong conceptual understanding of what is to be taught and be prepared to provide concrete real world examples while allowing students to become engaged with the content themselves, rather than merely providing information.

Engage

The "Engagement" task accesses the learners' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students' thinking toward the learning outcomes of current activities. (Bybee et al., 2006). The goals of the engagement phase are to invite learner's consideration, encourage interest and spur them to unearth their prior experiences with the formal concepts to be studied (Tanner, 2010).

Place. The first opportunity a teacher has with a student is to provide him with a place that invites questions. The teacher has to provide materials and questions that engage a student. Having a variety of complex experiences with which to engage, allows students to develop more cognitive flexibility (Ritter et al., 2012). By providing an atmosphere of challenge and encouraging students to be curious, adventurous and take risks, teachers can provide opportunities for increased creativity (Sparks, 2011).

Person. Students who are engaged consider their work to be more play than effort. In order to engage, they must see the activity as something that involves a degree of risk-taking and related to their interests (Sparks, 2011). Interestingly enough, a recent longitudinal study found that it is often students from lower socio-economic, disadvantaged background who are most willing to engage in scholarly "play" and risk-taking necessary for creativity, especially if they perceive that the purpose of the work is to enrich and assist their local communities (Heath, 2011). If the teacher establishes the classroom in such a manner that questions are asked, student questions are encouraged, and demonstrations of creativity are not only welcome but desired, schools today become training grounds for laboratories of tomorrow (Deo, Wei, & Daunert, 2012).

Process. The process of engagement comes about from the complexity of the problem that is presented to the student. In order to more fully engage the student's creative processes, the teacher must present unusual and unexpected events, or "schema violations" (p. 962) that require involvement in order to solve (Ritter et al., 2012). However, it is important to note that in order to be creative in a content area, prior knowledge contributes significantly to the degree of creativity possible (Kyung-Nam, Moon, & French, 2011). It is difficult for students to be creative in science, if they do not have a good general knowledge of science. Creativity must build from knowledge, but it is knowledge for a purpose. In other words, teachers cannot justify rote learning as preparation for creativity. Students must perceive a need for knowledge in order to solve complex problems. They then seek the knowledge in order for the second step of creative problem solving. It is the problem that drives the knowledge and the resultant creativity in a two-step process.

Product. There is a fairly agreed-upon relationship between creativity and usefulness- with several scholars positing that creativity occurs only if person goes through a process that results in an original and useful product (Gruber, 2012; Mayer, 2011). The initial engagement for students has to have a purpose, an end in mind. It is this mindful "solution" that has to be at the forefront of student thought in order to develop creativity. Creativity is inspired by a "usefulness" rather than mere cognitive thought- there is a desire to come up with a conclusion that serves a purpose (Gruber, 2012).

Explore

Exploration experiences provide students with a common base of activities within which current concepts (particularly misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation. (Bybee et al., 2006). Typically, teachers will devise activities in which students work alone or in groups to develop an understanding of the content, process or phenomenon. Students often encounter confusion, conflicting ideas and unanswered questions during their exploration (Tanner, 2010). This is why it is critical to foster an environment that does not punish "mistakes" and use the variations that students develop as teachable moments to better understand the concepts being taught.

Place. During the process of creative exploration, it is necessary to have relevant, and possibly irrelevant information and materials handy so that students can test the limits of their explorations. In this process, described by Eisner (2004) as the thinking within and through the limits of the material, students have access to resources that allow extensions of thought and ideas. Similarly, students should be provided interesting and hypothetical connections between and within a field to solve. It is during the exploration phase that essential knowledge can be sought to solve the original problem, but only if students know that such knowledge exists and have the skills to manipulate it.

Person. A person who is willing to explore a scientific concept is one who is willing to take risks and to play (Sparks, 2011). However, the teacher can encourage the element of persistence that is necessary to exploring a topic, or what Duckworth et al. (2007) call "grit". With persistence and task commitment, students move beyond engagement to an exploration of inter-connected topics. During the process of exploration, care should be taken that students do not rush to early judgments and decisions, but are encouraged to take the time to fully explore the questions. Early foreclosure of understanding will limit the depth of creativity.

Process. In the development of scientific creativity, the teacher cannot establish a goal of a single "static" answer but an evolving problem that continues to shift and to change. This "dynamic" nature of the exploration, in which a student explores solutions, and shifts their understanding as the situation shifts and changes is critical to developing creativity (Gruber, 2012). Teachers can train students to notice obscure information that can shift a problem's solution and create innovative approaches. In a study of problem-solving, students trained to notice and look for obscure information were able to solve 67% more problems than an untrained group (McCaffrey, 2012).

Product. In today's educational climate of single–construct educational standards, the development of multiple responses to a single set of problems or questions is one that can be problematic. However, it is necessary that while basic information can be used to solve problems, there must be a comfort with ambiguous, numerous, and evolving solutions. Defining a product as complete is not part of the Exploration stage- testing and proving is.

Explain

The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase. (Bybee et al., 2006).

Place. Optimally, the explanation phase involves active participation by both teacher and student (Tanner, 2010). All too often, this phase is dominated by the teacher and the lesson becomes one-sided and lecture-based. In a classroom that seeks to develop creativity, the discussion follows an intellectual coaching model, in which the teacher guides student thinking, but allows the students to do the explanation for themselves. There is less reliance on power point slides and static information and more dependence on student inquiry and student-generated need for information.

Person. During the explanation phase of instruction, the issues of scientific vocabulary and knowledge become problematic. Without access to the language of science, students will have difficulty explaining what it is that they are questioning. Great care, however, should be taken to ensure that scientific vocabulary is not taught out of isolation, but within the setting of the questions that are posited. It is also perhaps noteworthy to emphasize the importance of honest results. It has been found that creative people are more likely to cheat and to justify their unethical behavior (Gino & Ariely, 2012). In the pursuit of scientific creativity, the issues of ethics and reliable information are ones that must be dealt with on a personal and individual level.

Process. A recommended approach during this phase is that of Holmberg's guided didactic conversation. Essentially, there should be a constant interaction ('conversation') between the teacher and students that are stimulated through the students' interaction during the explore phase that is inherently linked to the formal content. There are five of the six basic characteristics of true, guided didactic conversation that Holmberg (1983) outlines that are pertinent:

1. Easily accessible (readability and complexity) presentations of content
2. Explicit advice and suggestions to the student as to what to do and what to avoid
3. Invitations to an exchange of views, to questions
4. Involve the student emotionally to take a personal interest in the subject
5. Personal style including the use of the personal and possessive pronouns.

Product. As students seek to explain their results, they are constructing and testing multiple ideas and products with an evolving set of criteria. Students should be encouraged to identify and define the criteria for their products, and encouraged to change these definitions as the problem changes. As conclusions do or do not fit the established criteria, students must be encouraged to reject their initial ideas or products and continue working.

Elaborate

Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities. (Bybee et al., 2006). During the elaboration phase, teachers should explicitly guide students in the application of presented content. In essence, the elaboration phase should let students try out their new understandings established in the explanation phases (Tanner, 2010).

Place. As in so much of creativity development, there is time needed for students to deepen their understanding and to allow the creative process to occur. Restricted time is one of the greatest limitations to developing creativity (Sternberg & Kaufman, 2010). However, in today's classrooms where there is a given scope and sequence of content, time is a luxury. In schools such as Thomas Jefferson High School in Arlington, Virginia, time has been "bought" by combining courses in a focused effort. For example, they have a course called "IBET"- or Integrated Biology, English and Technology, where students are encouraged to seek technological solutions to biological challenges and write up the results. Such combining of creativity with other subjects allows students and teachers to experience biology in a richer, more holistic manner.

Person. Perhaps one the strongest ties can be drawn between "failure" and creativity in that creativity is often spurred by a perceived failure, an awareness of what other choices could be made, and a willingness to try again (Rodgers, 2012). There must be a genuine relationship between teachers and students in order for a student to feel free to elaborate on their responses and to feel free to make mistakes. Mistakes must be seen as necessary steps towards a deeper solution and that by examining mistakes, students can learn. This growth-set mental orientation (Dweck, 2006), is one that encourages students to perceive learning not as a set outcome, but a dynamic and reiterative process.

Process. There are many methods to facilitate elaboration of content, which can consist of cooperative learning or discussion, lab or activity extensions or even deeper discussion. It is in the scientific processes of organization, dis-organization, and re-organization, that creativity occurs (Barker, 2012).

Product. The outcome of the problem or question should be explored well enough to flesh out the details and to make connections to other learning and information. The criteria for the product should explore these inter-connections and students need to more completely describe how their product meets the solution or criteria.

Evaluate

It is in the evaluation stage that all of the previous stages are given value and measure. The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives. (Bybee et al., 2006). The evaluation phase is one that most teaches are probably familiar with but complete in many different manners. Basically, the added "Experience" planning phase allows an instructor to define the level and depth of the evaluation and the types of assessment data that are required. In its simplest form, any evaluation data (formative or summative) should be used to drive instructional decisions and lesson reforms.

Place. Creativity is unique among psychological traits in that it is dependent upon dual evaluation of the person and an outside audience (Sternberg & Kaufman, 2010); both the creator and the audience have to decide that something is "creative" for it to fall under that construct. When students perceive that their attempts at creativity are going to be noticed by a teacher, they are more likely to be creative (Randel, Jaussi, & Wu, 2011). The evaluation in the classroom should be constructed so that both teachers and students are seeking creative results as an outcome, and creative output should be valued by class and teachers alike.

Person. It is important for teachers and students to place a student's creativity in the context of instruction. According to Ellen Winner, a respected researcher, there is a difference between "revolutionary creativity" in which a new style of insight is developed, and more general creativity, such as adding on to existing work. "It's not at all clear to me that this [revolutionary] kind of creativity can be cultivated, though perhaps it can be asphyxiated," she said (Sparks, 2011, p. 8). It cannot be expected, although it can be encouraged, to develop creativity that produces results original to the child, and not necessarily original to the field.

Process. The issue of grading is a significant one. When people know that they are being evaluated, such as for a grade or by a judge, they demonstrate less creativity (Collins & Amabile, 2010). However, when students are in competition with each other, creativity- and resultant stress- tends to increase (Eisenberg & Thompson, 2011). To determine a process of evaluation, both formative evaluations of the process of creating, and a summative evaluation of the usefulness of a product should be considered.

Product. Perhaps the hallmark of creative thought is divergent thinking (Sternberg & Kaufman, 2010). Certainly E. Paul Torrance (1981) in his classic measure of creativity provides guidelines for evaluating the creativity of products, including:

- Flexibility
- Originality
- Fluency
- Elaboration

These measures extend the concept of evaluation beyond that of mastery learning to one of increasing ideas, extending concepts and explaining interconnections. While the nature of the content should drive the evaluation of the usefulness of the product in terms of scientific merit, the creativity of a product should feature in its evaluation as well.

There is an assumption among working scientists that younger scholars have it easier these days than scientists of earlier times. Because of the emphasis on STEM programs in schools and the concern for developing creativity, the context of education has provided a nurturing environment for young scientists to grow. Needed is "an environment to foster creativity and facilitate research performance" (Deo, Wei, & Daunert, 2012, p. 2065). Yet, the mechanisms for such development are not clear, nor have there been extensive models of instruction developed that combine creativity with content. This chapter develops a model of instruction that directly promotes creativity within the content field of science through the integration of the 4Ps of creativity and the 5Es of inquiry-based science education.

SAMPLE COMPARATIVE LESSON PLANS

In Practice, a 5E lesson is quite similar to most traditional approaches to effective teaching and learning. In essence, two steps within the instructional process are switched, the change recognized in the 5E model allows for student discovery and group connection to the content. Table 4 outlines the two distinct models and basic teacher tasks for each. Following is a sample lesson plan comparing the two models for this process, along with questions and evaluation components that incorporate creativity with introductory science content.

Table 4. 5E versus traditional approaches to teaching and learning

Traditional		*5E*	
Step	*Action*	*Step*	*Action*
Warm-Up	Preview Content/ Standards	Engage	Connect to Content/ Standard
Direct Instruction	Lecture	Explore	Facilitate Student Centered Activities
Indirect Instruction	Facilitate Student Centered Activities	Explain	Lecture, Q & A, Didactic Conversation
Connection/Extension	Real World Connections	Elaborate	Real World Connections
Evaluate	Summative/Formative Evidence	Evaluate	Summative/Formative Evidence

Plainly, in the 5E model the process of direct and indirect instruction are switched compared to most traditional models of teaching and learning. Varied nuances exist within the inquiry-based approach associated with the 5E model. Nonetheless, in its simplest form the 5E allows for individual student and whole class "experience" of the phenomenon or content under investigation. Specifically, by allowing "Exploration" prior to direct instruction allows for common explorations and actions that all students participate within. This mitigates the problem that teachers often face of guessing student prior knowledge of a subject. A generalized example could center on the use of a roller coaster (conceptually or physically) to explain kinetic and potential energy. Traditionally, a teacher may start the class during the "warm-up" phase by asking: "Who in class has ever taken a ride on a roller coaster?" In most diverse classroom settings this preface is a crap shoot. A teacher may get several hands of students that have had this experience and focus on them solely to help explain concepts. The problem with this is that the other students are left out of the dialogue and still fail to connect to the concepts about to be taught. In contrast, in a

5E lesson the teacher's job at the start of the class is to "hook" the class, so they may show a clip of an extreme roller coaster or retell a story of riding a roller coaster and have students imagine themselves within that story. Again, in traditional instruction a teacher may begin the next phase of class by lecturing about the concepts of kinetic and potential energy and how they relate back roller coasters. Again, the students that have not had this experience still have nothing to relate to and the content presented is abstract. The most powerful component of the 5E model lies within the "explore" phase which can serve as the "great equalizer" since it puts students on a somewhat common footing with relation to the concepts about to be taught. In the above example, the 5E teacher in the next phase of class would allow students to manipulate a model coaster on a track and observe actions during incline, rest and decline. A technology based lesson, could have the students create an animation of a coaster and have the students again observe the same actions. Lastly, in a resource poor classroom, teachers could have students physically replicate the motion of a coaster by forming a line and going uphill, resting on top and going down the hill. Nonetheless, what hold true in all the examples is whole class participation to preview concepts that are going to be covered. In the next phase of the 5E, when the teacher wants to provide definitions and concepts in direct instruction he or she can cite examples from the activity that everyone just participated within. The 5E is in no way a silver bullet for instructional issues, but its simplicity and power to provide a common experience is an element that any teacher would find beneficial to reach a greater spectrum of students.

Below is a step by step basic lesson of creating simple circuits with a battery, insulated wire and a mini light bulb. The first description is of the traditional model and approach to teaching and learning that is followed by the 5E (+1)model. Differences are then highlighted and at the conclusion of this section the 4P process and its integration are explained.

Step 1

Traditional: Warm-up. Teachers typically preview the content standards associated with circuits and electricity. In addition, questions may be asked about prior knowledge or reviewed from previous classes. The structure of the day's activities is previewed.

5E: Experience and engage. The teacher has to have been exposed to the concept of "playing" with circuits. In addition, to play the experience, the teacher has to think of the materials that students might want to work with, such as different forms of energy and different conductors. One enterprising teacher brought in dog poop for the methane as a source of energy in addition to a battery for students to experiment with. Teachers could also model the concept of circuits by rapidly turning on and off the lights and then asking students if they know how that process works. Students may illustrate their preconceptions of how a light turns on and off. In an obligatory sense, content standards associated with circuits and electricity is previewed without being rote.

Comparison. All too often, traditional K-12 classrooms are started with a standardized procedure of a warm up that focuses on examining the content standard to be previewed and many times homework is reviewed or questions are presented on content that has not been deeply explored. In contrast, the engage phase is suppose to spark interest, by breaking from the norm and flashing the lights and having students provide preconceptions without fear of being wrong such that students can fully engage within the classroom processes about to be undertaken.

Step 2

Traditional: Direct instruction. Transitioning from the warm-up phase, often in traditional instruction a teacher will move to a mode of direct instruction that involves a mixture of lecture and note taking and some question and answering. The motive behind this practice is to build a base of knowledge through verbal communication of concepts that can later be drawn upon. In essence, students are supposed to build a library of factual knowledge that they can later apply in discussion and extensions.

5E: Explore. The explore phase takes a leap of faith by the teacher to allow students to manipulate and investigate the phenomenon. In this example, the students would be provided the simple materials, given the task to light the bulb and draw how they did it, if and when successful. This will set the stage for the next phase by providing a common basis of student experience. The students are encouraged to explore the relative materials in order to pursue a common goal- lighting the bulb.

Comparison. The goal of both processes is to develop a foundation of student knowledge. The difference is that the traditional approach aims to build a basis of factual knowledge first whereas the 5E approach is more of an experiential foundation. Going forward, teachers within both models would attempt to draw upon either facts (traditional) or experiences (5E) in applications and elaborations in the content.

Step 3

Traditional: Indirect instruction. Progressing from the elements of direct instruction, teachers often establish time for students to practice or extend upon the content that was projected in the lecture. This can take many forms based on the content. Examples include, cooperative and collaborative learning and discussion, exploration and or investigation. Using the example above, this is where students would build circuits that are most likely a part of a cookie-cutter lab activity. The purpose of this technique is to allow students to apply or extend their knowledge formed from the prior stage.

5E: Explain. Transitioning from the explore phase, teachers utilizing a 5E model often move to a more traditional mode of direct instruction. The caveat within this phase is that the teacher will utilize a more didactic mode of conversation that draws upon the experiences of the students while tying them to the standards and concepts related to the content. The talking head mode of direct instruction is avoided while students are allowed to provide examples that the teacher can use to explain the traditional concrete concepts of electricity and circuits.

Comparison. The main difference between these phases lies within how they were preceded within the lesson. The opportunity for discovery and exploration is lacking in the traditional model. Students were exposed to what constitutes a circuit and how a light bulb works, this may make the student centered learning portion more of a rote exercise of practice rather a time of creativity, discovery and exploration. In addition, the direct instruction model becomes more robust with the implementation of student perspectives and the ability to draw upon preconceptions. Engagement in this process is increased compared to the traditional talking head mode of direct instruction.

Step 4

Traditional: Connections & extensions. In a traditional model of instruction teachers typically want to establish time to review and make/draw extensions to the student centered indirect instruction. In the example above, a teacher would typically review the lab worksheet and try to review the multiple ways that were discovered to light the bulb but reiterate the key elements. The teacher may then preview complex circuits or relate it to house or building wiring systems.

5E: Elaborate. The elaborate phase is similar to the traditional approach of connections and extensions. Simply, teachers want to extend knowledge and preview and connect related content. Based on student understanding teachers may be able to allow students to explore creating more complex electrical circuits. But at minimum, teachers utilize this time to gauge student understanding and establish critical understanding of concepts.

Comparison. The key differences among this phase may depend on how well students understand concepts based on prior steps. The goal or outcomes of this phase is the same, but the depth of understanding may differ, based mainly on the personal connection that could have been established within the 5E model. In any case, both models need to complete a cyclical nature of reviewing the lessons objectives and outcomes.

Step 5

Evaluate. Any effective instruction will incorporate both formative and summative assessment within lessons and units. In the above example, the traditional model may have students create a summative statement about circuits as "ticket out the door" to end the class. The teacher can later evaluate these statements for accuracy and misconceptions. In the 5E model, the teacher may have the students revisit their preconception and expand upon their initial thoughts. Fluency of ideas can be measured, and originality determined. Teachers can evaluate this work for growth and understanding. Both models could utilize a lab element that grades student participation in creating and documenting successful and unsuccessful models of circuits.

Connection with 4ps

Throughout this lesson, the creative person, place, process and products were supported by teacher actions, using the 5E (+1) model as the structure. In a more traditional lesson, the student is led inexorably to the final conclusion, with little to no input from the student. There is a "wrong" and a "right" set of knowledge and skill development sequence. In the development of creativity within the science classroom, students are encouraged to actively participate within the process, developing the knowledge and skills as a result of the need to solve the problem, rather than the problem supporting the acquisition of limited knowledge and skills.

CONNECTING SCIENCE WITH CREATIVITY

In 1957, spurred by the launch of Sputnik, United States schools launched an effort to recruit the best and the brightest American minds to form a new generation of leaders and innovators in science and engineering. It was an effort that ended too quickly. By 1983, the Nation at Risk report noted that the ideal of academic excellence as the primary goal of schooling had faded across the board in American education. The next 25 years has not changed the essential nature of schools.

Recent reports warn that our world cannot progress with a work force that has mastered only minimum competencies. Reiterating a nation's interest in developing creative youth, Florida (2005) notes that it is the creative graduate who is the most highly sought-after commodity and valuable resource pursued by global economies. The National Science Board recommends that today's educational programs 1) Provide opportunities for excellence, 2) cast a wider net, and 3) foster a supportive ecosystem (NSB, 2010). "Tough Choices or Tough Times", a report from the

National Center on Education and the Economy (2006) noted that students of the future "will have to be:

- comfortable with ideas and abstractions,
- good at both analysis and synthesis,
- creative and innovative,
- self-disciplined and well organized,
- able to learn very quickly, and
- work well as a member of a team, and
- have the flexibility to adapt quickly to frequent changes in the labor market as the shifts in the economy become ever faster and more dramatic" (p. 8).

Today's world problems can only be solved using new strategies. Yet, our school systems are often so focused on bringing all students to a single point of instruction or developing a single set of skills, that the process of learning has been reduced to a single method of instruction, contained within a teacher's manual. Recent teacher surveys indicate that 65% of teachers have never received any information or training about how to develop creativity (Farkas & Duffet, 2008). The P's and E's model integrates two distinctly unique processes of instruction: science content instruction with the development of creativity. It is our hope and goal that teachers use this model to design a variety of science lessons and units that will allow students to explore, create, and ultimately, learn how to find and solve problems- all with a spirit of deep engagement and appreciation for the joy and wonder of exploring.

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