

STEM PROJECT-BASED LEARNING

STEM Project-Based Learning

An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach

Second Edition

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PREFACE: OVERVIEW FOR THE DESIGN OF STEM PBLS

Well-Defined Outcome and Ill-Defined Task

Our definition for STEM PBL drives all of the design and implementation decisions discussed in this book. Therefore, a quick deconstruction of our definition is useful prior to reading through the chapters, reviewing our sample PBLs or designing your own.

As we were conceptualizing the book we did not want anyone to have to read the book in its entirety before beginning the planning and implementation process. Instead, we envisioned strategic reading or just in time reading. We believe the layout of the book is mostly sequential, following the 7 Design principles. We also wanted chapters to be readily accessible when questions arise during the implementation phase. So in Chapter 1 we intend that this chapter will help to explain what STEM PBL is and the rationale for using it for classroom instruction. Chapter 2 highlights the humble roots of STEM PBL and carefully articulates the history of the project method of instruction. In Chapter 3, it covers the theoretical underpinnings for designing STEM PBL activities and then to build on your first endeavor. Chapter 4 can be used to continually improve your projects. Once you build your own PBL and you want to start getting colleagues involved it provides the who, where, and when for using STEM PBL instruction. Once you have colleagues on board it is important to deal with the issues surrounding interdisciplinary teaching and learning in Chapter 6. Then as a team of teachers begins to build toward fully implemented projects it is essential to understand the relationship between Inquiry Learning and STEM Project Based Learning and questioning. Chapter 8 details the important role technology plays, not as an add on, but as the means for facilitating the teaching and learning process. No book on STEM PBL or chapter on technology would be complete without the topic of virtual worlds. The power of virtual worlds can energize STEM PBL instruction and maximize learning while providing important learning affordances. Because there are so many tangible instructional possibilities it is important to think about STEM PBL as an educational tool for all children, and Chapter 10 details the possibilities for Exceptional and Diverse Learners. Whenever a teacher tries to implement a new teaching method he or she often marks his or her success by the students' behavior and not by an objective examination of the effect on student learning. So because students will likely have to learn how to learn in a STEM PBL environment Chapter 11 details classroom management considerations. Hand in hand with classroom management are concerns for assessment, how, when, and what are explained in Chapter 12. The final two chapters deal with two issues of paramount importance, English Language Learners. These two topics are essential because STEM PBL should be for all learners and can incorporate what happens in the Social Studies class as well as be implemented into the social studies class. Finally, we provide many sample rubrics, forms, guidelines, samples, and preparation documents to assist you in implementing STEM Project Based Learning.

Well-defined outcome – The well-defined outcome comes from the dual influence of the engineering design process and high-stakes accountability and standards. An engineer always starts with an end in mind (e.g., span this river, minimize fuel consumption, etc.) and in today's high stakes testing environment so should designers of instruction. Our STEM PBL design process always begins with a measurable object in mind and typically includes the design of summative assessments prior to instructional design to ensure that the students will in fact meet the objective. In the best scenario, these summative assessments will include open-ended assessments that look a great deal like learning activities from the PBL and multiple choice questions that are similar in style and content to local, state, and national assessments that students will be taking in the future. This is NOT teaching to the test, it is designing to the objective.

Because the majority of our work is in the state of Texas, we have chosen to use Texas state standards (<http://www.tea.state.tx.us/teks/>) to model our design process but other local, state, or national standards that guide your instruction would be the beginning of your *well-designed outcome*. All of our STEM PBLs start with a well-defined outcome (could have been labeled as the primary objective). The well-defined outcome was developed through the integration of the secondary objectives and it is the integrated well-defined outcome that initiated the design process, informed our summative assessment design and all subsequent instructional design decisions. The secondary objectives are crucial as they define the integration and provide the STEM for our PBL. Group planning is also encouraged by including substantive secondary objectives. Secondary objectives are assessed to varying degrees (formative and summative) depending upon the intent of

PREFACE

their inclusion. Please resist the temptation to pull a single concept out of a secondary objective and implement the PBL with that as the primary objective. If you change the well-defined outcome, you will need to change the PBL.

Ill-defined task(s) – The ill-defined task(s) are essential to the inquiry process. Too often, hands-on activities are verification of known - or at least taught – concepts. The ill-defined nature of STEM PBL requires higher order thinking skills, problem-solving, and increased content learning. One misconception about PBL in general is that it is chaotic or haphazard. Nothing could be further from the truth. Ill-defined is not ill-designed. The teacher must design tasks that allow for student investigation, multiple solutions, and engaging contexts all of which converge in a common understanding of the ill-defined outcome.

Putting it all together in a STEM PBL classroom – As a teacher, you and your students will need practice and support as you transition to STEM PBL tasks and learning. A simple suggestion, which may hasten the transition, is an extended 5-E model of instruction. We have chosen to use the 5-E model to communicate our design, but recognize that there are other appropriate inquiry models that can be modified to fit STEM PBL. Resist the temptation to tell the students what they are going to learn, let them learn it! But plan to let your students talk, plan to talk yourself, just don't talk first, last, or the most. We have included a limited number of examples of STEM PBLs that we have used in the past and recommend as well-tested exemplars for you as you learn to design and implement STEM PBLs. This is not a comprehensive list and we do not think that providing one would dramatically improve your chances of implementing STEM PBL. Your local and state standards are different, your resources are different, your potential partners are different ... and thus your STEM PBLs should be different. Good luck!

ROBERT M. CAPRARO AND SCOTT W. SLOUGH

1. WHY PBL? WHY STEM? WHY NOW? AN INTRODUCTION TO STEM PROJECT-BASED LEARNING: AN INTEGRATED SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) APPROACH

INTRODUCTION

The belief that all genuine education comes about through experience does not mean that all experiences are genuinely or equally educative. (Dewey, 1938, p. 25)

STEM Project-Based Learning (PBL) requires a professional teaching force empowered with the skills necessary for designing learning experiences that maximize student potential. Therefore, effective STEM PBL requires teachers to experience high quality professional development to learn how to design high quality experiential learning activities. Not all professional development activities are created equal (Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001) and not all enactments meet the expectations of high quality professional development (Capraro, Capraro, & Oner, 2011; Capraro, & Avery, 2011; Han, Yalvac, Capraro, & Capraro, 2012).

Science, Technology, Engineering, and Mathematics (STEM) Project-Based Learning (PBL) integrates engineering design principles with the K-16 curriculum. The infusion of design principles enhances real-world applicability and helps prepare students for post-secondary education, with an emphasis on making connections to what STEM professionals actually do in their jobs. Our view of STEM learning is one in which the fields are all supportive and integrated where applicable with the design principles in Chapter 4 undergirding the problem solving processes contained in the project.

This book discusses STEM PBL and establishes a set of expectations for implementing STEM PBL. You may want to skim some chapters reading those chapters that hold promise to answer questions you already have while reserving some chapters for when you encounter questions as you implement STEM PBL in your own classroom. This brief chapter will outline some of the vocabulary, discuss the basic tenets of STEM PBL, and familiarize the reader with what to expect from implementing it in their school.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- the nature of STEM Project-Based Learning
- STEM PBL concepts and terminology

When you complete this chapter you should be able to:

- communicate using STEM PBL terms
- explain the basic tenets of STEM PBL
- make informed decisions about which chapters to read first

OVERVIEW OF STEM PBL

Why PBL?

Project-Based Learning has been around for many years and it has been undertaken in medicine, engineering, education, economics, and business. Project-Based Learning is often shortened to PBL, but this acronym is often confused with problem-based learning. The two terms are not synonymous. In this book, we endeavour to keep problem-based learning in lower caps to help you, the reader, differentiate the two when it is

necessary for us to discuss problem-based learning. Project-Based Learning is broader and often is composed of several problems students will need to solve. It is our belief that PBL provides the contextualized, authentic experiences necessary for students to scaffold learning and build meaningfully powerful science, technology, engineering, and mathematics concepts supported by language arts, social studies, and art. STEM PBL is both challenging and motivating. It requires students to think critically and analytically and enhances higher-order thinking skills. STEM PBL requires collaboration, peer communication, problem-solving, and self-directed learning while incorporating rigor for *all* students. STEM PBL builds on engineering design as the cornerstone and as the foundation on which students bring their compartmentalized knowledge of science, technology, and mathematics to bear on solving meaningful real-world problems.

Why STEM?

The idea of PBL is not new; however, what is new is the emphasis on STEM education and linking secondary education with post-secondary practices. It is common in post-secondary institutions for students to be required to work in groups to solve complex problems situated within larger projects. While problems and projects do not necessitate convergent solutions, students are required to explain their solutions and to be able to justify the suitability of a proposed solution to the specifications of the PBL. Commonly, this process has been termed problem solving and it is often expected to be taught in mathematics classes. However, STEM professionals engage in complex problem solving and in most cases there are multiple possible solutions each with its strengths and limitations. Therefore, it is important for secondary students to develop broad knowledge that allows them to be successful on high-stakes tests, but also develop the depth of knowledge to allow them to reflect on the strengths and limitations of their solutions. The STEM PBL process develops critical thinkers who will be more likely to succeed in post secondary institutions where these skills are essential. The focus on STEM in this book is different than most definitions that continue to consider STEM as four discrete subjects. STEM PBL acknowledges that learning and job success is interdependent and that expertise is built iteratively across all subjects, even when one has a particular focus one more than any other. Therefore, job success is dependent on the interaction of knowledge from within each and also across STEM disciplines. So student learning settings and expectations should mimic this very complex learning design – at least in part.

An additional advantage to integrating STEM and PBL is the inclusion of authentic tasks (often the construction of an artifact) and task-specific vocabulary through the inclusion of design briefs. After identifying the learning goals, the teacher develops expectations for the authentic task to be completed or the artifact to be constructed along with the necessary constraints to establish boundaries for the learning. The constraints are often included in the design brief and are the most basic of requirements often considered essential. Therefore, not meeting the constraints would indicate an inadmissible attempt. The design brief contains both the constraints and the criteria informed by knowing exactly which objectives or standards students will be expected to master. The criteria are measurable. These criteria help students know how they are progressing on the tasks and it is these criteria that inform assessment. In fact, it is the criteria that form the basis of all assessments used throughout the PBL.

Why Now?

As the pressures build and the pressure from external constituents force schools to relegate good teaching to the back burner while putting testing for accountability front and center, there must be an instructional model that provides students with high value tasks that foster rigorous subject matter engagement. We define STEM PBL as an *ill-defined task within a well-defined outcome situated with a contextually rich task requiring students to solve several problems which when considered in their entirety showcase student mastery of several concepts of various STEM subjects*. Well-defined outcomes include clear expectations for learning connected to local, state, and national standards *and* clearly defined expectations and constraints for the completion of the task. The ill-defined task allows students the freedom to interpret the problem, constraints, and criteria informed by their subject area knowledge to formulate diverse solutions that will meet the well-defined outcome. STEM PBLs engage students in authentic tasks that result in specific learning essential in the current standards-based educational model, while connecting K-12 and post-secondary education and addressing the future workplace learning needs.



Building a Common Language

It is important to understand what is meant by somewhat common terms in relation to STEM PBL. For example, “brainstorming” is commonly used to simply generate ideas and not engage in the evaluation of any particular one. In addition, in PBL, brainstorming is used as a pedagogical technique to establish teams and encourage a common focus. It is during brainstorming sessions that teams develop shared knowledge and a group dynamic that will serve as the incubator for their work together and eventually will lead to their unique solution. The term relevance has to have many meanings, the usefulness of the education to life-long learning, meaningfulness to self, importance to society, real-world applicability, and finally the formation of moral decision making. In STEM PBL, relevance is not an oversimplification of these ideas just a prioritization that is used to align learning with formal standards or student expectations. So in STEM PBL we talk about educationally relevant and it is this educational relevance that facilitates the development of rigorous and challenging experiences for students.

An important consideration when deciding to adopt STEM PBL is that of the interdependent nexus of learning objectives, assessment, and student learning. It is common to refer to student objectives. The phrase “student objectives” has come to be interpreted in behavioristic terms. STEM PBL would be considered the polar opposite to behavioristic paradigms of teaching and learning, therefore, we use the term student expectations or SEs. We feel the term SEs is not laden with prior notions, but still conveys the message that teachers must use some form of objective, national or state standard, learning goal, or performance expectation in order to align teaching, learning, and assessment in this era of accountability. So rather than be stereotyped into a specific paradigm the perspective of this book is to accommodate many views and regardless of personal perspective, one can fit those views for describing what students will learn in STEM PBL.

Given the importance of establishing SEs, it is essential to also use some form of assessment to determine the extent to which students master the learning goals. PBL is well suited to rubric assessment but NOT to the exclusion of other forms of assessment. It is important to have a mix of assessments and to build student experience with as many forms of assessment as possible.

Many schools that adopt STEM PBL also establish a professional learning community (PLC). A PLC can be an important and very productive school-based initiative that provides for and sustains STEM PBL. The formation of a PLC facilitates discussion about roles and responsibilities, establishes group norms, and sets expectations for everyone involved in the PLC. Often PLCs have stakeholders from across the continuum, but it is just as common for school-based PLCs to have representation from a more limited set of stakeholders.

What Is Engineering Design and Why in K-12

Engineering design has many forms with varying numbers of steps. There is no single foundational model broadly accepted across all engineering schools or practicing engineers. Some engineering design models have as few as three steps while others can have 10 or more. Some engineering designs are partially linear with iterative portions, but some are completely iterative while others are hierarchical and linear. The steps are often formulated to meet specific needs. Our model depends heavily on its intended purpose, teaching and learning that rely heavily on problem solving and internalizing or learning new content. This is different from many other models with the intended purpose being quality control, parsimony of resources, elegance, or applicability.

The Flow of the Book

The book is designed to provide a modern STEM approach to PBL that is informed by research. It covers the typical major topics, but also includes a historical perspective, a modern perspective on assessment that works in symbiosis with high-stakes testing, and includes insights into the formation of PLCs and their impact on sustaining school change. It is not written as prescription or novel, we hope readers select chapters as they journey from dabbling in STEM PBL to mastery. This new edition is in a new format that allows duplication of the worksheet pages, lessons, rubrics, and observation instrument. We hope the new format is helpful to both teachers and workshop providers.

Vocabulary for Reading the Book

Constraint. Parameters established as part of the project to structure the deliverables of a PBL event. Constraints are placed on the design process and the product. Constraint is not synonymous with criteria. A constraint could be that a presentation must include research and contain a marketing component that lasts no more than three minutes, no two puzzle pieces can be the same, the boat must float for 2 minutes, or materials cannot be cut. All constraints must be met to have an admissible project.

Criteria. Items written to support specificity that can be ranked or may demonstrate the continuum between expert and novice knowledge of the learning outcome. Generally, it is these criteria that function as part of the assessment component. Designer defined criteria are used to select among plausible designs and may include a wow factor, personal insights, complexity, novelty, or cost.

Design Brief. The parameters for a PBL. The design brief contains the constraints, establishes criteria, may or may not establish evaluation standards, clearly communicates the deliverables, and outlines the conditions under which the PBL inquiry occurs.

Problem-based learning. PBL for the purposes here is the use of a problem statement that both guides the learning and any resultant activities to explore the topic. Generally, PBL is context rich but textually and informationally impoverished. The focus of learning is on individual and groups to (a) clearly identify what information they need to solve the problem and (b) identify suitable resources and sources of information.

Professional Learning Community (PLC). Communities of practitioners, students, administrators, community stakeholders, and district personnel whose mission is to facilitate the teaching and learning process where the goals are to establish common language, expectations, standards, to facilitate increased student outcomes. It is also not uncommon to have a more limited set of stakeholders depending on the level of district commitment.

STEM Project-Based Learning (PBL). An ill-defined task with a well-defined outcome situated within a contextually rich task requiring students to solve several problems, which when considered in their entirety, showcase student mastery of several concepts of various STEM subjects. PBL here is the use of a project that often results in the emergence of various learning outcomes in addition to the ones anticipated. The learning is dynamic as students use various processes and methods to explore the project. The project is generally information rich, but directions are kept to a minimum. The richness of the information is often directly related to the quality of the learning and level of student engagement. The information is often multifaceted

and includes background information, graphs, pictures, specifications, generalized, and specific outcome expectations, narrative, and in many cases the formative and summative expectations.

Relevance. Refers to the real-world connections that should be fostered in each PBL, it is also associated with facilitating student development of a personal connection to the project and fosters “buy-in” for solving individual problems presented in the project.

Rubric. May be co-developed with the students before the project starts and provides clear criteria that rank the extent to which a team or individual meet the expectations. Multiple rubrics can be developed to assess cooperation, collaboration, presentation, content, completeness, language, visual appeal, and marketing. The evaluator can be the individual, peers, teacher, administrator, or external stakeholder.

Small Learning Community (SLC). These are formed by ensuring that all the content area teachers (mathematics, science, social studies, reading/language arts) teach the same students and have common planning, behavior management plans, and performance expectations. SLC affords teachers the opportunity to become better acquainted with students and improves communication among teachers about student progress on common issues.

Student Expectations (SEs). Specify learning goals where the focus is on the verbs. Clearly defined student expectations facilitate the alignment of teaching, learning, and assessment.

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2. THE PROJECT METHOD IN HISTORICAL CONTEXT

INTRODUCTION

Project-Based Learning (PBL) has been a long tradition in America's public schools, extending back to the 19th century to the work of Francis W. Parker and John Dewey. As a method for general education, the idea of project-based classroom instruction was co-opted from agriculture and the industrial arts and, after first being applied in the elementary schools, was extended to all grade levels. Initially focused on "real-world" problems with tangible, measurable outcomes, the project method was quickly adopted and applied to any activity of interest to students, however transient and/or insignificant. The lack of a succinct definition for the project method has prevented the assessment of its success, regardless, the "method" became the "current" model of instruction in all subjects for all students, often failing to meet the needs of children, teachers, or society. The project method, as a descriptive term for school *practice*, was replaced with child-centeredness and the activity curriculum. After a period of near obscurity, PBL has been reclaimed by educators to educate 21st-century students.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- the origins of the idea of the Project Method
- the early applications of the Project Method
- reasons why the Project Method failed to have a lasting influence in 20th-century education practice

When you complete this chapter you should be able to:

- explain the origins of the Project Method
- identify some of the major proponents of the Project Method
- explain how the lack of a clear definition of the Project Method contributed to its decline in the public schools
- explain how the idea of the Project Method changed into the ideas of child-centeredness and the activity curriculum

In this chapter, the authors present (1) a brief history of the project method, both before and after Kilpatrick's widely read and cited article and (2) some of the issues related to the application of the project method in public school classrooms. We also examine the definition of "project" and how that definition was applied to the use of the project method in the school.

When William Heard Kilpatrick published "The Project Method" in the *Teachers College Record* in September of 1918, he started the piece saying, "The word 'project' is perhaps the latest arrival to knock for admittance at the door of educational terminology" (p. 319). He also posed the following two questions:

... is there behind the proposed term ... a valid notion or concept which proposes to render appreciable service in educational thinking? Second, if we grant the foregoing, does the term "project" fitly designate the waiting concept? (p. 319)

Kilpatrick's questions encompassed the whole range of issues related to the "project method," both its history and application to practice. Over the next five years, many authors offered definitions and explanations for the project method and how it should be enacted in schools. However, the definitions were diverse enough to encompass almost any instruction and failed to give teachers specific criteria against which they could measure their practice and, in the end, satisfied neither the theorists nor the practitioners.

Kilpatrick is frequently cited as one of the most popular professors and often criticized scholars of the Progressive Era; ultimately, his career spanned six decades (Cremin, 1961, p. 220; Kliebard, 1986, p. 176; Ravitch, 2000, p. 178). At the time that he published "The Project Method," however, Kilpatrick was struggling to earn a promotion to full professor at Teachers College at Columbia University. Before joining the faculty in 1911, Kilpatrick had been a student at Teachers College, studying under Dewey. Consequently, Dewey pragmatism and experiential learning philosophy shaped Kilpatrick's pedagogical theories and, more specifically, his approach to the project method (Cremin, 1961, p. 215). The attachment of Kilpatrick to the project method in twentieth century educational literature is due to the fact that his article was reprinted tens of thousands of times all over the world (Cremin, 1961, p. 217; Kliebard, 1986, p. 159). Despite being identified as the father of the modern project method, Kilpatrick readily acknowledged that he is a late comer to the use of the term project, that he is unaware of its heritage, but that he sees value in using the term. "I did not invent the term nor did I start it on its educational career. Indeed, I do not know how long it has already been in use. I did, however, consciously appropriate the word to designate the typical unit of the worthy life described above?" (1918, p. 320).

Although Kilpatrick is unconcerned with pinning down the beginnings of the project method, other authors have located the origin of the term in agriculture, manual training, and domestic science (Horn, 1922), or with Dewey and others at Chicago and Teachers College (Parker, 1922b). Parker (1922b) also credits Francis W. Parker and C. R. Richards for popularizing the idea of pupil planning as part of the project process as early as 1901 (pp. 427-429). von Hofe (1916) wrote, "The sixth-grade pupils in the Horace Mann School are studying science regardless of every artificial division. The class chooses a project, something that has attracted attention and in which they are vitally interested. The teacher then presents the information to follow not the so-called logical development found in textbooks but the trend of thought of the pupils" (pp. 240-241). While not defining the practice as a "method," von Hofe described a practice that would shortly become popularized as the project method.

Writing in 1997, Knoll states

Recently, however, historical research has made great progress in answering the question of when and where the term "project"- "progetto" in Italian, "projet" in French, "projekt" in German, and "proekt" in Russian-was used in the past to denote an educational and learning device. According to recent studies, the "project" as a method of institutionalized instruction is not a child of the industrial and progressive education movement that arose in the United States at the end of the 19th century. Rather it grew out of the architectural and engineering education movement that began in Italy during the late 16th century (Knoll 1991a, 1991b, 1991c; Schöller, 1993; Weiss, 1982). The long and distinguished history of the project method can be divided into five phases:

- 1590-1765: The beginnings of project work at architectural schools in Europe.
- 1765-1880: The project as a regular teaching method and its transplantation to America.
- 1880-1915: Work on projects in manual training and in general public schools.
- 1915-1965: Redefinition of the project method and its transplantation from America back to Europe.
- 1965-today: Rediscovery of the project idea and the third wave of its international dissemination (Knoll, 1997).

Still others push the origins back to the "Sloyd" system of manual training, which emphasized domestic projects for the purpose of building neatness, accuracy, and carefulness, and a respect for labor in a social context (Noyes, 1909). Sloyd education first took root in 1865 in Finland under the influence of Uno Cygnæus, a devoted follower of Froebel and Pestalozzi – but gained widespread popularity at Otto Salomon's school in Naas, Sweden (MacDonald, 2004, p. 306). During the 1870s and 1880s teachers and scholars from around the world traveled to Naas to undergo Salomon's courses in sloyd. According to one such scholar, Evelyn Chapman (1887), Salomon's *educational sloyd* was introduced into "France, Belgium, Germany, Austria, Russia, and the United States" and "even far-distant Japan" (p. 269). Given Cygnæus's admiration for Froebel, it is perhaps unsurprising that Chapman goes on to draw a connection between sloyd and kindergarten, "... in the adoption of the kindergarten system, the very soul of which is its response to the child's need of activity and production; and sloyd is the same principle at work, only in a form suited to the growing powers of our boys and girls" (p. 269).

In the United States, perhaps the most prominent example was the Sloyd Training School for teachers in Boston, Massachusetts. According to its founder and principal, Gustaf Larsson (1902, p. 67), approximately 22,000 pupils were receiving instruction from its graduates in the year 1900. Notwithstanding, while there are clearly overlapping themes between the project method and educational sloyd, the extent to which sloyd influenced the project method remains unclear.

Unconcerned with these historical considerations, Kilpatrick's goal in his article was to lay out the pedagogical and psychological principles of learning on which the idea of the project was based and provide direction to teachers. He goes on to say that the purposeful act is the basis for a worthy life and that we admire the "man who is master of his fate, who with deliberate regard for a total situation forms clear and far-reaching purposes, who plans and executes with nice care the purposes so formed. A man who habitually so regulates his life with reference to worthy social aims meets at once the demands for practical efficiency and moral responsibility" (1918, p. 322). Kilpatrick, following the idea of Dewey and others that school is not for life but is life, continues to explain the value of a purposeful act, "As a purposeful act is thus the typical unit of a worthy life in a democratic society, so also should it be made the typical unit of school procedure. ... education based on the purposeful act prepares best for life while at the same time it constitutes the present worthy life itself" (1918, p. 323). Dewey's thought is often difficult to pin down, but the roots of Kilpatrick's ideas are consistently evident in Dewey's writings of the late nineteenth and early twentieth centuries. In fact, in his most notable work on education, *Democracy and Education*, Dewey quite directly connects education as a purpose of life. In one of his more concise statements on the issue he says, "The continuity of any experience, through renewing the social group is a literal fact. Education in its broadest sense, is the means of this social continuity of life" (Dewey, 1916, p. 2).

In his 1997 article, Knoll summarized Kilpatrick's ideas on the project

Kilpatrick (1925) defined the project as a "hearty *purposeful* act." "Purpose" presupposed freedom of action and could not be dictated. If, however, "the purpose dies and the teacher still requires the completion of what was begun, then it [the project] becomes a task"-mere work and drudgery (Kilpatrick, 1925, p. 348). Thus, Kilpatrick established student motivation as the crucial feature of the project method. Whatever the child undertook, as long as it was done "purposefully," was a project. No aspect of valuable life was excluded. Kilpatrick (1918) drew up a typology of projects ranging from constructing a machine via solving a mathematical problem and learning French vocabulary, to watching a sunset and listening to a sonata of Beethoven. In contrast to his predecessors, Kilpatrick did not link the project to specific subjects and areas of learning such as manual training or constructive occupations; the project did not even require active doing and participating. Children who presented a play executed a project, as did those children sitting in the audience, heartily enjoying it.

Despite Kilpatrick's efforts to ground the project method in Dewey's thought, seldom in the many articles and books that followed and explanations of the method of the project does one find either the connection between the purposeful act (the project) and preparation for democratic life or that education is life; the first seemingly is ignored, the second seemingly a given. One difficulty adopters of the project method encountered was, in addition to the attempt to apply a method used in manual training and agriculture to academic subjects and questions of its applicability to non-manual subjects (Ruediger, 1923), was the lack of a concise definition. Several authors questioned the appropriateness of the method for academic subjects. Ruediger found the project method inappropriate, writing

The fact that the project idea in its original meaning is not applicable to the teaching of academic subjects has given rise to a number of interesting yet confusing developments. As used in agricultural education, the project has reference to the use of productive activities for teaching purposes. ... something of objective significance is produced. A genuine vocational activity, somewhat circumscribed perhaps, is used for educative purposes. When we come to the academic subjects this idea of a project is not so easily realized. In reading, in arithmetic, in geography, and in history it is not easy for the pupil to produce something of inherent significance, something that society values regardless of personal sentiment. (p. 243)

Horn's criticism of the project method also went to the motivation and appropriateness of the application of the method to academic subjects. "The most serious confusion in recent years has resulted from the teaching of those who define the 'project' as a wholehearted, purposeful act project by children" (1922, p. 95) showed Horn's concern for the lack of preciseness and relationship to social utility and purpose. He wrote, in his 1922 article, that the original purpose of the project had been ignored and student interest and choosing had become guiding principles, rather than the nature of the project.

The worth of such "projects" [referring to traditional projects such as baking a cake, raising a plot of corn, building a bookcase] was measured by the degree to which they duplicated projects and activities found in life, by the degree to which they use the best materials and best methods, and by the degree of success that resulted. These "projects" may be defined as highly practical, problematic activities taken in

their natural setting and involving the use of concrete materials, usually in a constructive way. They are to be distinguished, in general, from other school activities in that: (1) they are organized more directly about the activities of life outside the school; (2) they are more concrete; and (3) they afford a better test of working knowledge. (p. 93)

Despite his best efforts, Kilpatrick contributed to the uncertainty of what is a “project” when he wrote

[T]he richness of life depends exactly on its tendency to lead one on to other like fruitful activity; that the degree of this tendency consists exactly in the educative effect of the activity involved’ and that we may therefore take as a criterion of the value of any activity – whether intentionally educative or not – its tendency to directly or indirectly to lead the individual and others whom he touches on to other like fruitful activity. (1918, p. 328)

It is the special duty and opportunity of the teacher to guide the pupil through his present interests and achievement into the wider interests and achievement demanded by the wider social life of the older world. ... Under the eye of the skillful teacher the children as an embryonic society will make increasingly finer discriminations as to what is right and proper. ... The teacher’s success – if we believe in democracy – will consist in gradually eliminating himself or herself from the success of the procedure. (1918, pp. 329-330)

Here then Kilpatrick sets the stage for the removal of the teacher from the process of choosing activities but this only occurs after the child has developed skill and knowledge necessary to choose wisely. The developed abilities of the child become less important than the child’s interest in later publications explaining the project method.

Kilpatrick is true to his ideas when he defined the project “to mean any unit of purposeful experience, any instance of purposeful activity where the dominating purpose, as an inner urge, (1) fixes the aim of the action, (2) guides its process, and (3) furnishes its drive, its inner motivation. The project thus may refer to any kind or variety of life experience which is in fact actuated by a dominating purpose” (Kilpatrick, Bagley, Bonser, Hosic, & Hatch, 1921, p. 283). This broad definition thus became the justification for most any type of educational activity that either motivated students or students said motivated them to learn, regardless of the social utility of the product or the ability of students to benefit from the activity or their maturity to allow them to conduct the activity.

Parker, in one of his 1922 articles, provided the briefest definition of project teaching by writing, “A pupil project is a unit of practical activity planned by the pupils” as a way of summarizing his longer definition of

The central element in project teaching is the planning by pupils of some practical activity, something to be done. Hence, a pupil-project is any unit of activity that makes the pupil responsible for such planning. It gives them practice in devising ways and means and in selecting and rejecting method of achieving some definite practical end. This conception conforms with the dictionary definition of a project as “something of a practical nature thrown our for the consideration of its being done” ... Furthermore, it describes with considerable precision a specific type of improved teaching that has become common in progressive experimental schools since 1900. (1922a, p. 335)

Parker thus places the interest of and planning of action by the student as the central tenet of the project method. He defines practical as “not theoretical” but does not ground the practical in utility or social purpose beyond that desired by the student.

Parker (1922a) reported, as an example of project teaching, a historical construction project where fifth-grade students constructed a castle from cardboard to illustrate life in the medieval period and wrote a poem and play concerning their work. Here one sees an example for which Ruediger later criticized the project method as producing something with no inherent significance but, which Parker justified, because he believed it had high motivational value.

Freeland, once a student teacher supervisor and principal of the teacher training school at Colorado State Teachers College, makes little distinction between problem and project teaching and wrote of their relatedness by first defining the problem method and then the project.

The problem is used to appeal to and develop the child’s thought (p. 6). ... The project may be defined in relation to the problem as something the child is interested in doing and which may involve thinking, but need not always do so. ... If it involves much thinking, it may contain problems (Freeland, 1922, p. 7).

[T]he project is different from the problem in that its essential feature is the provision of something to organize, investigate, or accomplish, rather than to stimulate thought. It may be a problem or part of a problem, and it may embrace problems. The more good problems a project affords the better it is for educational purposes. To afford something to do, the project must necessarily arise from the interests of the children. (Freeland, 1922, p. 45)

Freeland then still intends teachers to focus on the nature of the instructional act rather than focusing on the interest or intentions expressed by students. “The distinct advantage of the project method over the old topic or question and answer method is that it provides for continuous work on the part of the pupil rather than assignment from day to day” (p. 46).

The idea of definition became, to later authors, less of an issue than the adoption of the philosophy of the project method and its focus on children’s interests. Hosic and Chase, an associate professor and Teachers College and elementary school principal respectively, wrote in the Preface to their book, *Brief Guide to the Project Method*, “There is a limit to the amount of abstract theory which workers in the schools, and students preparing to join them can assimilate and apply” and “However imperfectly we have interpreted the project method, we believe that it is a fruitful concept of living, learning, and teaching, destined to influence profoundly the educational practices of the future, and that for good” (1924, p. iii). They conclude their introductory chapter with the sentences

[T]he Project Method means providing opportunity for children to engage in living, in satisfying, worth-while enterprises – worth-while to *them*; it means guiding and assisting them to *participate* in these enterprises so that they may reap to the full the possible benefits. ... The Project Method, then, is a point of view rather than a procedure. [emphasis in original] (1924, p. 7)

In his 1926 book, *Modern Methods in High School Teaching*, Douglass, devotes separate chapters to Problem Teaching (chapter 10, pp. 295-322) and Project Teaching (chapter 11, pp. 324-356) making a clear distinction that projects could include problems and that problems could, at some point, become projects (pp. 324-325). Douglass, while making a distinction, sees the classification of an activity as a “problem” or a “project” as something teachers should not spend a lot of time on.

The underlying principles of procedure for problems and projects are essentially the same. Problems and projects possess very much the same values, and the merits of them as teaching procedures are based on the same psychological facts. It is not necessary, or desirable even if possible, to attempt here to draw a sharp distinction between the two. (p. 324)

Teachers are inclined to waste much valuable time in quibbling over what technically constitutes a project and what does not. An activity may technically constitute a project and yet be a very inferior educational activity. Merely being a project does not necessarily carry with it merit. A good problem, yes, even a good, old-fashioned, arbitrary, autocratic, daily assignment and recitation, is a much better teaching procedure than a poorly managed project. Not much good can come from merely learning the definition of a project. What is important for teachers is to appreciate the psychological principles which lie behind the project, and which account for its merit and effectiveness. (p. 326)

A little over 20 years later, in another version of the text, Douglass and Mills (1948) devote only 8+ pages to the project method as a part of a chapter on Teaching Units of Learning and 9+ pages to problem teaching as part of a chapter on Questions and Problems in Teaching. The authors cite Douglass’ 1926 definition of project in describing a project. “The project as used in a teaching is a unit of activity carried on by the learner in a natural and lifelike manner, and in a spirit of purpose to accomplish a definite, attractive, and seemingly attainable goal” (Douglass, 1926, p. 325; Douglass & Mills, 1948, p. 209).

Although early in his 1918 article, Kilpatrick emphasizes the connection between a whole-hearted purposeful activity and the social environment in which the activity takes place (p. 320), the ideas of whole-hearted and purposeful came to dominate the defining attributes of the activity.

And, while in 1918, initially emphasizing the necessity or importance of individualized self-directed motivation on the part of the student in choosing the purposeful activity, by the time he writes his 1925 book, *Foundations of Method*, Kilpatrick he has accepted the fact that the teacher may have a role in the planning and encouragement of interest in the project “We have, so far, not based any argument on the child’s originating or even selecting (in the sense of his deciding) what shall be done. So far, all that we have claimed will be met if the child whole-heartedly accepts and adopts the teacher’s suggestion” (1925, p. 207).

Douglass adheres more closely to Kilpatrick's original statement on self-selection as he includes as one of the characteristics that a project must include as "The learner approaches the task in an attitude of purposefulness; it is a self-imposed task, rather than one imposed arbitrarily by the teacher or the course of study" (Douglass, 1926, p. 325). Douglass does not however ignore the role of the teacher in planning and assisting students in the selection and management of projects. "As in the case with any teaching procedure, the project method in itself does not provide a complete educative situation. Merely having students purposing, planning and executing projects may or may not be good procedure, depending upon what projects are being completed and the nature of the procedure followed" (p. 341). This statement was followed by 8 criteria a teacher should use in selecting projects.

By the mid 1920s, the project method, which seemingly had something for every student and teacher, had been used to justify the child-centered and activity movements where all curricular plans were to begin with the interests of the child, even if the child was not motivated to have interests. These concerns were not missed by those promoting the project method, even as the idea of the project was being developed. Bonser, an associate professor at Teachers College wrote

A second danger of misinterpretation is that of assuming that all expressed interests of children are of equal worth. By such an interpretation, that which is trivial or relatively insignificant is permitted to divert efforts from activities which in themselves lead to higher levels of interest and worth. ... One very important function of the teacher is to select and direct interests and activities of children so that they may continuously lead forward and upward to higher stages. (Kilpatrick et al., 1921, pp. 298-299)

In attempting to use the interests of children, many teachers are tempted simply to "turn the children loose," and to allow them to follow any interests which they individually express, or to do nothing to stimulate desirable interests if such are not expressed. This results in indulgence rather than direction, in a form of anarchy rather than of orderly procedure. It has already been noted that all interests and activities are not of equal worth. It is the providence of the teacher to select, stimulate, and direct activities whose worth is high n leading forward toward objectives of unquestioned value. (Kilpatrick et al., 1921, p. 302)

Of all the speakers in the symposium on the project method (Kilpatrick et al., 1921), Hosic was the only one to reiterate Kilpatrick's early emphasis on democracy as his fourth point.

The project method is the application of the principles of democracy. Any one who will undertake to put into effect in his school the factors of socialization as set forth by Professor Dewey, namely, common aims, the spirit of cooperation, and the division of labor, will find that he is using the project method. No special devices for socializing the recitation will be necessary. (p. 306).

Later, in continuing the concern over the over-generalization of the tenets of the project method, Hosic and Chase (1925), in their chapter on "Dangers and Difficulties," warn against mechanistically turning control of the class over to students.

First, let us observe that the project idea should not be interpreted as a doctrine of *laissez faire*. The fact that the project teacher invites the pupils to assume a large measure of responsibility does not mean that she turns the school over to them. Both the community and the individual are to be served. The school is intended to provide a selected and controlled environment. If this were not so, the education of the children might as well be left to the more or less accidental ministrations of other agencies. (p. 86)

The reaction to the student-centeredness of the project method began almost as it was gaining popular acceptance. Curriculum theorists and practitioners were concerned over the lack of direction and purpose of the method. "According to Dewey, the method of surrounding the pupil with materials but not suggesting an end result or a plan and simply letting pupils respond according to whim, was ridiculous" (Tanner & Tanner, 1980, p. 295). Rugg and Schumaker, in their 1928 work, *The Child-Centered School*, wrote, "We dare not leave longer to chance – to spontaneous, overt symptoms of interest on the part of occasional pupils – the solution to this important and difficult problem of construction of curriculum for maximum growth" (p. 118).

The project method thus led to the notion that activity on the part of students was a measure of success and critical to learning. By the 1930s, the project method, as seen in schools, was under attack by the very person who supposedly was one of the originators of the method, John Dewey. Dewey was concerned that teachers had abandoned their proper role in education. "It is the business of the educator to study the tendencies of the young so as to be more consciously aware than are the children themselves what the latter need and want. Any other course transfers the responsibility of the teacher to those taught" (Dewey, 1934, p. 85). Also, by the

1930s, public schools were under scrutiny and attack for their perceived role in either not preventing the Great Depression or not “fixing” the Great Depression once it had begun and educational innovation began to fade.

In summarizing the failure of the child-centered project method, Tanner and Tanner wrote

... experience had made it abundantly clear to many educational theorists that a curriculum based solely on the spontaneous interests of childhood was an impossibility. Such a program could have no sequence and no predetermined outcomes, not even predetermined psychological outcomes. Even a play school had to have objectives and a program that was planned to meet those objectives. Otherwise, the child might as well stay home. (1980, pp. 296-297)

Projects, as a form of child-centeredness, again appear on the educational scene in the 30s in the form of the *Building America Series*, edited by Paul Hanna and sponsored by the Social Frontier group at Teachers College. Rugg, also a member of the Social Frontier group at Teachers College, identified the project method as a useful method in social reconstruction at the national level (Rugg, 1933). In his book, *Educational Frontier*, Kilpatrick (1933) discusses the social and educational reconstructivism movement of the 1930s. More specifically Kilpatrick addresses the need to reform the education system to prepare students for life in contemporary society – a society that requires collaborative efforts to solve problems. In this book, Kilpatrick offers a societal justification for using the project method in schools to achieve social reconstruction.

Later, in the immediate post-war period of the late 1940s and early 1950s, in an attempt to meet the needs of a changing society where more students enrolled in and graduated from high school, the project method reappeared in the form of the life adjustment or continuing life situations movement led by Florence Stratemeyer, again from Teachers College. Just as the project movement had been criticized for its attention to the immediate interests of children, so too was the life-situations curriculum.

Although the aim of this curriculum is to meet the needs of children and youth throughout their lives, needs also determine the choices of the problems to be studied. ... Like Kilpatrick, Stratemeyer and her associates stressed that not all children's interests are equally valuable ... but, as in the case of Kilpatrick's project method, it is preferable of the problems to be based on the child's immediate concerns rather than on adult claims of children's needs. (Tanner & Tanner, 1980, p. 387)

The various teaching innovations of the previous 50 or so years came under attack in the 1950s and soon disappeared from classrooms. The project method had a brief revival in the 1960s in response to the perception that education was failing the nation in science and mathematics. Educators again took an interest in the motivation of children to learn, thinking “that the thrill of discovering scientific concept autonomously would not only result in more effective learning but also instill in children the desire for further, more significant, discoveries” (Tanner & Tanner, 1980, p. 403). However, as Tanner and Tanner write, “this time the model was discipline-focused, not social-problem focused. Discover teaching was a disciplinary effort to teach children to think like scientists instead of children” (p. 403).

THE PAST AND THE FUTURE OF PROJECT LEARNING

As a popular method for general education in the early to mid 20th century, the project method borrowed its theory from agriculture and the industrial arts education and applied that theory to all subjects. However, lacking a clear definition, educational leaders and teachers often used their “definitions” to justify classroom activities driven solely by student interest, regardless of the educational value of the activity. Some (e.g., Douglass 1926, Hosic and Chase 1924) tried to prevent the overgeneralization of the term in classrooms; few practitioners listened and the focus became the interests of students. The social upheavals of the Great Depression and World War II refocused parents and leaders on societal needs rather than the wants of learners. Despite the brief activity in the later 1940s of the life-adjustment movement, the project method was thoroughly rejected by educational leaders as failing to meet the needs of children, teachers, or society.

In the last 10 years, augmented by research on learning and the effect of the learning environment on the learner, Kilpatrick's goal of explaining the pedagogical and psychological principles of learning has come closer to being realized. The next chapter, the *Theoretical Framework for STEM PBL*, provides guidelines for implementing PBL in today's classrooms. Although the question of applying the project method to academic subjects was never answered in the 20th century, STEM PBL illustrates that the project method is appropriate for academic subjects.

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3. THEORETICAL FRAMEWORK FOR THE DESIGN OF STEM PROJECT-BASED LEARNING

INTRODUCTION

Do you remember learning how to ride a bike? Or do you remember teaching someone to learn how to ride a bike? Learning to ride a bike or teaching someone to ride a bike is an iterative process where the learner wants to “experiment” too quickly and the teacher tries to impart his/her wisdom so the learner does not make the same mistakes that his/her did. In the end, the learner probably had to repeat many of the same mistakes; and most importantly, no one would have pronounced one of the early experiences as a failure because the learner was not ready to ride in the Tour de France. Learning to teach Project-Based Learning (PBL) effectively requires that an individual practice some of the patience and techniques required to teach someone to ride a bike, patience to allow the learner to take control and become more experienced in the techniques that build upon the expanding experience and knowledge base as a catalyst for accelerated learning. Just as learning to ride a bike – or learning to let the learner learn on his/her own – is not an all or nothing process, learning to learn in a PBL environment and learning to teach in a PBL environment are not all or nothing propositions.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- how implementing PBL in the classroom occurs in stages, over time, and is informed by research on the design of learning environments and the learning sciences

When you complete this chapter you should be ready to:

- implement PBL components into your teaching
- read the rest of the PBL handbook
- discuss the theoretical underpinnings for PBL with other teachers and administrators

PBL is a special case of inquiry. While the use of inquiry, inquiry-based schooling, and PBL are not new concepts in science and mathematics per se, PBL’s prominence in the national educational standards (Bonnstetter, 1998) and the integration of engineering standards in K-12 are more recent emerging trends (Roehrig, Moore, Wang, & Park, 2012). Additionally the increased emphasis on the E (engineering) in STEM (Science, Technology, Engineering, and Mathematics) naturally supports the project-based design ethos in the simple definition for STEM PBL “a well-defined outcome with an ill-defined task” (Capraro & Slough, 2006, p. 3). Complimentary ideas that incorporate design in instruction include learning by design (Kolodner et al., 2003), design-based science (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004), or design-based learning (Apedoe, Reynolds, Ellefson, & Schunn, 2008). The recent emphasis on inquiry-based teaching and PBL has been informed by research in both the learning sciences (Bransford, Brown, & Cocking 2000; Donovan & Bransford, 2005; Goldman, Petrosino, & Cognition Group and Technology Group at Vanderbilt 1999) and the design of learning environments (Linn, Davis, & Bell 2004). The design of learning environments emphasizes 1) making content accessible, 2) making thinking visible, 3) helping students learn from others, and 4) promoting autonomy and lifelong learning. The learning sciences emphasize the importance of 1) pre-existing knowledge; 2) feedback, revision, and reflection; 3) teaching for understanding; and 4) metacognition.

DESIGN OF LEARNING ENVIRONMENTS

The following design principles impact the design of PBL:

- making content accessible
- making thinking visible, which includes using visual elements to help the learner and using learner constructed visual elements to assess learning
- helping students learn from others
- promoting autonomy and lifelong learning

Although these four design principles are presented separately for discussion purposes, they are integrated in practice.

Design Principle – Making Content Accessible

Content is made accessible by allowing learners to engage in problems, examples, and contexts that connect new ideas to personally relevant prior knowledge and is grounded in three pragmatic pedagogical dimensions: building on student ideas, use of personally relevant problems, and scaffolding inquiry (Linn, Eylon, & Davis, 2004). Thus effective instruction should provide opportunities for students to ask their own questions; refine those questions through the design and conducting of personally relevant investigations; evaluate data and scientific evidence according to their own personal understanding; verbalize their own theories and explanations; and participate in active science learning. Scaffolding and feedback are essential supports for inquiry. Scaffolding allows the learner to “become more like experts in their thinking” (Krajick et al., 1998, p. 5), which allows them to more deeply participate in the inquiry process. Examples of scaffolds include modeling; coaching; sequencing; interacting with more knowledgeable others; reducing or gradually building complexity; highlighting critical features; modeling/prompting; and using visual tools (Goldman et al., 1999; Krajick, Czerniak, & Berger 1999; Kozma, 1999). Timely feedback is essential to help students analyze their own reasoning, making them less dependent on the teacher to diagnose their problems.

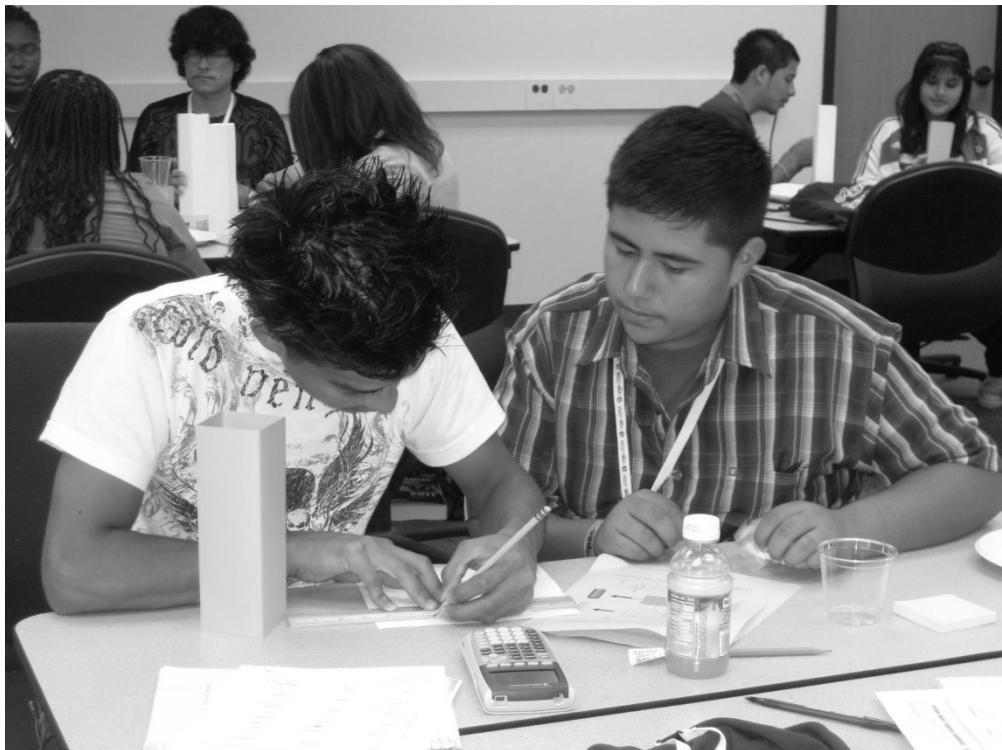
Design Principle – Making Thinking Visible

Making thinking visible is grounded in how ideas are connected (Bransford et al., 2000) and includes three pragmatic pedagogical dimensions: modeling scientific thinking, scaffolding students to make their thinking visible, and providing multiple representations (Linn, Davis, & Eylon, 2004). Science is often taught as a body of knowledge with little understanding of the true nature of science. Students are frequently frustrated when their designs are unsuccessful. Modeling the scientific process allows students to “distinguish among their notions, interpret feedback from others, reconsider information in light of experimental findings, and develop a commitment to the scientific endeavor.” (p. 57). Scaffolding students to make their thinking visible provides opportunities for students to explicitly monitor their own learning, which encourages reflection and more accurately models the scientific process (Bell, 2010; Bryan & Slough, 2009). Providing multiple representations is essential to allow students to actively participate in the interpretive process of science (Linn et al., 2004). Computer animations, modeling programs, dynamic representations and scientific visualizations represent the cutting edge of science and make them more accessible to the learner. Recall of one type of representation can support recall of another type of representation of the same material (Baddeley & Longman, 1978; Brunner 1994). Making thinking visible makes scientific thinking visible to the learner and thus more accessible; makes student thinking visible and thus affords opportunities for students to actively build metacognitive skills and facilitates more effective scaffolds and feedback from the teacher; and makes use of multiple representations and thus facilitates student interaction between the two worlds of science and learning.

Design Principle – Helping Students Learn from Others

Helping students learn from others is grounded in social constructivism (Vygotsky, 1978), cooperative learning (Johnson & Johnson, 1989), and communities of learners (Brown & Campione, 1994; Pea 1987) and includes four pragmatic pedagogical dimensions: encouraging listening to others, design discussions, highlighting the cultural norms, and employing multiple social structures (Linn et al., 2004). Students must be trained to listen to others and to think before responding or acting. Reciprocal teaching (Palinscar & Brown 1984) emphasizes communities of learners observing and learning from role models. Design is often a central component to PBLs. When students design, they must discuss. In a design discussion, students must have time to “reflect, incorporate the ideas of others, and compose their contributions carefully rather than formulating imperfect arguments” (Linn et al., 2004 p. 62). It is especially important that these design

discussions overtly establish the cultural norms of science, which requires the inclusion of all ideas – including ideas that are ultimately rejected, justification for ideas/designs/rejections, and attribution to experts or evidence. Students must be allowed to establish criteria for scientific explanations, to evaluate their own progress, to analyze the progress of others, to describe the connections between their ideas and those of others, and to critique connections proposed by others. These processes are facilitated by the creation of social interactions and norms that enable learners to hear ideas in the words of peers, experts, and members of diverse cultural groups.



Design Principle – Promoting Autonomy and Lifelong Learning

Promoting autonomy and lifelong learning is grounded in metacognition and inquiry and includes four pragmatic pedagogical principles: encouraging monitoring, providing complex projects, revisiting and generalizing the inquiry processes, and scaffolding critique (Linn et al., 2004). One misconception about student-centered instruction is that teachers do nothing, when in fact, the teacher is more active than in most teacher-centered, didactic, presentation-styled instruction. Too little or too much monitoring and feedback deters student learning (Anderson 1982). “Optimal instruction balances feedback with opportunities for students to evaluate their own ideas” (p. 66). Complex projects lend themselves specifically to complex learning and generally to the inquiry process. Through these processes students are enabled to devise personal goals, seek feedback from others, interpret comments, and adjust behavior accordingly. Students must be encouraged to organize ideas, construct arguments, add new evidence, and revisit phenomena in new contexts. Teachers are encouraged to design ways to scaffold students as they devise new explanations and arguments in the context of inquiry.

Summarizing Foundations for Learning and Design Principles

Changes in conceptual understanding(s) occur as teachers engage and problematize students’ pre-existing knowledge. Inquiry and project-based learning allows the teacher an opportunity to engage the prior knowledge, skills, concepts and beliefs students bring with them to the learning environment. In order for thinking to become visible and therefore shaped, students must be given the opportunity to expose their own thinking through feedback, revision, and reflection with themselves, teachers and other students. Inquiry and PBL can be structured in such a way to provide students with these opportunities. Inquiry and PBL also

promote teaching for understanding by allowing teachers to make available many examples of the same concept at work in different conditions. Metacognition, the awareness of and reflection upon ones' own thinking, is a skill, which allows people to distinguish when they comprehend and when they need more information. Inquiry and PBL may afford students the opportunity to take control of their own learning by situating the learning goals and monitoring their progress – both academically and cognitively.

Changes in conceptual understanding(s) are facilitated by overt design decisions that build on the foundations for learning. Making content accessible is facilitated by building on pre-existing knowledge; student discourse; and scaffolds feedback by allowing learners to engage in problems, examples, and contexts that connect new ideas that are personally relevant. Using visual elements in instruction and promoting student construction of visual elements promote making thinking visual. As students learn from others, they have the opportunity to learn the cultural norms of science – including the notion that ideas are accepted or rejected based on evidence – and the attribution to experts or evidence. Promoting autonomy and lifelong learning occurs as students learn to devise personal goals, seek feedback from others, interpret comments, adjust behavior accordingly, and evaluate their own ideas.

FOUNDATIONS IN THE LEARNING SCIENCES

The following foundations in the learning sciences impact the design of PBL:

- preexisting knowledge
- feedback, revision, and reflection
- teaching for understanding
- metacognition

Although these foundations in the learning sciences are presented separately for discussion purposes, they are integrated in practice.

Preexisting Knowledge

Humans are goal-directed arbitrators of information they receive beginning at birth. This information forms a wide range of knowledge, skills, beliefs, and concepts. This preexisting knowledge influences what they observe around them and how they organize and make sense of this information. As children are initiated into the formal learning environment and as they continue throughout their academic career, these prior understandings will significantly influence how they make sense of what they are taught (Bransford et al., 2000).

Mrs. Gonzalez's Ninth Grade Integrated Physics and Chemistry (IPC) Vignette

In a PBL on Non-Newtonian Fluids (see Appendix A) Mrs. Gonzalez introduces the following ill-defined task while playing with a large ball of silly putty at the front of the class (engagement 5E model):

What effect does %water have on the viscosity of silly putty ... and how can the general forms of functions help us interpret this relationship?

The students are then given time to explore how to make silly putty, what exactly is viscosity, how is it measured, what is the general form of a function, what do we have at the school that can be used to make silly putty and measure viscosity, and why is Mrs. G using math terms in a science class? The classroom becomes a blur of motion and the noise level increases. As an experienced teacher, Mrs. Gonzalez seems to ignore the noise and student motion; but upon closer inspection shows us that she is moving from group to group checking progress, providing suggestions – never “the answer” – and keeping students on-task. After the initial exploration phase (5E model), Mrs. G has the students share ideas with the whole class before full-scale testing occurs.

Students develop preconceptions about how the world operates through their daily interactions with people, places, and things. Students develop logical ideas of how and why things operate based upon these experiences. While prior learning is a powerful support for further learning, it can also lead to the development of conceptions that can act as barriers to learning (Bransford et al., 2000). A powerful example of how students' prior understanding may act as a barrier to future learning in science

can be found in the Private Universe research project (Schneps & Sadler 1987). For example, students know that the closer one stands to a campfire, the hotter he or she feels. Students then use this logic to impose a new understanding to every situation where they feel warmer – it is hotter because I am closer to the heat source. This is a logical and acceptable hypothesis. But, a problem arises when the student brings this naïve conception into a formal school setting where a teacher is attempting to teach the causes of the seasons – essentially trying to determine why it is hot in the summer and cold in the winter. Logical interpretations of the students' lived experience imply that the Earth must be closer to the sun in the summer and farther away in the winter. The teacher explains it is direct and indirect sunlight, which determine the Earth's seasons with distance from the Sun having little or no influence. If students' preconceptions about distance from the Sun are not directly addressed by the teacher, students are likely to 1) memorize the teacher's explanation of direct and indirect sunlight whenever it is relevant for a test or assessment and revert back to their initial preconceptions of distance once the student leaves the formal school environment, 2) develop a theory of the cause of the seasons which blends both the teacher's explanation and the student's lived experiences into one unusual theory, or 3) never be able to grasp the concepts of the teacher's explanation.

Student's preconceptions, the naïve theories they bring with them into the classroom, can impose serious constraints on understanding formal disciplines. These preconceptions are often difficult for teachers to change because they generally work well enough for students in their daily real-world contexts. Students' preconceptions must be directly addressed or they often memorize content for the classroom but still use their experience-based preconceptions to act in the world (Bransford et al., 2000).

Teaching for Understanding – Factual and Conceptual Knowledge

Similarities and differences between how experts and novices think and how each group approaches problem-solving have led to a better understanding of the relationships between factual and conceptual knowledge (Larkin, McDermott, & Simon, 1980; Nathan, Koedinger, & Alibali, 2001). Factual knowledge is a key component of a person's ability to plan, observe patterns, connect concepts and ideas from other disciplines, and to develop and deconstruct points of view, arguments, and explanations. While factual knowledge plays a vital role in teaching and learning these skills, students with only a large body of disconnected facts is not sufficient. In order for factual knowledge to become working or usable knowledge, students must be able to place facts into a conceptual framework (Bransford et al., 2000). In order for students to learn with understanding, factual knowledge must be balanced within a conceptual framework.

<p>Mrs. Gonzalez's Ninth Grade Integrated Physics and Chemistry (IPC) Vignette (continued)</p> <p>In a PBL on Non-Newtonian Fluids (see Appendix A) Mrs. Gonzalez's class is now fully engaged in the exploration phase to answer their ill-defined task:</p> <p>What effect does %water have on the viscosity of silly putty ... and how can the general forms of functions help us interpret this relationship?</p> <p>It is the second day in a multi-day PBL and Mrs. G is still working the room. Students have found various recipes for making silly putty, GAK, and a host of other substances on the Internet. Mrs. G has provided a limited set of materials, so the students are forced to chose the recipe that includes glue + borax + water = silly putty. After all of the groups have experimented with the mixture, Mrs. G again has a whole class discussion to make sure that all of the students are on-task and to remind them how important taking good notes and multiple trials will be in the next phase of data collection.</p>

A student learning with understanding is situated within two foundational concepts: (1) understanding requires that factual knowledge is suspended within a conceptual framework, and (2) concepts are given meaning by multiple representations that are rich in factual detail (Capraro & Yetkiner, 2008; Muzheve & Capraro, 2011; Parker et al., 2007). Learning goals, what the student should know and be able to perform at the end of instruction, are built on neither factual nor conceptual understanding alone. A longstanding debate in education has been and continues to be whether factual knowledge or conceptual understanding should be the primary focus of curriculum and instruction. While these two concepts appear to be in conflict with one another, factual knowledge and conceptual understanding are actually mutually supportive. Conceptual knowledge is clarified when it is used to organize factual knowledge, and the recall of factual knowledge is

enhanced by conceptual knowledge. Experts in any STEM discipline work from a set of core concepts, which organizes factual knowledge and conceptual understanding. Thus, teaching for understanding would overtly emphasize the organization of these same core concepts to help learners organize factual knowledge and their individual construction of concepts (Clement & Steinberg, 2002; Gilbert & Boulter 2000; Lehrer & Schauble, 2000; Penner, Giles, Lehrer, & Schauble, 1997).

Metacognition

Metacognition is broadly defined as a person's knowledge and skills to be aware of and reflect upon one's own thinking (Brown, 1978; Flavell, 1979). Progress in the learning sciences emphasizes the importance of helping people take control of their own learning. Because understanding should be the goal of curriculum and instruction, people must learn to recognize when they understand and when they need more information (Koschmann, Kelson, Feltovich, & Barrows, 1996). Teaching and learning which emphasizes the metacognitive process is proactive. Students do not passively receive information as others make sense of it for them. Students must proactively engage in the learning process and must determine for themselves how this new information is connected to current understandings. In order for this to occur, students must be aware of and able to reflect upon their own thinking.

Mrs. Gonzalez's Ninth Grade Integrated Physics and Chemistry (IPC) Vignette (continued)
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In a PBL on Non-Newtonian Fluids (see Appendix A) Mrs. Gonzalez's class is now fully engaged in the exploration phase to answer their ill-defined task:

What effect does %water have on the viscosity of silly putty ... and how can the general forms of functions help us interpret this relationship?

It is the third day in a multi-day PBL and the students are wrapping up their explorations and beginning explanation (5E model). Mrs. G is focused today because she knows how critical today's transition is ... without good data, the student's explanations will be weak. She has really taken a risk by requiring that the students use functions to explain their science, but as she checks the students notes she only needs to make gentle reminders as the groups have all recorded good data. As the students begin to analyze data, questions about what type of graph to use, how many points it takes to make a graph and a variety of questions about functions start to permeate the room. After several small group interventions, Mrs. G decides to have a short whole class review on functions and graphing. She takes the time to find out where each group is at and facilitates an exchange that is largely student driven because she knows where the groups and individuals are in the process. The students return to their groups and work well to complete their analysis and start with their presentations.

The actual and intended goal(s) of education are often disputed, but most would agree that formal schooling should produce self-directed lifelong learners capable of making sense of new information even after their formal education has ended. This includes fostering the development of metacognitive criteria for knowing when one knows and does not know, the ability to assess what needs to be learned in a particular problem context, the ability to identify and use resources efficiently to improve the state of one's knowledge, and the ability to reflect upon this process to improve its efficiency and effectiveness (Koschmann et al., 1996, p. 94). To meet the goal of producing self-directed lifelong learners, 1) students must be explicitly taught metacognitive strategies, 2) reflecting upon one's own thinking should be modeled by the teacher, and 3) opportunities for students to make their thinking visible need to be incorporated into the learning environment.

To better understand the metacognitive strategies to be employed in a successful learning environment, it is useful to narrow the broad definition of metacognition into three classifications: awareness, evaluation, and regulation. Metacognitive awareness relates to an individual's understanding of 1) where they are in the learning process, 2) the factual and conceptual knowledge, 3) personal learning strategies, and 4) what has been done and still needs to be done to meet the cognitive goals. Metacognitive evaluation refers to judgments made regarding one's cognitive capacities and limitations. Metacognitive regulation occurs when individuals modify their thinking (Schraw & Dennison, 1994). Students must be explicitly made aware of their own thinking, taught how to evaluate this understanding, and then given the opportunity to regulate or modify these concepts.



As noted by Bransford et al. (2000), students who are more aware of their own metacognitive learning processes and are provided opportunities to express their own thinking tend to learn better. It is important that these strategies are embedded throughout the instructional framework rather than taught as isolated skills. Making discussions of metacognitive processes a part of daily language urges students to more explicitly attend to their own learning (Pintrich, 2002). Metacognition is often an internal dialogue and students with no experience making this dialogue external may be unaware of its importance (Vye, Schwartz, Bransford, Barron, Zech, & Cognition Group and Technology Group at Vanderbilt, 1998).

Metacognition has been shown to predict learning performance (Pintrich & DeGroot, 1990). Students with high metacognitive skills outperformed those with lower metacognitive skills in problem-solving tasks, regardless of their overall aptitude. General aptitude and metacognitive abilities appear to operate independently (Swanson, 1990). Integrating metacognition into curriculum and instruction is a component of effective teaching and learning for understanding.

Feedback, Revision, and Reflection

Effective instruction must incorporate opportunities for students to reflect upon their own thinking, to receive feedback from others about their thinking, and the freedom to revise one's thinking as a result of this new information. These metacognitive characteristics are critical to the development of the ability to regulate one's own learning (Goldman et al., 1999).

Mrs. Gonzalez's Ninth Grade Integrated Physics and Chemistry (IPC) Vignette (continued)
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In a PBL on Non-Newtonian Fluids (see Appendix A) Mrs. Gonzalez's class is now fully engaged in the exploration phase to answer their ill-defined task:

What effect does %water have on the viscosity of silly putty ... and how can the general forms of functions help us interpret this relationship?

It is the fourth day in a multi-day PBL and Mrs. G is rewarded by students who come to class and immediately start on their projects. Most of the students are focused on completing graphs and placing them in PowerPoint presentations. Mrs. G notices that while the students were able to collect useful data and were able to determine the equation on their lines, they really had not focused on answering the question. From experience, she had expected this and had planned some extension activities (5E model)

that would hopefully prompt the students to think beyond just the graph and to understand how the shape or form of the line was critical to differentiating between linear and non-linear flow. Examples of appropriate extensions include: what would the data for a Newtonian fluid look like? Or How do engineers take advantage of nonlinear flow?

Often “hands-on” activities fail to be “minds-on” because students’ understanding is not engaged. Criticisms of these activities focus primarily on the lack of opportunities for student reflection. Bettencourt (1993) argued that, “unless hands-on science is embedded in a structure of questioning, reflecting, and re-questioning, probably very little will be learned” (p. 46). Typically, in the traditional classroom, these activities 1) do not allow students the appropriate amount of time to make sense of the new information, 2) tend to be taught in isolation and unrelated to one another, and 3) focus on the manipulation of objects and events rather than on the understanding of a phenomenon (Schauble, Glaser, Duschl, Schulze, & John, 1995). Once a learner has reflected upon his own thinking, the next logical step is to make his internal dialogue external – to make his thinking visible to others. Whether through group discussions, concept mapping, or written communication, students need to share their thoughts and understandings with others. This allows the learner to acquire feedback on their conceptual understanding. This feedback often supports aspects of their understanding, problematizes other elements, and leads the student to proactively change his own thinking rather than act as a passive receiver of information. Effective teachers have students revise their own conceptual understandings, to place factual knowledge within a conceptual framework, rather than passively memorizing new information.

STEM disciplines are made available to learners by allowing them to connect new thinking to pre-existing knowledge. Effective instruction should provide opportunities for students to evaluate scientific evidence according to their own personal understanding, to articulate their own theories and explanations, and to participate actively in learning. One would expect to see participants in the learning environment given multiple opportunities to communicate their understanding to others, often engaging to solve problems within the context of a project or a problem, and readily able to present their understanding in the same manner as a professional within the discipline.

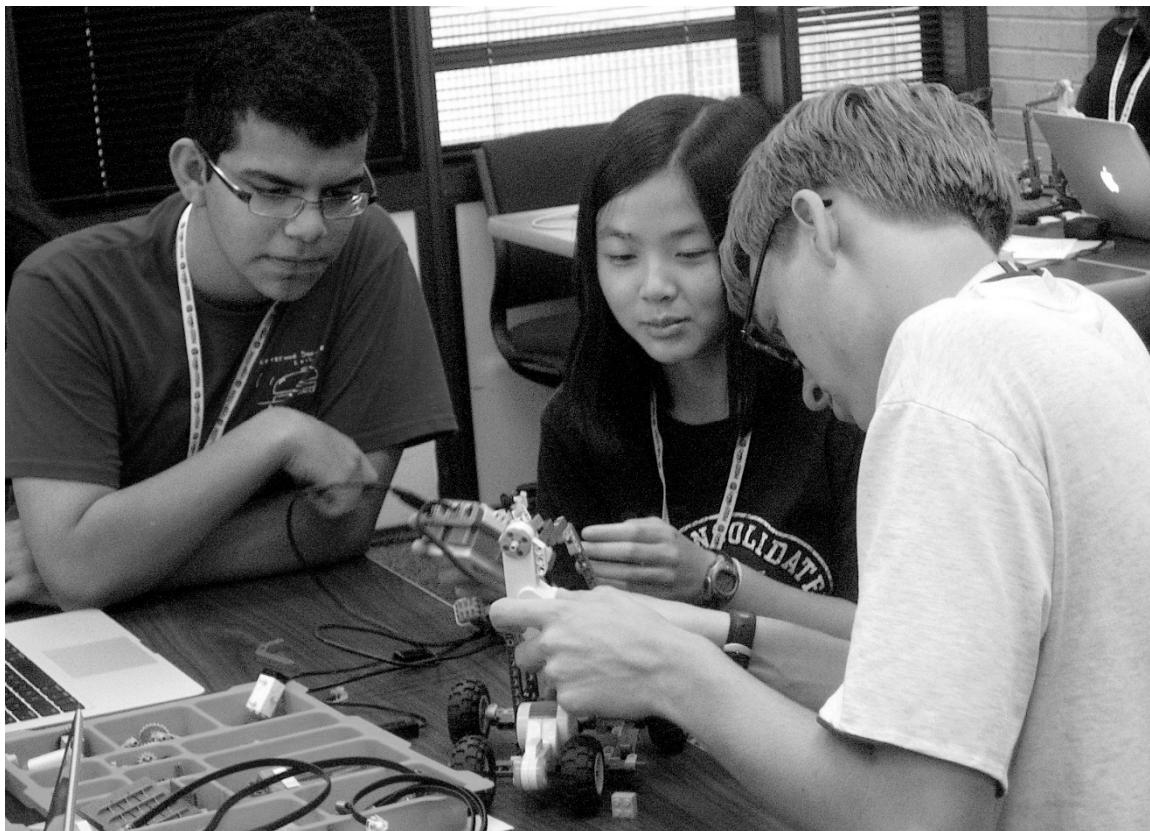
PROJECT-BASED LEARNING AS AN EVOLUTIONARY PROCESS

The national standards for science and mathematics curriculum and instruction are dynamic. As each transforms to incorporate more inquiry and PBL, so too does the emphasis on training teachers and students to define and use these methods appropriately. Bonnstetter (1998) broadly examined inquiry as he opens a dialogue on how to define inquiry, how to determine specific levels of inquiry based upon student-centeredness, and its potential for success when used in classrooms by teachers and students. Bonnstetter described inquiry as an evolutionary process across five levels of inquiry; traditional hands-on, structured, guided, student directed and student research, with six levels of implementation: topic, question, materials, procedures/design, results/analysis, and conclusions. A teacher progresses across the inquiry continuum by facilitating additional student control up the implementation continuum. For instance, the teacher is in control of everything in a traditional hands-on environment, but in the structured inquiry the student is in control of the conclusion with the teacher and student sharing control for the results/analysis.

Settlage (2007) argued against this model and other incarnations of open inquiry, stating that open inquiry should not be promoted because it is not effective in all school settings, it rarely occurs, and the “examples provided within the National Science Education Standards of inquiry are fictionalized (p. 465).” A common misconception – or myth – about open inquiry is that as classrooms become more student-centered the teacher becomes less responsive to student needs. When in fact, just the opposite is true. As a class progresses toward open inquiry on the Bonnstetter model, the teacher becomes an active facilitator not a bystander. Thus Slough and Milam (2007) broadened the scope of this discussion on inquiry by proposing a model that extends the Bonnstetter model (1998) and addresses the Settlage (2007) deficiencies by emphasizing the How People Learn framework of the novice, informed novice, and expert learners (Bransford et al., 2000); adds a level of community-centeredness that is warranted by both the foundations for learning and design principles; and creates a standards-based assessment category along with some minor edits to the implementation continuum ... and recognizes the importance of time (see [Table 1](#))! Finally, Huber and Moore (2010) quote noted classroom management guru Harry Wong (Wong & Wong, 1998) as urging educators to give permission to beginning teacher to engage students with traditional hands-on labs and worksheets as they transition to more pedagogically engaging methodologies.

Table 1. Project-Based Learning as an Evolutionary Process

	Traditional Hands-on (Verification of Facts)	Novice (Factual Knowledge)	Informed Novice (Understand facts/ideas in context of conceptual framework)	Expert (Adapts conceptual frameworks through transfer)	Researcher (Creation of new knowledge and/or conceptual frameworks)
Standards-based Assessment	State/ Teacher	State/ Teacher	State/ Teacher	State/ Teacher	State/ Teacher
Topic	Teacher	Teacher	Teacher	Teacher	Student/Researcher/Community
Task	Teacher	Teacher	Teacher	Student	Student/ Community
Resources	Teacher	Teacher	Teacher	Student/ Community	Student/ Community
Procedures/ Design	Teacher	Teacher	Teacher/ Student	Student/ Community	Student/ Community
Artifacts/ Analysis	Teacher	Teacher/ Student	Student/ Community	Student/ Community	Student/ Community
Outcomes	Teacher/ Student	Student	Student/ Community	Student/ Community	Student/ Community



PROJECT-BASED LEARNING CONTINUUM

Traditional Hands-on Lab (Verification of Facts)

The emphasis in the traditional hands-on lab is on the verification of facts already presented to the learner. The teacher controls the assessment, topic, task, resources, procedure/design, artifacts/analysis and often even the outcomes. This type of experience is often dominated by worksheets and fill-in-the blank forms.

Novice (Factual Knowledge)

The differences between traditional hands-on and novice are subtle. Instead of verifying factual knowledge previously learned, the student is generating factual knowledge, which is novel to them. Although the lab and its' components have been determined by the teacher, this constructivist approach allows the learner to analyze the data and determine the outcomes. It is important to note that at this novice level, the outcomes and determinations by the student are only factual in nature. For example, if I drop a ball, it falls to the ground. At the traditional hands-on level, this lab would verify previous teachings that when a ball is dropped, it falls to the ground. At this novice level, it is the student who constructs the factual understanding.

Informed Novice (Understand Facts/Ideas in Context of Conceptual Framework)

At the informed novice level, chunks of factual knowledge are connected to build a conceptual understanding. Students rationalize the relationships and connections between multiple pieces of knowledge. In the previous example, students determined that when they drop a ball, it falls to the ground. Perhaps in another lab, students also learned Newton's Law of Gravity. At the informed novice level, the purpose of the lab is to connect these two pieces of factual knowledge to form a conceptual understanding. If I drop a ball, it falls to the ground. Newton's Law of Gravity states that objects with larger mass attract objects of a smaller mass. Therefore, the ball drops to the ground because it has a smaller mass than the ground (Earth). Students analyze relationships between facts to develop more complex conceptual understandings.

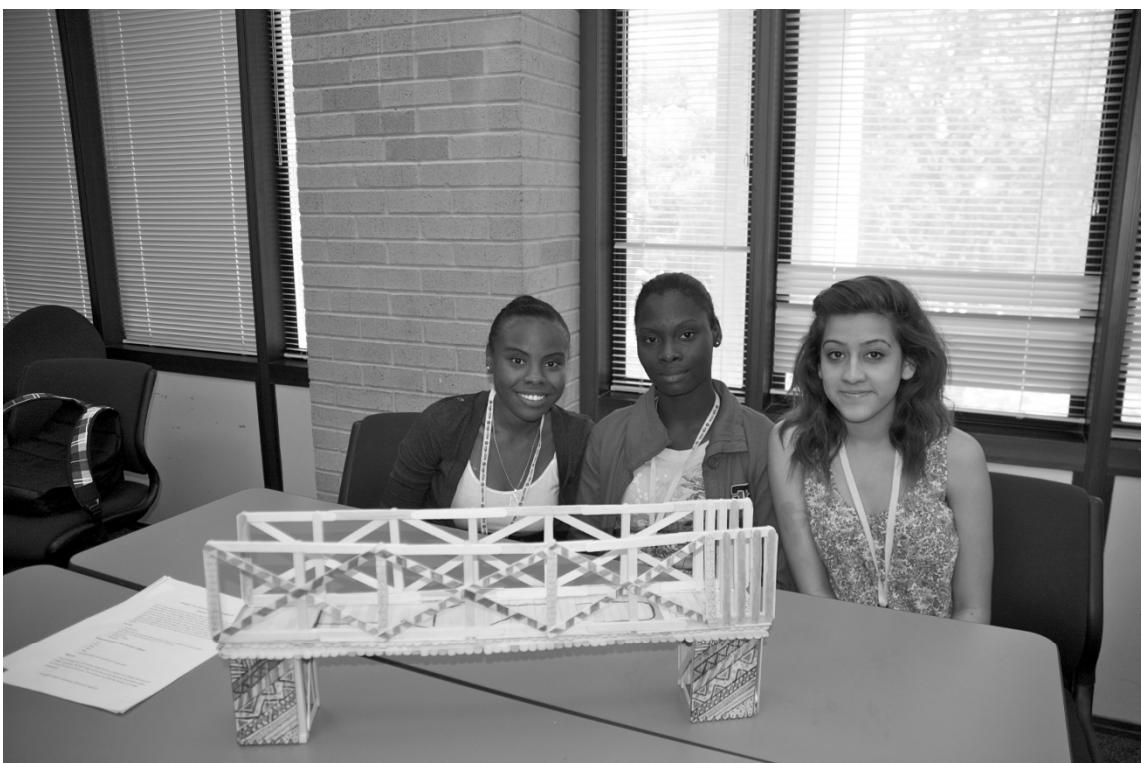
At this level, the idea of community becomes vital. Students must be given opportunities for discourse with each other, with experts, and with the teacher. Opportunities to dialog about ideas and naïve theories with one another, to determine what information is valid and reliable, and to decide how factual information is connected to form a conceptual understanding, all of which should be community-centered. The community of learners ultimately decides which naïve theories become appropriate knowledge and understanding. The importance of community continues to deepen as the levels of complexity increase.

Expert (Adapts Conceptual Frameworks through Transfer)

In general, experts are capable of applying their knowledge and expertise to novel situations. The ability to transfer knowledge into new situations successfully is a crucial assessment component when teaching for understanding. At the expert level, the goal is for the student to be able to transfer his or her understandings of the material to novel situations. There is usually more than one method for solving problems. The student and/or the community must be given more freedom of choice when determining 1) how to approach the problem, 2) what acceptable resources to use, 3) how the data is analyzed, and 4) how the results are interpreted. The teacher and the student must both have experience and success operating with fewer constraints. Therefore, the expert level not only requires deep factual knowledge and a solid conceptual framework, but also the ability to work more independently than in the past.

Researcher (Creation of New Knowledge and/or Conceptual Frameworks)

At the Researcher level, the learner is in control of his or her learning. Students are capable of choosing the topic of interest and are well equipped to make learning happen. This level requires many years of practice and the learner must be scaffolded at each step. Reaching the researcher level is analogous to obtaining a terminal degree – you have been given the tools to learn independently. This should be the goal of education regardless of subject matter. One cannot expect a student or teacher to effectively operate at this level without proper training and experience. To expect either to move from any previous level to the researcher level without this training and experience is irresponsible – movement must be slow and thoughtful.



IMPLEMENTATION CONTINUUM

The implementation continuum has one major addition and a couple of minor edits to Bonstetter's original continuum (1998) to better match PBL in a standards-based environment. The major addition centers on standards-based assessment. PBL will never be teaching to the test and it should not be, but it is critical that PBL address specific assessment standards as mandated by the national, state, or local authorities – well-defined outcomes. Additionally, conclusions become outcomes to match the definition – ill-defined tasks and well-defined outcomes (Capraro & Slough, 2008, p. 3). Artifacts replace results to highlight the choices that students make as they chose how to demonstrate/interpret data, and resources supplant materials to reflect the incorporation of various digital technologies available in today's classroom.

Teacher/Student/Community-Centeredness

Perhaps the most important aspect of the new model is the overt design of community. Our definition of community begins in the classroom and expands to the global community as the learner matures. The teacher, students, administrators, parents, businesses, neighborhoods and churches are all part of community. But community also refers to norms of the learning environment. As students interact with the teacher and each other, are their ideas valued? Do they feel safe to make their thinking visible? Are they properly scaffolded through the process of inquiry? Providing the learner a community-centered learning environment is a component of effectively incorporating PBL into the classroom.

Settlage (2007) posited that open inquiry is rare, fictionalized, and apparently unavailable for all learners. Without a community that has been built to support PBL, he is probably correct. But, with the purposeful incorporation of community, the teacher can purposively design learning environments that take advantage of foundational knowledge from the learning sciences and design principles. As the student becomes more autonomous from the teacher, they require a larger community in which they interact, especially if the expectation is that all students learn.

TIME

Time is often the forgotten dimension in today's fast-paced environment, but research has shown that it takes three to five years for meaningful changes in curriculum and instructional practices following a professional

development experience (Horsley & Loucks-Horsley, 1998). This time (and the time following the experience) must be spent consistently advocating for and pursuing significant change in teacher, student, and community behavior. In short, significant change in teacher, student, and community behavior takes more than resources; it takes time. This has implications for effective implementation of PBL strategies. If a teacher enters a professional development seminar at the most teacher-centered level of PBL, this educator should not be expected to operate at the more sophisticated student-centered levels of PBL immediately. Students, from kindergarten to post-secondary levels, enter the learning environment at various levels of sophistication and experience with PBL resulting in an “unresolved tension between the practical doing and the content learning (Kanter, 2008, p. 527). They too should not be expected to work completely outside of their comfort levels. Growth towards a more sophisticated level of PBL should be incremental and within the appropriate zone of proximal development (ZPD) (Vygotsky, 1978) of all participants – teachers, students, and the community. If teachers and students operate beyond their ZPD, failure is likely. Mistakenly, this failure may be blamed upon the PBL itself or on the inability of teachers and students to work within the PBL framework. In actuality, success or failure depends as much on understanding levels of PBL and working within the appropriate ZPD as it does on the teachers’ actual ability and knowledge to implement this new technique.

ILL-DEFINED TASKS AND WELL-DEFINED OUTCOMES

An engineer always starts with the outcome in mind – build a bridge to span the Golden Gate in the San Francisco Bay, but is often rewarded for elegance. In this sense of the word, elegance refers more to the unusually effective and simple design of the Golden Gate Bridge, but it is easy to see the secondary meaning of elegance as defined grace. Just as engineers design toward a known outcome, teachers’ must design toward a known outcome. Further just as the engineer is allowed the freedom to purposively design for elegance, the teacher is allowed to design unusually effective and simple designs of PBL. Thus ill-defined tasks allow the teacher to take advantage of all of the foundations for learning and design principles while ensuring the well-defined outcomes mandated in high-stakes accountability standards are addressed.

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4. ENGINEERING BETTER PROJECTS

INTRODUCTION

The requirements for a successful career in the 21st century are completely different than they were in the 20th century. With the ever changing technological advances and new problems being identified daily, we must prepare students for jobs and challenges that possibly do not even exist today. Therefore, students must be equipped with problem-solving skills that enable them to systematically find solutions regardless of the specific problem they face. In addition, the Internet has made information easily and quickly accessible, which has caused a shift from the need for memorization to learning how to acquire valid information and create new information based on observations and analysis. Machines have also decreased the need for unskilled labor, making it vital that our students know how to apply concepts instead of merely understanding concepts. These new demands are the reason engineering, Project-Based Learning (PBL), and the design process are now a focus in 21st century curricula.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- the importance of engineering in today’s curricula
- the steps of the engineering design process
- how the engineering design process relates to the 5E Model
- the essential elements needed to define a project
- an educator’s role in a PBL classroom

When you complete this chapter you should be able to:

- define, manage, and assess projects more efficiently and successfully
- guide students with real-world methods that will enable them design better solutions
- adapt projects for different proficiencies
- equip your students with 21st century skills

WHAT IS ENGINEERING?

Engineering applies concepts from mathematics, the sciences, and technology to solve complex problems in a systematic manner. While the process is systematic, it does require creativity in the application of scientific principles in order to achieve a solution. Because engineering addresses real-world problems, it provides an excellent context in which to illustrate concepts that otherwise may be difficult for students to visualize. Moreover, because engineering problems are relevant to students and society, students are likely to be more motivated to gain a deeper understanding of mathematics, science, and technology curricula.

WHAT IS THE DESIGN PROCESS?

Importance of Design Process

The design process is a systematic approach followed when developing a solution for a problem with a well-defined outcome. There are many variations in practice today, but most of them include the same basic steps. Following a well-structured design process is important because it provides the structure needed to formulate the best solution possible, and the act of following a design process builds problem solving skills and logic.

STEPS OF DESIGN PROCESS

Engineering design can be represented utilizing a seven-step process. The process is, by nature, iterative in that engineers almost never work linearly through these steps but, instead, alternate between the various steps until the final design solution is identified. The seven steps, illustrated in [Figure 1](#), are outlined below.

Step 1: Identify Problem and Constraints

Although this task may seem minor, it is actually of great importance. By identifying the problem, engineers clearly and concisely describe the goal of the planned design work. This provides an opportunity for all individuals involved in the design to come to agreement on the goals and scope of the project. However, some project stakeholders do not have a direct voice in the process. For example, consumers may not be a direct part of the design team and yet will have a critical role in determining whether a product succeeds. Also, society is impacted by the products developed, particularly in a large-scale project, such as infrastructure development. Engineers must find a way to incorporate these points of view, possibly through focus groups or town-hall meetings.

In addition to defining the design goal, the team needs to identify all appropriate constraints and criteria. Constraints are limitations, such as time and supplies. Criteria are desirable characteristics of the final product, such as aesthetically pleasing and energy efficient. It is important to note that constraints are either met or not met, while criteria can be judged and used to compare numerous project ideas.

Step 2: Research

Background research provides information necessary to formulate and critically analyze design ideas. It is most efficient for engineers to investigate prior work on the specific topic of their design in an attempt to avoid duplicating effort. In addition, engineers need to be familiar with applicable laws, rules, ordinances, local customs, and appropriate industry design standards. Engineers must research how to best assess and incorporate the perspective and needs of those stakeholders. Finally, environmental issues related to the project must be researched so negative effects can be minimized.

Engineers must fully understand the properties of the materials being used in the manufacture of products. In understanding these properties, engineers often rely on design and implementation of experiments followed by analysis of collected data. The selection of materials is key for satisfying project constraints, such as limited funds or completion deadlines, while meeting criteria, such as durability. Local access to suppliers, shipping processes and fees, contract terms, negotiated bulk pricing, reliability, and political issues all need to be investigated when selecting a supplier. In addition, if foreign suppliers are included, import taxes must be considered. Although the selection of a supplier is almost always a step in the design process, it is important to note that engineers are often restricted to materials available from pre-approved or local vendors and suppliers.



Step 3: Ideate

Effective design involves the generation of multiple solution ideas, and creativity is an essential part of this process. To this end, design engineers often employ brainstorming techniques. Brainstorming is particularly useful for attacking specific (rather than general) problems and where a collection of good, fresh, new ideas is needed. Therefore, brainstorming techniques should be used to develop a thorough list of ideas for solving the problem and to identify all risks and benefits associated with each idea.

Although many believe they know how to brainstorm, they often have not truly developed it as a skill or realized the value added from proper brainstorming. Brainstorming should be performed in a relaxed environment. If participants feel free to relax and take risks without being criticized, they will stretch their minds further and produce more creative ideas. Creativity exercises, relaxation exercises or other fun

activities before the session can help participants relax their minds in order to enhance their creativity. When a team brainstorms, they are not focused on perfecting or developing their ideas or evaluating whether or not the ideas are even possible. They are simply recording every thought that comes to mind.

The final idea is often a conglomeration of all thoughts, and sometimes the seemingly impossible idea ends up being the best one some amount of refinement. By permitting and encouraging team-members to think outside the boundaries of ordinary, normal thought, brilliant new solutions can arise. Brainstorming is often performed in “Think-Pair-Share” activities, which work well for spiraling one idea from a previous one. (Johnson, Johnson, & Smith, 1991)

Step 4: Analyze Ideas

After preliminary ideas have been identified during the Ideation step, they need to be refined and more fully developed. Engineering applies math, science and technology principles for this purpose. Mathematical and scientific models are generated that can be used to predict the performance of the different solutions being considered. The results of these models must be analyzed within the context of the project criteria and constraints in order to identify the viable alternatives, so that the design efforts may be concentrated in refining and improving those options.

Engineering requires students to grapple with complex systems. Because engineering problems are audience-specific and context-specific, there are typically many feasible solutions that need to be analyzed in order to select the best one. To sort through possible solutions, students are required to consider multiple goals, criteria, and constraints that frequently conflict. Engineering design does not address a single correct answer; rather it aims to identify the best solution out of several possibilities.

Identification of the best solution for a design problem requires careful, objective assessment of the top alternatives. This type of exercise requires students to critically evaluate and communicate the various benefits and drawbacks of each design alternative and should be carried out using a systematic process. A table is therefore often used to rank viable options (those that meet all design constraints) for a set of defined criteria. The best solution is a function of both the problem criteria as well as how these criteria are weighed. Although two different teams may have identical problem criteria, they may decide to give greater weight to different items. For example, although two teams both have product reliability and adaptability as criteria, one team may value reliability more than adaptability whereas the other might place higher value on adaptability. Neither choice is necessarily wrong nor is the weights given to the criteria constant. Reliability may be highly rated up to a certain level, beyond which any additional gains are no longer of primary importance. For example, a student may want the product to be highly reliable over a period of 10 years, but past that time span, it may be acceptable for the reliability to be significantly reduced.



Step 5: Build

After applying mathematics, science, and technology to fully develop the best design idea, an attempt at building a full-size working model, or prototype, should be undertaken. Materials, suppliers, and assembly processes must be finalized in order to build the prototype.

Remember, products are not always physical. For example, the goal of a project may be to define a new process. The Build phase is still applicable, as processes need to be built and tested as well.

Step 6: Test and Refine

The prototype’s performance will be experimentally evaluated and tested under all possible conditions. For each evaluation, thorough documentation should be recorded, including predictions, testing conditions, observations, and results. Although testing conditions should emulate the actual environment of the finished product, these conditions are sometimes not known at this point in the project. In addition, exact simulation of the actual environment is often not possible. Any deviation, as well as factors that may vary from one test to another, must be identified and recorded. Photographs or videos of the prototype from different angles are

beneficial in most cases. A common item of known size (so as to provide a sense of scale), the date, and the designer's signature should also be visible in all shots. Finally, during tests, teachers should ensure that detailed observation notes are recorded. For example, in the design of the houseboats, students should test assumptions about the viability of their design. These results, as well as the limits under which the design meets the purpose, should all be part of the observation notes.



After testing and observing a prototype, new information will be identified that may improve the design. At this point, it is important to go back to the start of the Ideation phase to brainstorm alterations, analyze and select an updated or alternative design, build a new prototype, retest, and refine again. It is possible that the engineer will need to revisit problem constraints and objectives based on the new data or research further. This refinement process is cyclical until the final design is selected. However, limited time and money typically constrain the efficiency that may be achieved, which affect the extent of the refinement process.

Step 7: Communicate and Reflect

Engineering design requires effective communication. The days of engineers working independently in cubicles with little interaction are a thing of the past. Now, engineering problems require experience in at least four styles of communication: interpersonal, oral, visual and written.

Engineering design is most often done in teams to facilitate broad ideation, share workload, and take advantage of individuals' diverse strengths. This teamwork setting requires significant interpersonal communications and emphasizes the importance of constructive and professional interaction.

Oral communication is often required to receive validation, approval, and funding for projects. Good engineers must develop the skills to explain their design in layman's terms while being able to back it up with technical concepts and terminology. Many great designs go undeveloped simply because the designer cannot gain the trust of investors or customers based on their technical explanations.

The use of illustrations, sketches, blueprints, diagrams, graphs, and other visuals are beneficial throughout the design process. They help communicate difficult concepts and undeveloped ideas, and they serve as input for the build phases of the project. If a physical product is being designed, detailed dimensions are also required. Standard dimensioning practices should be followed to avoid confusion and to allow products to be produced with precision.

Written communication and documentation is essential to the design process. Engineers typically record all their thoughts, research, rough drawings, detailed sketches, test results, and interactions in a journal. The format of a journal varies with personal preference, but all journals should be bound to ensure pages are not removed or added. It is important to keep documentation in chronological order to accurately represent the progression of design ideas. Reflection on the process and results will help develop the best design possible, but it may take time for everything to come together, thus recording these thoughts in a journal is critical to the success of a project. Proper journaling will also prove ownership of ideas, which may be needed for obtaining patents. More importantly, this activity will improve metacognition, and thinking about thinking leads to deeper learning.

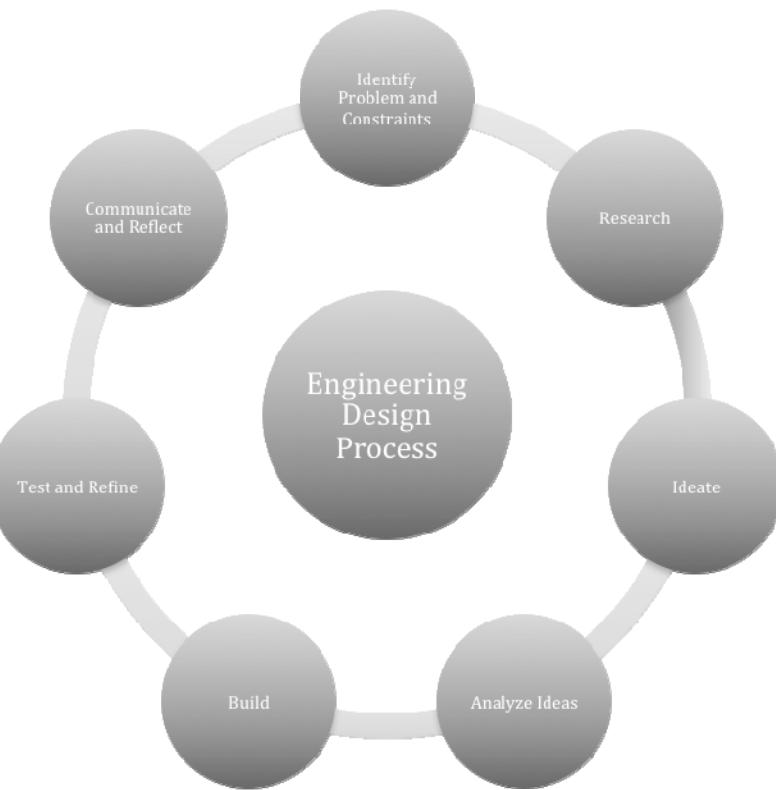


Figure 1. Seven-step design process.

THE PROJECT DESIGN BRIEF, CONSTRAINTS, AND CRITERIA

Key Elements of Project Design Brief

All projects should be introduced to the students with a Project Design Brief. This document includes the design problem, constraints, and criteria. The design problem should be presented in a personal way that excites the project team about taking ownership. A *well-defined outcome* should be provided, but the path to achieving that outcome must be determined by the team. Project design briefs are presented at the start of every project, and a rubric outlining how the project team will be assessed is typically provided concurrently.

Constraints and Criteria

Successful engineering considers multiple constraints and criteria that should be satisfied with the final design solution. Balancing the importance of each criterion, while honoring all constraints, can be challenging, especially if team members have different priorities. To make things even more complex, many projects now involve stakeholders from different countries and diverse cultures, a fact that adds complexity and additional limitations that need to be considered.

Each project will have constraints, or limitations, which will often conflict. For example, two common project constraints, low cost and a short implementation timeframe may be mutually exclusive. Constraints are often focused on the process used when designing a solution or on the limited resources and conditions for the project.

Defined criteria, sometimes referred to as requirements, focus on the desirable or necessary characteristics of the final design. For example, it may be desirable that a product is visually appealing and necessary that it be safe to use. Remember, criteria are typically evaluated on a scale, with a minimum level often being specified, whereas constraints are simply met or not met.

In the classroom setting, criteria and constraints are typically provided by the teacher. However, student project teams can and periodically should be required to define or identify constraints and criteria on their own, making explicit decisions as to how the different criteria will be weighed when analyzing their solution, as trade-offs between criteria are inevitable. For example, a solution may be slightly more reliable at a corresponding higher cost; it is important that the students explicitly address those trade-offs.

As an example of possible criteria and constraints, specifications for the design of a toaster are given in [Figure 2](#). Notice that the elements under criteria can all be assessed on a sliding scale. For example, although a toaster must be safe to use, some designs may be safer than others. Additionally, minimum performance levels are defined for some of the criteria. The toaster must operate without defects for at least one year, though better designs will operate without defects for longer time spans. As previously discussed, students may need to research in order to more fully define the criteria listed. Deciding on the target consumer and identifying what may be affordable for that person may be part of the project. This can be particularly useful in cross-curricular projects; for example, the teacher can potentially integrate the toaster problem with a social studies, economics course, or mathematics course.

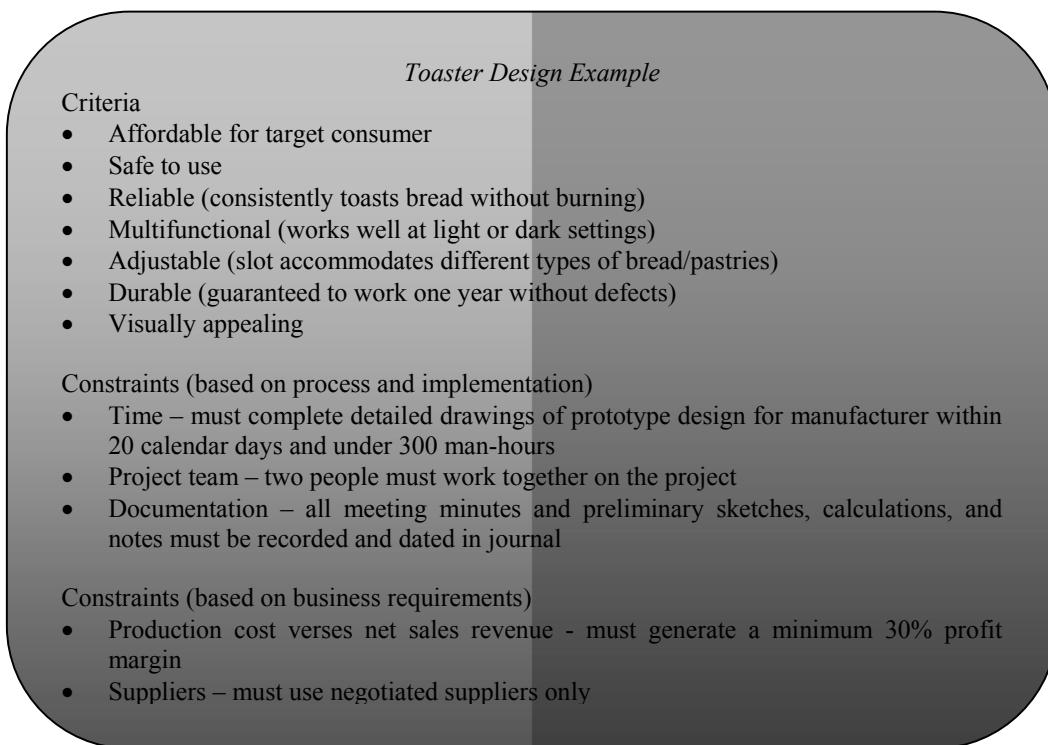


Figure 2. Example of defined criteria and constraints.

ENGINEERING IN THE CLASSROOM

Benefits

Using engineering design in the classroom adds many benefits to the learning process. Engineering:

- Requires higher order thinking
- Provides a realistic context for the application of math and science
- Provides a good structure for breaking down complex problems
- Builds 21st century skills, such as problem solving and creativity
- Makes connections between mathematics, science, and technology to real world products and processes
- Increases business sense, identifying connections between industries
- Promotes ownership based on discovery learning and development of unique solutions
- Cultivates skills required for successful collaboration and teamwork
- Develops a stronger interest in science, technology, and mathematics concepts

- Provides an environment where metacognition and journaling are of great importance and the purpose of these activities are better understood and appreciated

Process

The learning resulting from engineering fits well with accepted learning cycles and instructional models. One widely used instructional model is the BSCS 5E model (Bybee & Landes, 1988), which provides a structured sequence of learning steps. Table 1 summarizes the steps of the 5E model and ties them to steps in the engineering design process. This comparison also could be extended to the Science Curriculum Improvement Study learning cycle (Karplus & Their, 1967) or other models. Regardless of the model used, it is sufficient to say that *engineering design enhances the learning process*.

Table 1. Alignment of 5E Model with Engineering Design Process

5 E step	Design Process step
Engagement	Identify problem and constraints
Exploration	Research; Ideate; Analyze ideas
Explanation	Research; Ideate; Analyze ideas
Extension	Build; Communicate
Evaluation	Test and refine; Reflect

Important Connections between the Engineering Design Process and the BSCS 5E Model

Engagement – Identify problem and constraints

Before introducing a project to your students, you must capture their interest in the design problem. Brainstorming sessions in combination with class discussions based around what the students already know are a great way to kick off a project. Questions related to the human element and relevance of the design problem are especially important.

In today's classrooms, video clips, role-play, podcasts, field trips, or guest speakers are effective methods used to engage students. Students typically relate to the problem easier when it is presented with these tools rather than through a traditional lecture. In addition, these methods normally satisfy most learning styles.

Exploration – Research, Ideate, & Analyze Ideas

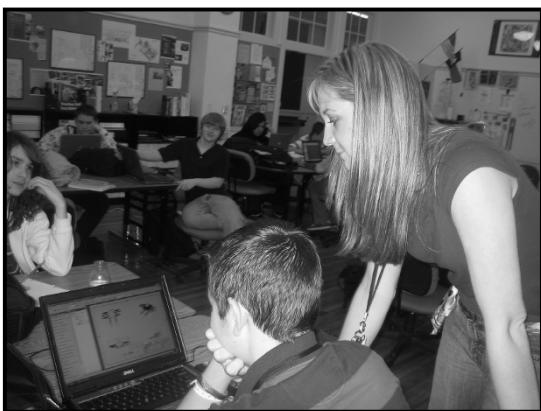
During the research phase, it is vital that a purpose is provided behind *all* activities. In addition, these activities must model *real world* tasks and be based on discovery learning. During this phase, tasks should be designed so that students have common experiences upon which they continue formulating concepts, processes, and skills.

Students must consider the “big picture” when creating and communicating their designs. For example, cultural diversity, local environmental issues, and legal requirements may need to be considered.

Throughout the project, teachers must continually assess student progress, provide feedback, and celebrate successes. It is particularly important to recognize and encourage creative thinking at this stage. Students typically do not associate creative solutions as part of the mathematics and science curricula and may be uncomfortable that there is not one “correct process or solution”.

Explanation – Research, Ideate, & Analyze Ideas

In addition to validating data, assumptions, and project designs, teachers must evaluate the processes being used to carry out the project and how well project teams are working together. As teachers assess the students, they should provide guidance where needed, but it is important that they do not lay out specific procedures for the students to follow. Often, the best guidance comes in the form of open-ended questions a teacher poses to the student team.



- Can students adequately justify decisions made related to design constraints and alternative selection?
- Can students appropriately apply requisite mathematics, science, and technology concepts that are related to their designs?
- Are the tools and resources used to gather information valid and accurate?
- Are project teams following the design process?
- What are the dynamics of the team? How can we improve efficiency?
- Are the project teams staying on schedule?
- Is detailed documentation being maintained and dated?

Ensure students follow a real world design process, and *always allow, demand, and reward creativity and rigor!*

Extension – Build & Communicate

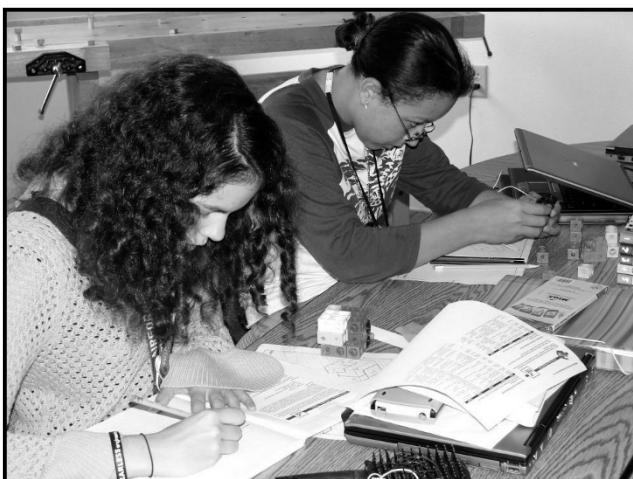
Discovery learning or problem solving through hands on tasks is a “must” at every phase of the process. The development of prototypes provides a tangible connection to abstract scientific and mathematical concepts. Many students learn best when they:

- have opportunities to acquire information in a context that allows them to see how course material relates to the real world (concrete)
- process information in an environment that allows them to fail safely (active)

A key component of PBL is effective and continuous written and oral communication. An oral presentation rubric is included in Appendix C. Students will be required to communicate to both technical and lay audiences. An example of an individual presentation rubric is included in Appendix D (See Appendix E for an example of a group presentation rubric). In addition, they must also communicate within a team, as a team, and on an individual basis during the different steps of the design process.

The project team must discover the best means of transmitting its ideas and, in the process, discover or be introduced to domain-specific communication mechanisms. For example, Gantt Charts are typical in engineering management as a mechanism to visually organize and keep track of schedules and major project milestones.

Evaluation – Test and refine & Reflect



Based on the testing results, students will refine their design solution. This process requires that they analyze the results based on the problem criteria and objective. In comparing the results of different tests with their predictions, students should critically think about both the strengths and weaknesses of their design. This is one of the most critical parts of the design process. Students’ comprehension level tends to increase when making discoveries based on their own unique experiences.

Additionally, students should be encouraged to consider:

- How would a design change if the audience or context were different?
- How would changing the priority of design constraints or criteria influence the final design solution?

Students need to be encouraged to revisit previous steps, such as ideation. Initially, students may consider this a step-back in the process, or even a failure in their part. Teachers need to be conscious of reinforcing that the design process is iterative and not a straight path through the basic steps.

The teacher is responsible for providing feedback during all phases of the project and should require the students to communicate to a target audience as much as possible. Peer evaluations, presentations open to the community and school officials, and presentations seeking approval to move forward on the project are a few motivators that a teacher may want to consider when having the students present. Due to the significant time requirement and complexity of each project group conducting presentations, it is vital that learning continues during this phase. To ensure this occurs, feedback must be provided not only on the design but also on the project's delivery and students' communication skills. In addition, open discussions should be allowed after each presentation to review and expand on the information presented by each group.

At each phase, milestones or progression points should be assessed, and successes should be celebrated. As such, both formative and summative evaluations must be part of the process.

Formative assessment should focus on the design process and whether the students are conscious of the decisions being made and understand the basic principles being applied. Teachers should ask students to:

- Explain the mathematical and scientific principles used in the development of their product.
- Justify or explain decisions related to design constraints and alternatives analyzed during the design process.
- Discuss various solution alternatives and how well they meet the selected design constraints.
- Evaluate their progress in both completing project tasks and developing new knowledge and skills.

These self-evaluations and discussions not only provide a basis for the formative assessment, they also can guide students into explicitly developing their metacognition skills. Metacognition, or thinking about thinking, is a vital part of all projects. It must be done incessantly, and all reflections should be well documented. It is important to reflect individually and within a team setting.

Metacognition is also important for students to do at the conclusion of each project phase, especially at the end of the project. Considering what they learned throughout the design process, they should identify what changes they would make not only to their design but also within their journey.

Summative assessment includes the evaluation of how well the final product meets all the problem criteria and if it meets all defined constraints. The oral, written, or graphical artifacts prepared during the course of the project are also evaluated. A target audience should be clearly defined by the teachers for all communication artifacts and the students must format their presentation for that audience. A presentation that would be suitable for a technical audience would not be the same as that for a layperson. It is beneficial if students are asked to present their work to different audiences so as to develop a broad communication skill set. This can be accomplished without having the students duplicate their efforts. For example, the written report should be geared towards a more technical audience, allowing the teacher to fully assess the rigor of the approaches used by the student team. The in-class presentation can be geared towards a lay audience. The presentation to a lay audience facilitates assessments when students are asked to role-play and sell their idea to potential customers, who can be represented by their classmates.

Adaptations for Different Proficiencies

Engineering projects can easily be adapted to meet various levels of proficiencies while still holding students accountable for high levels of rigor. Projects can be modified in the following ways:

Providing additional help (Closer Monitoring) of self-management of learning. It can be difficult for some students to manage their time effectively and not get overwhelmed by the breadth and depth of a project. A teacher can help the students slowly develop the necessary skills by providing frequent and clear feedback on where students should be in the design process.

Breaking down tasks of long duration. Some students can lose their motivation when tasks are of long duration, as they do not have a sense of accomplishment. By breaking down long tasks into smaller ones, students more readily see their progress towards meeting the project goals.

Extending deadlines. Most students can meet any criteria and level of rigor given enough time to complete a task. Balancing the time provided to complete tasks against a student's ability is a critical element in developing an appropriately challenging project.

Creative partnering (Group Projects). Team projects take advantage of the different strengths of the members. Although you do not want to partner students of such different abilities that the stronger members feel like they need to do all the work in order to achieve the grade they desire, balancing different abilities can lead to deeper learning for all students.



The above modifications are often all that is needed to get any student group to meet the project criteria. When necessary, additional modifications can be made by simplifying project criteria and constraints, such as:

Eliminating some constraints. By eliminating constraints, a wider solution set is available, and students can more easily meet the project objectives. However, a wider solution set can occasionally make it more difficult for the students to select their best design alternative. As a result, they may need more guidance during that phase of the project, or a rubric that provides a more detailed mechanism for weighing the various design criteria.

Modifying criteria and rubric. Typically, this modification is tied to eliminating constraints. More detailed criteria and rubrics can be useful to students who are not yet comfortable making decisions or accepting that multiple solutions may be possible.

These modifications should be a last resort, however, as most students can meet the desired project criteria and constraints if given enough time and support during the process.

SUMMARY

Discovery learning or problem solving is the best way to prepare our students for jobs that do not even exist today (Resnick, 1999) As technology and problems evolve at an ever increasing pace, students need to develop the skills to creatively apply fundamental principles to new challenges. Although knowledge of language arts, social studies, science, and mathematics have traditionally been the fundamentals of the U.S. educational system, students in the 21st century require an expanded set of basic skills that emphasize thinking and problem-solving. In particular, students must be able to connect knowledge and skills learned in one topic area to another topic area as well as make connections to real-life applications of that knowledge.

Engineering PBL inherently addresses these needs, though it is complex in nature and spans multiple disciplines. The design process provides a structure for approaching complex problems while encouraging creativity in achieving project goals. Projects are easily adaptable to meet the needs of different student populations by changing project criteria, constraints, and overall project duration. Students with diverse learning styles all benefit from the project, as different stages are more directly related to different learning styles. This allows students to operate within their comfort zone at least part of the time and can provide an environment that allows them to learn from their mistakes safely. The questioning and analytical elements of the process also serve as self-assessments on the state of each student's own learning and understanding. Additionally, projects emphasize 21st century skills, such as teamwork, communication, and problem-solving skills that will be important to all students regardless of their future educational or career goals.

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5. W³ OF PROJECT-BASED LEARNING

Who, Where, and When: Revisited

INTRODUCTION

Schools' responsibilities for educating students extend beyond the schools' borders. Project-based learning (PBL) provides authentic teaching and learning environments for students, teachers, and administrators. Applications of PBL use in schools extend from kindergarten to college. With different aims at each level, PBL supports individual control over learning. Thus, PBL promotes lifelong learning. This updated perspective of PBL extends the scope of who should implement PBL as well as when, and where.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- who should implement PBL
- when should PBL be implemented
- where should PBL be implemented

When you complete this chapter you should be able to:

- decide for whom, when, and where PBL can be implemented

WHO SHOULD DO PROJECT-BASED LEARNING?

Administrators

Administrators have substantive roles in the promotion and the implementation of PBLs. Administrative school support has an effect on teachers' intrinsic motivation for implementing PBL (Lam, Cheng, & Choy, 2010). Cognitive Evaluation Theory, presented by Deci and Ryan (1985), investigated intrinsic motivation from autonomy versus control perspective (Ryan & Deci, 2000). Ryan and Deci (2000) discussed the negative effect of "not only tangible rewards but also threats, deadlines, directives, pressured evaluations, and imposed goals" (p. 70) on intrinsic motivation. Importantly, this research found that autonomy improved intrinsic motivation (Lam et al., 2010; Ryan & Deci, 2000). Thus, administrators have important role in increasing teachers' intrinsic motivation by providing a more autonomous environment for them.

Administrators are also responsible for establishing a system for teacher collaboration on implementation of PBL ("Leading a Project-Based School," 2009). In addition, because PBL might be a novel instructional approach for many teachers, administrators can provide teachers with the training they need to successfully implement PBLs in their classrooms (Mathews-Aydinli, 2007). PBL trainings can be in the form of professional development where teachers with expertise in PBL share their knowledge and experiences and help the teachers implement their first PBLs. Teachers' competency in PBL may increase their intrinsic motivation in implementing PBL in practice (Lam et al., 2010). Teachers' motivation is found to be higher if they believe in the good practice of PBL (Jesus & Lens, 2005). So, as it is necessary in every instructional approach, ongoing professional development will support teachers as they implement PBL.

Administrators also play an important role in PBL by providing teachers with necessary resources (Mathews-Aydinli, 2007). Resources can range from small tools to be used during the project to technological equipment, and instructional technology such as computers, and field trips. For successful implementation of PBL, teachers need to have access to appropriate resources. Educational technology has important uses in PBLs; therefore, administrators also need to support their teachers in becoming proficient users of technology.

Administrators can also evaluate the implementation of PBL in the classrooms and make necessary modifications when needed (Mathews-Aydinli, 2007). In this regard, administrators may conduct classroom observations to understand how PBL work and identify strengths and weaknesses of PBL implementation. Based on classroom observations, administrators can provide teachers with constructive feedback. Classroom observations may also promote administrator support of PBL as it allows them to experience the rich learning environment of PBLs.

Teachers

Teachers from every content area (e.g., science, mathematics, social studies) in every grade from pre-K to college can implement PBL in their classrooms. Project-based learning might be a novel instructional approach for many teachers; however, if teachers take the effort to do PBL, they generally think the outcomes are worth the effort. Both entry-level and veteran teachers can implement PBL or apply the foundational concepts and ideas of PBL to some extent in their classrooms.

In PBL, teachers act more as facilitators, mentors, or coaches than disseminators of knowledge. They guide the learning process through effective questioning and support students in reflecting upon the questions rather than providing direct information. Teachers should catch students' attention and grab their imaginations. As students explore the content and adapt the skills covered within the project, teachers need to provide direction for research and inquiry. Teachers should ask students thought-provoking questions to push students' imaginations and to increase their motivation for learning (Larmer & Mergendoller, 2010). Teachers should provide room for student inquiry and let students pose driving questions. They should facilitate learning by monitoring students' contribution and participation and engaging students in learning that is personal and cooperative and encourage students to develop deeper and more meaningful understandings of concepts (Johari & Bradshaw, 2008). Teachers should also provide a public presentation for student projects, because public presentations are more meaningful for students than those done only for classmates and their teacher (Larmer & Mergendoller, 2010).

Project-based learning necessitates that teachers share the control of the learning environment with students. This change in the roles can be hard for teachers to adapt or at times confusing for teachers who have predominantly taught using traditional teaching approaches. Another factor that may inhibit their adoption of this new learning approach is that most of the teacher education programs still rely on traditional lecture formats. It is difficult for teachers to adopt learning methodologies they have never experienced before (Ward & Lee, 2002). Thus, administrators can play an important role in the adoption of PBL by providing teachers with professional development (Jesus & Lens, 2005). Professional development opportunities can prepare teachers to develop projects, implement them in the classroom, generate self-learning environments, and evaluate the various outcomes of PBL through multiple assessment models including ones that are closely aligned with standards-based assessments. Such professional developments provide teachers with a safe environment to practice what they learn and share responsibilities with other teachers. In addition to or as a substitute to professional development, teachers can take advantage of the online resources that help teachers to develop and implement PBLs. These online sources include various projects that are fully developed and that were already implemented in classrooms. Through different websites, teachers can also share their experiences as they do PBLs and benefit from other teachers' knowledge and insights.

Teachers in all subject areas can implement PBL in their classrooms. In addition, because PBL is an interdisciplinary instructional approach, teachers from different disciplines can work collaboratively on various projects. Initially, PBL may require more planning than traditional class preparation. Teachers from each discipline need to know their respective standards and align them with other disciplines and develop projects where they can address these standards efficiently. It is often a good idea to include students in the development of the project so that they feel an ownership of the project.

Project-based learning has been used in colleges, particularly medical and engineering schools, and today its use has been extended to all levels of pre-K-12 education. Teachers can start using PBLs in as early as early childhood education programs. Research in preK-5 education shows positive impacts of PBLs (Katz, 1994; Chard, 1992). In early childhood, children are curious about different aspects of life; therefore, teachers can utilize PBLs to engage and challenge them and help them to develop collaborative learning skills. As students move to middle- and high-school, teachers can utilize PBL to help students develop conceptual understanding and apply their theoretical knowledge.

Although the transition from the traditional classroom environment and teaching to PBL can be time-consuming and challenging, teachers in general acknowledge that outcomes of PBL are worth the effort. The interdisciplinary approach of PBL helps develop collaborative learning environments among teachers. Teachers can also develop partnerships with professionals in their communities who are related to and

contribute to the projects. In this endeavor, administrators need to provide the support and encouragement that teachers need.

Students

Students from all ages, pre-K to college, have been effectively involved in PBLs. After its initial appearance in colleges, students today engage in PBLs as early as in early childhood education contexts. In fact, it is even better to have students to experience PBLs in the early stages of their education to help them develop the life-long essential skills such as self-directed learning, effective inquiry skills, and peer collaboration as early as possible. Project-based learning promotes self-directed learning environment, so students need to take control of their learning and develop self-learning skills. Research shows that students' work habits, critical thinking skills, and creativity are positively affected by project-based learning (Tretten & Zachariou, 1997). Thus, promoting PBL in earlier grades may prepare students for their future academic and non-academic careers.

Students from every grade level learn how to gather and apply knowledge to become life-long learners. The collaborative working environment in PBL encourages students to work in diverse learning settings with students from different ethnic or socio-economic backgrounds (Kaldi, Flippatou, & Govaris, 2011). Different abilities or skills a project may require help students with diverse abilities contribute to the success of the project in various aspects. Therefore, although every student may not be proficient in every content or skill, they feel accomplished with their contributions.

Students have essential tasks in the development and execution of PBLs. It is recommended that they be involved throughout the duration of PBL, from the development of the projects to the assessments. Most students have been instructed using the traditional lecture approach and are used to the role of the teacher as disseminators of knowledge. It can be stressful for them to take on a more self-directed role in their learning. However, it is important to keep in mind that project-based learning does not have to completely replace traditional instruction. There might be times, particularly if students and the teacher are new to PBL, where a lecture-style instruction is needed.



Community Partners

Students find projects more compelling if real inquiry is conducted (Larmer & Mergendoller, 2010). Students may lose their motivation if the task requires finding information from resources and bringing them together to present. If the real world problems and projects could be imitated in a school environment, students' desire to be part of them will be increased. Further, students will have higher motivation if they present their projects

to people who are from outside their schools (Larmer & Mergendoller, 2010). Therefore, projects in PBL should be as realistic as possible, and teachers should create an environment where community partners and/or parents can be involved in students' projects.

Professionals in the community can serve a valuable role in project-based learning as contributors to projects. During project development, application, and assessment, teachers can collaborate with professionals to give greater authenticity to the projects. These professionals can be within the school's community, or today through the use of web professionals from different parts of the world can participate in the PBLs. Professionals can be of substantive help for teachers in the development of the projects with the insights and up-to-date information they provide. In general, students value professionals' contributions to projects and the outside-school knowledge they bring to the learning environment. When the professionals are involved in the evaluation of their projects, students feel more motivated to make a positive impression on the professionals.

WHEN SHOULD PBL BE IMPLEMENTED?

Two out of three students are bored in school at least every day according to Indiana University's High School Survey of Student Engagement (HSSSE) survey. Nearly 300,000 students from 110 high schools across 26 different states in the U.S. participated in HSSSE. Two main reasons for students' boredom in school are lack of interesting material and lack of relevant material (Yazzie-Mintz, 2007). When students are bored, they become less engaged in the material taught. Moreover, bored and unengaged students are less likely to learn (Blumenfeld et al., 1991). On the other hand students are more likely to learn better when they are authentically engaged in meaningful material (Hancock & Betts, 2002).

Many teachers, regardless of their disciplines, ask themselves how they can make their students think (Duch, 2008). Underlying premise of PBL, as in Dewey, is that "students will develop personal investment in the material if they engage in real, meaningful tasks and problems that emulate what experts do in real-world situations" (Krajcik & Blumenfeld, 2006, p. 649). Thus, PBL "challenges students to learn to learn, working cooperatively in groups to seek answers to real world problems. These problems are used to engage students' curiosity and initiate learning the subject matter. PBL prepares students to think critically and analytically, and to find and use appropriate learning resources" (Duch).

Problem solving, particularly complicated everyday problem solving, has been a major concern in education. One of the essential goals for schools is to educate students who are able to experience the richness and excitement of knowledge about the natural world, who are aware of difficult real-world problems, and who use appropriate processes and principles in making personal decisions (National Science Educational Standard [NSES], 1996). Students have to learn ill-structured, well-structured, and unstructured problem-solving skills by experiencing various real life situations in order to make personal decisions.

Ill-structured Problems

Problems that students face in schools are very different than they would face in real life. Problems found in most textbooks and asked by teachers are mostly well-structured problems. However, the problems in everyday settings are either open or ill-structured. Well-structured problems are convergent to a solution and require limited number of skills whereas ill-structured problems may contain several solutions and multiple paths to each solution (Chin & Chia, 2006).

Ill-structured problems set the base for implementation of PBL. In solutions of ill-structured problems, there is no clear and readily available path. On the other hand, ill-structured problems may have many possible solutions since they are complex and ill-defined. Ill-structured problems introduce concepts to students by challenging them to find answers. These problems are usually real world problems. Dealing with real world problems makes the knowledge relevant and increases the transfer of skills and knowledge from the classroom to outside world (Bransford, Brown, & Cocking, 2000).

The best way to approach an ill-structured problem is by gathering information about the problem and the setting where the problem occurred. The *best* solution to ill-structured problem depends on the priorities underlying the situation. For instance what is *best* today may not be the *best* tomorrow. Ill-structured problems require the development of higher order thinking skills, since they do not have unique solution to the problems. A critical skill students develop through this distinct learning process is to identify the problem and set parameters on the development of a solution. Students need three steps when approaching ill-structured problems (iStudy, 2006):

1. Define the problem,
2. Identify the reasons of the problem, and
3. List the outcomes if the problem is solved.

The Summer Reading Program

The St. John Public Library and Morgantown Middle School are sponsoring a summer reading program. Students in grades 6-9 will read books to collect points and win prizes. The winner in each class will be the student with the most reading points. A collection of approved books already has been selected and put on reserve. The chart below is a sample of the books in the collection.

Title	Author	Reading Level (By Grade)	Pages	Student's Scores on Written Reports	A brief Description of the Book
Sarah, Plain and Tall	Patricia MacLachlan	4	58		Note: <i>On a "fold out" page, two or three sentences were given to describe each book. – Was it a history book, an adventure book, etc.</i>
Awesome Athletes (Sports Illustrated for Kids)	Multiple Authors	2	288		
A Tale of Two Cities	Charles Dickens	9	384		
Much Ado About Nothing	William Shakespeare	10	75		
Get Real (Sweet Valley Jr. High, No. I)	Jamie Suzanne & Francine Pascal	6	144		

Students who enroll in the program often read between ten and twenty books over the summer. The contest committee is trying to figure out a fair way to assign points to each student. Margret Scott, the program director, said “Whatever procedure is used, we want to take into account: (1) the number of books, (2) the variety of the books, (3) the difficulty of the books, (4) the lengths of the books, and (5) the quality of the written reports.”

Note: The students are given grades of A+, A, A-, B+, B, B-, C+, C, C-, D, or F for the quality of their written reports.

YOUR TASK: Write a letter to Margaret Scott explaining how to assign points to each student for all of the books that the students reads and writes about during the summer reading program.

Figure 1. An ill-structured problem example from Lesh, Zawojewski, & Carmona (2003)

Even though ill-structured problems do not have a certain way of solution, iStudy suggests nine steps for solving an ill-structured problem:

1. Determine the real problem
2. State the real problem
3. Identify alternative perspectives
4. Determine constraints
5. Gather information
6. Generate possible solutions
7. Choose the best solution
8. Plan the steps for implementing the solution
9. Adapt the solution

Figure 1 shows an example of an ill-structured problem.

Ill-structured problems are the organizing center of PBL. They have complex and messy nature and “has no simple, fixed, formulaic, *simple*, solution” (Illinois Mathematics and Science Academy [IMSA], 2004). According to Jonassen (1997), the best solution to an ill-structured problem is “the one that is most viable, that is, most defensible, the one for which the learner can provide the most cogent argument” (p.81). With ill-structured problems, students start to investigate multidisciplinary elements beyond the boundaries of school settings and learn inquiry skills (Chin & Chia, 2006).

Group Discussions

Project-based learning is a collaborative learning approach. Group work is a strategy that promotes participation, interaction and collaborative work among students. Interaction in groups helps students to develop valuable professional team work skills and effective communication skills which are required qualifications in every professional environment. After graduation, students in their work environments need to work collaboratively with their co-workers and supervisors in order to be productive (Savery, 2006). The format of the PBL provides opportunities for students to improve these skills.

Teachers have a role of promoting active student participation in group work by asking open-ended questions that encourage critical thinking and collaboration. These questions to any and all members will ensure teachers that group members shared the information related to the problem (Savery, 2006). Even though students work collaboratively with each other in the group, they have individual responsibilities, which increase individuals' motivation (Savery & Duffy, 1995). Collaborative group environment provides students the opportunity to freely express their ideas and critique each other's views (West, 1992). When students are working in a group, they take responsibility not only for their own learning but also for their group mates' learning.

WHERE SHOULD PBL BE IMPLEMENTED?

The roots of PBL lie as far back as the early 1900s in Dewey's Constructivist Learning Theory, which promotes experiential, hands-on, and student-centred learning (Markham, Mergendoller, Larmer, & Ravitz, 2003). Constructivism is highly supported learning theory that students construct new knowledge through accommodation and assimilation from their experiences. In constructivist learning, students are actively engaged in *doing* rather than just receiving the information.

PBL has been implemented in K12 schools as well as universities and professional schools. Promising reports have been revealed about its effective use in K-12 schools, it has yet to be widely adopted by K-12 teachers (Ertmer & Simons, 2006). Not only schools but also government, commerce, and industry seek for the high-level competencies and transferable skills which are facilitated by PBL. Thus PBL is implemented in where there is need for active learning.

PBL in Elementary School

We, as educators, want students to take responsibility for any kind of problems they may face in their life and become life-long learners. In order to achieve this goal, students have to gain life-long learning skills at an early age. Edutopia has several examples of implementation of PBL in K-5 classrooms. Lilli Land, Auburn Early Education Centre (AEEC) principal, says in one of the Edutopia PBL videos where students are working on a project about their virtual trip to Brazil (Ellis, 2007):

These kids have a very authentic, real purpose for learning ... When you want to find something out, what do you do? You go to the computer, you get on the Internet, you get a book. You don't go to an adult and just have them feed you all the information. You have to learn to be a problem solver; you have to learn to be resourceful. So we teach them to be lifelong learners, and you have to keep them excited about the process of learning.

These kind of student-driven projects help kindergarten students become life-long learners (Ellis). Edutopia (<http://www.edutopia.org>) has several examples and videos about project-based learning in elementary school. Inquiry Schools (www.inquiryschools.net) also shares quality educational practices in PBL and they provide videos about their practices.



PBL in Middle School

Similar to elementary grade but more comprehensive projects can be implemented into middle grade curricula. The National Science Resource Center (1998) argues that middle graders learn more when they are actively involved in finding solutions, rather than selecting the solutions provided to them. Making contributions to real life problems is highly motivating and inspiring for students. Sharon Campbell, Art teacher in Redwood Middle School at Napa, California, provides her students with opportunities to learn by touching, feeling, manipulating and analyzing. For example, in her energy conservation project, she let her students pedal a bicycle to generate electricity for their classroom (see video at <http://www.edutopia.org/redwood-energy-conservation-video>). In this example, students are able to see the conservation of energy from pedaling to electricity. Middle graders are interested in active involvement in real life problems (Jennings, 1995). Moreover, they feel that they can change the world and find solutions to the real world issues more than other age group students (Daniels, 2005). Within this age group, middle grade students decide about their future plans, education, and careers. Even though, project-based learning requires more time than regular instruction and is not easy to implement, the time spent on projects is worthwhile in helping students make decisions about their lives (Bernt, Turner, & Bernt, 2005).

PBL in High School

Project-based learning starts in the kindergarten and teaches students how to become self-motivated learners. Throughout their elementary school and then middle school, they experience PBL with more extensive projects, and PBL helps them to flow in a direction they would like to be in the future. Continuation of PBL in high school will provide students with additional opportunities to explore their interests. Even though similar strategies for middle graders will work with high school students, the format of PBL may vary in high school. High school students mostly do not want direct supervision by their teachers and prefer to work independently (Lambros, 2004). In PBL teachers are facilitators and guides, and they will be ready when students need help

from them. Thus, high school students' preference for working individually will make them actively engage into the solution of the problems and deeply learn the concepts.

PBL in Higher Education

Unlike K-12 schools, college classes might have large classroom sizes, which makes the implementation of PBL more difficult. Nevertheless, using different strategies, PBL can still be applied to college classes and can be effective to motivate college students (Ram, 1999). In large classroom settings, such as college classes, multiple PBL groups can be formed, and peer facilitators can be assigned to each group to monitor group processes. With this strategy, the cooperative and collaborative structure of PBL is conserved within college classroom also (Allen, 2004).

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6. INTERDISCIPLINARY STEM PROJECT-BASED LEARNING

INTRODUCTION

Project-Based Learning (PBL) is defined as a “model for classroom activity that shifts away from the classroom practices of short, isolated teacher-centered lessons and instead emphasizes learning activities that are long-term, interdisciplinary, student-centered, and integrated with real-world issues and practices” (Holbrook, 2007, Internet). Additionally, PBL has been described as an “identification of suitable projects and integration into a curricular unit ...” (Powers & DeWaters, 2004, p. 2). As can be seen from the above statements and the previous chapters, an essential component of PBL is the bridging of discrete subject areas into projects that address challenging questions or issues. These questions or issues drive students to encounter and struggle with the central concepts and principles of a discipline (Thomas, 2000).

STEM is particularly suited for PBL because of the natural overlap between the fields of science, technology, engineering and mathematics. In the real world, solving social and environmental problems does not occur in isolated domains, but rather at the boundaries of STEM fields. Therefore, STEM PBL, in which students engage in interdisciplinary inquiries that are often focused on real-world issues, is very relevant to the actual collaboration that takes place within the STEM fields. Research shows that the integration of mathematics and science may also lead to improvements in student achievement, greater student interest in subject matter and enhanced student motivation (Stinson, Harkness, Meyer, & Stallworth, 2009). In one study students reported that their experiences participating in interdisciplinary STEM PBL helped them to better understand the world around them (Fulton & Britton, 2011).

STEM PBL is also suited for building STEM literacy, which is now identified as an important outcome of education for ALL students. According to Zollman (2012), in order to enact “STEM literacy for learning ... STEM areas cannot be viewed as independent silos of content” (p. 15). Instead, STEM learning within the classroom should be seen as a “meta-discipline,” in which curricular areas are integrated in a way that promotes analysis and deep understanding.

CHAPTER OUTCOMES

When you complete this chapter you should be able to:

- provide reasons for how interdisciplinary STEM PBL helps to develop students’ conceptual understanding
- be aware of the advantages and limitations of interdisciplinary STEM PBLs
- select the best environment for planning a STEM PBL with the help of small learning communities and community partners
- decide if community partners can help you plan an interdisciplinary STEM PBL
- use a concept map to begin planning a STEM PBL
- reflect on your readiness to plan an interdisciplinary STEM PBL

WHY INTERDISCIPLINARY STEM PBL?

Research shows that when learning is fragmented, students often fail to understand how various subject areas are integrated with each other. While discipline-specific learning is important, particularly for basic understanding of a subject area, interdisciplinary learning has the potential for building higher-order thinking skills and helping students form meaningful connections between subject areas (Ivanitskaya, Clark, Montgomery, & Primeau, 2002). Conceptual knowledge results when disciplines are integrated and learners are involved in socially-interactive learning (Cobb & Bowers, 1999). STEM PBL is perfectly suited for developing students’ conceptual knowledge, because well-designed PBLs are inherently interdisciplinary and collaborative in nature. STEM PBL facilitates the integration of content from different subject areas, which naturally fits the science, technology, engineering and mathematics (STEM) focus of this book.

SO WHAT DOES AN INTERDISCIPLINARY APPROACH TO TEACHING LOOK LIKE?

There are important similarities and differences between traditional instruction and PBL instruction. [Table 1](#) will be used as an advanced organizer for this chapter by providing a comparison of these two pedagogical approaches.

Table 1. Comparison between Traditional and PBL Classrooms

Traditional Classrooms	PBL Classrooms
Defined task	Ill-defined task
Loosely-defined outcomes	Well-defined outcomes
Individual learning	Cooperative, group learning
T is the giver of knowledge	T is the facilitator of knowledge
Objective driven	Standards driven
Single subject/topic	Multidisciplinary
Textbook driven	Problem driven
Teaching based on covering skills	Teaching based on learning and curriculum needs
Success based on grades	Success based on performance
Individual activities with teacher-directed challenges	Cooperative activities with self-directed challenges
Focused on segmented coverage	Focused on culminating performance
Dependent problem solving	Independent problem solving
Narrow curriculum	Comprehensive curriculum
Tests and quizzes to assess knowledge acquisition	Culminating artifacts/experiences at the end of the PBL to determine knowledge gained

The definition of interdisciplinary is the mindful involvement and integration of several academic disciplines and methods to study a central problem or project (Jacobs, 1989). Put another way. "... Interdisciplinary refers to the explicit recognition and connection of content and instruction from more than one subject or academic discipline in a teaching and/or learning experience (Taylor, Carpenter, Ballengee, & Sessions, 2000, p. 7). PBL is suited for interdisciplinary instruction because it naturally involves many different academic skills, such as reading, writing and mathematics and is suited for building conceptual understanding through the assimilation of different subject areas. For example, PBLs typically address written and oral communication skills because students communicate their findings to their classmates through written products and presentations. PBLs may also incorporate other academic skills such as critical-thinking and problem solving skills and visual and fine arts skills. PBL is also suited for instruction across a broad spectrum of subject areas. For example, PBLs often include content related to social sciences and government because the issues and problems that are investigated as a part of PBL are real and directly applicable. An example of an interdisciplinary PBL is contained in Appendix G.

Working to implement interdisciplinary PBL necessitates that teachers have opportunities to collaborate with colleagues. Therefore schools that are looking to enact PBL should focus attention on creating opportunities for teachers and other school personnel to work together for the benefit of students. Scheduling common planning times for teachers requires the cooperation of all stakeholders. This planning may take place before, during or after school hours. In other schools, the administrators or department heads may develop a schedule whereby teachers can plan in small groups, among or across grade groups, or among or across subject areas depending upon the master schedule of the school.

During small group planning time, an interrelatedness of knowledge must be present among teachers. Subject-area boundaries would be difficult to distinguish if a school was truly striving to work towards this interdisciplinary approach. When teachers plan interdisciplinary PBLs together, topics or projects should necessitate understanding from various subject-area teachers.

FOSTERING UNDERSTANDING THROUGH PBL

PBL encourages students to become independent problem solvers and fosters students' understanding across diverse subject areas. In STEM PBL, students typically work in cooperative learning groups on meaningful activities that are relevant to real-world issues. These activities are designed to motivate students through their content and by appealing to students' personal interests. As teachers carefully plan these projects, a natural interconnectedness of topics is supported that introduces curriculum more comprehensively. This comprehensiveness and connectedness fosters student understanding and motivation.

It is important to note that the total integration of all subject areas with the implementation of every PBL is not always possible or even desirable. Successful PBLs are not always interdisciplinary. There are also several factors that can impede the successful integration of subject areas. In this regard, students and teachers may not be ready for the heightened expectations of interdisciplinary PBL. There may also be constraints on the time that teachers have to collaboratively plan interdisciplinary PBLs and to schedule joint classes. Students may also lack subject area knowledge to support effective integration of subject areas. However, various levels of integration are possible as can be seen in [Table 2](#) in the next section. Thus teachers can decide for themselves based on available resources, their readiness and students' readiness for PBL, the degree to which they would like to enact interdisciplinary PBL.

CONTINUUM OF PBL CURRICULUM INTEGRATION

So what exactly does the continuum of PBL curriculum integration look like in the classroom setting? Teachers typically vary in the degree of curriculum integration present in their classroom. [Table 2](#) below illustrates the continuum of curriculum integration. In level one, all understanding is rigorously constrained to that which is explicitly defined within a single subject area. No intrusion of other subjects is typically present. In levels two and three, there is an understanding from various subject areas that is connected and related together; however, topics are still treated as discrete subjects. Teachers from different curricular areas may plan together, but each carries out lessons focused on their discrete subject areas during their own classes. Minimal extensions to other subjects may be present. In level four, there is complete integration of subject areas to the degree that subject-area boundaries are no longer recognizable.

[Table 2](#) illustrates the key characteristics of each level of curriculum integration. Examination of this table provides insight into the forms of planning, topics and learning environments typical at each level of curriculum integration. One can also locate the role of the teacher and the student at each of these levels.

Table 2. Continuum of PBL Integration

Level	Planning	Standards Topic	Learning Environment	Role of the Teacher	Role of the Student
1 Individual classroom	Individual/Daily/ Weekly	Single Subject	Focus on Learning Objectives/ Single Classroom	Generally giver of all knowledge	Generally works individually/ Receiver of knowledge
2 Themed Unit	Grade Level/Subject Area/Weekly	Theme/Unit/No attempt to Integrate	Generally single classroom instruction	Knowledge giver/Sharer	Individually/Small Group/Receiver of Knowledge
3 Multidisciplinary	Grade Level/Subject Area/Small Learning Communities	Two or more subjects, Some attempt to integrate	Focus on student achievement	Shared learning/Facilitator	Shared Learner/Knowledge Gatherer
4 Total Integration/Interdisciplinary	Small Learning Communities	Seamless integration within and between disciplines	Focus on acquisition of knowledge	One of many facilitators of PBL	Knowledge Gatherer/Work in small groups/PBL in SLC

WORKING IN INTERDISCIPLINARY PLANNING TEAMS

In order to successfully implement interdisciplinary STEM PBL, teachers should have the opportunity to participate in professional learning communities (PLCs). PLCs are a staff development approach in which teachers and other school personnel are provided with common planning time to collaborate and plan

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instruction. This approach has been shown to yield improvements in student achievement (Anfara, Andrews, Hough, Mertens, Mizelle, & White, 2003; Sweetland & Hoy, 2000). A recent research study funded by the National Science Foundation showed that when STEM teachers participated in PLCs, teacher instruction and student achievement improved (Fulton & Britton, 2011).

PLCs are typically comprised of 4-6 teachers. The teachers may all teach in the same curricular area; however, they are often interdisciplinary in nature. Research has shown that there are several characteristics of effective teams. In this regard, effective teams work collaboratively, display a strong sense of community, are proactive rather than reactive, have an intense commitment to student achievement and work closely with parents.



ESSENTIAL COMPONENTS FOR FORMING INTERDISCIPLINARY TEAMS

Common planning time promotes interdisciplinary collaboration among teachers. The planning time allotted for interdisciplinary teams should encompass a sustained period of time and include the same interdisciplinary groupings of teachers over the school year. Working and planning in close surroundings, such as one wing of a building also helps to promote collegiality among interdisciplinary teams. Teams should ideally consist of a small number of teachers, somewhere between three and five with a student population between 100-150 students.

These interdisciplinary teams could be the building blocks for Smaller Learning Communities (SLCs) (Cotton, 2004). As teachers feel more comfortable planning and working collegially in these small teams, they can transition into SLCs, which are interdisciplinary teams of teachers. A SLC may contain one or more teams, but never has more than a few hundred students. Each interdisciplinary team of teachers shares common students and organizes instruction to gain more instructional time with fewer students. Over time, it becomes easier to move on the continuum from level one to level four; however, change takes time and so generally teachers should expect to move from one level to the next rather slowly.

INTERDISCIPLINARY AND MULTIDISCIPLINARY PLANNING FOR A PBL: ALWAYS PLAN WITH THE END IN MIND

Planning for an interdisciplinary STEM PBL necessitates first identifying what learning objectives need to be covered in each subject area by determining the well-defined outcomes. Teachers should always think first about what they want their students to know at the end of the PBL. Assessments with interdisciplinary rubrics can assist in this process as will be illustrated in Chapter 12. At the end of the PBL, students should be able to demonstrate their learning to peers and teachers by presenting their artifacts.

An interdisciplinary concept map is a useful tool for teachers to use when determining what skills should be covered in the PBL. Concept maps provide a simple visual representation (see [Figure 1](#)), which allows teachers to imagine all the possibilities for an interdisciplinary STEM PBL. The concept map below is simplistic, but can be developed to include all the state standards involved in rocketry STEM PBL.

Collaborative planning among teachers is not always easy. The following section reviews some of the issues that can arise when teachers are engaged in collaborative planning through SLCs or other groups. Awareness of these potential issues beforehand can help to prevent later problems.

What Are Some of the Issues That Can Arise When Trying to Plan Together?

There are several factors that may reduce the success of interdisciplinary groups, including logistics, personality differences, and teacher roles. Logistics here refers to the challenge of organizing and finding common planning times for teachers. The district and building leadership is critical in ensuring that teachers are supported in having common planning time. Personality differences can also contribute to difficulties in forming working partnerships. The first step will be to break down the barriers so all stakeholders can develop mutual understanding. The central focus always needs to be on what all stakeholders can do to improve the achievement of students. Teachers' roles can also become a source of conflict when the goals of cooperative planning are not clear.

To promote successful collaboration, teachers should be provided with training in interdisciplinary teamwork. Teams work best when their roles are clear from the outset. Feedback from an experienced leader can be helpful in this process.

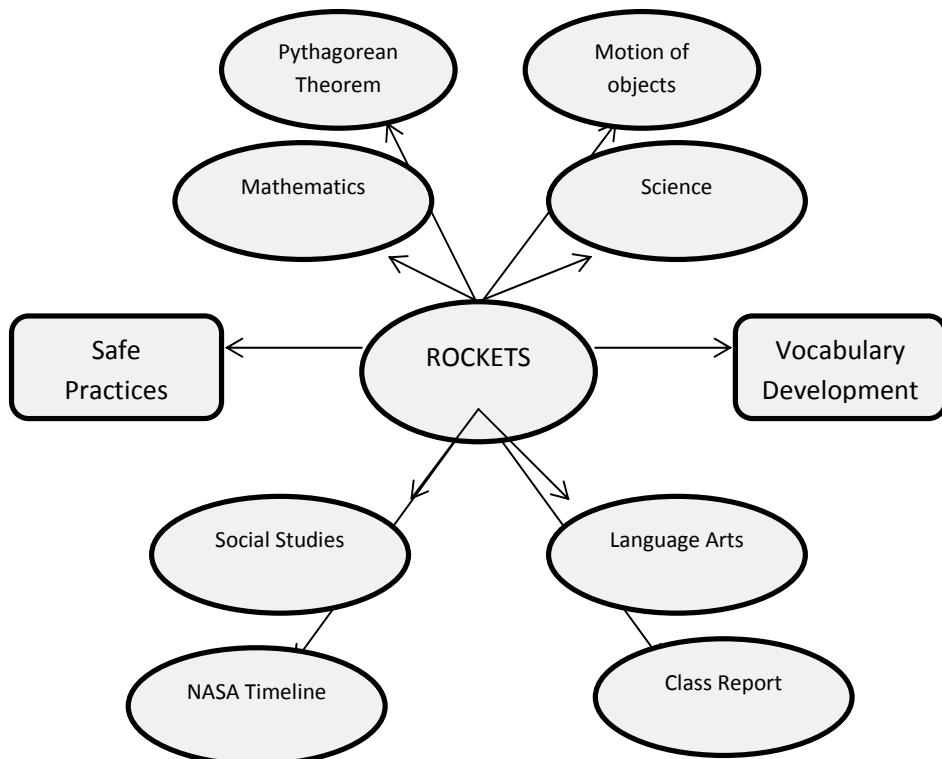


Figure 1. Interdisciplinary rocketry PBL concept map

WORKING WITH BUSINESSES AND COMMUNITY AGENCIES AS PARTNERS

Forming partnerships with businesses, government agencies and community organizations can be an asset in planning and implementing interdisciplinary STEM PBL. External partners often provide students with greater insight into real-world issues that can be addressed in the STEM PBL and hands-on learning experiences. Research shows that when schools and external partners commit to specific activities intended to

benefit students, this can lead to improvements in student achievement and help accomplish school goals (Kanter, 1999). Many high schools are moving towards forming academies around a subject area theme to prepare students to enter the workforce. Involving partners from businesses and outside community agencies can serve to strengthen these academies.

Individual schools may initiate a partnership by recruiting a business, community organization, or government agency as a partner. Science museums, technology companies, workforce organizations, and local arboretums are a few examples of potential STEM partners (Broward County Public Schools, 2006). For example, partners can help to develop a mock business in the school, serve as guest speakers, facilitate field trips to their business sites or provide job-shadowing opportunities for students. Major corporations, such as Bank of America and Pizza Hut have helped schools organize their own restaurants and banks. Motorola has assisted schools with setting up robotics programs. The breadth of imagination is the only barrier to the opportunities that can be afforded through partnerships between schools and outside entities. The discussion below can assist a school in deciding if a partnership will be an asset in planning and implementing interdisciplinary STEM PBL.

Excellent partnerships are: (1) designed to improve student achievement and are an integral part of school planning, (2) committed to improving the quality of public education in order to prepare all students to live and work in the 21st century, (3) guided by written, realistic action plans that include planning, goal setting, communication, recognition and evaluation, (4) able to demonstrate progress toward priority goals; thus, they should be to assist in planning and contributing to activities that will strengthen the educational value to students, and (5) evaluative of their success primarily on the basis of improvements in student achievement rather than on programmatic success with their own structure (Broward County Public Schools, 2006).

The benefit of partnerships to schools and students include: (1) providing teachers with ideas for novel teaching/instructional strategies, (2) providing additional human and financial resources to schools, (3) demonstrating to students that education is important for life, (4) supporting efforts to improve student academic achievement, (5) delivering the message that the community cares about students' academic success, (6) providing opportunities for greater awareness of career options (7) increasing students' self esteem, and (8) enhancing learning opportunities in nontraditional settings.

ADVANTAGES AND LIMITATIONS OF INTERDISCIPLINARY STEM PBLS

There are several advantages of using interdisciplinary STEM PBL (Hall, 1995). Some of the advantages include:

- Elimination of a fragmented curriculum – Interdisciplinary PBL provides an alternative to the traditional curriculum in which learning is typically highly fragmented by subject area. In PBL, learning is more natural and suited for building deep conceptual understanding.
- Developmentally appropriate – Interdisciplinary PBL is developmentally appropriate because the curriculum changes depending upon the individual needs of the students. This results in students being more active and engaged in their learning.
- Flexible curriculum – Interdisciplinary PBL has a flexible curriculum so teachers can meet their curriculum mandates while leading students into their own explorations.
- Meets needs of diverse learners – Students' needs are met by being empowered with the responsibility for their own learning (Low & Shironaka, 1996)

Like any other instructional approach, interdisciplinary PBL also has some limitations (Coate & White, 1996). Some of these limitations include:

- Time constraints – not all educators think there is adequate time to plan and implement interdisciplinary PBLS
- Difficulties in planning and implementation – scheduling common planning time for teachers from different subject areas can be challenging and nearly impossible without administrative support
- No textbook or classroom routine – During PBL, students will be moving around the classroom rather than seated at one assigned desk. Not all teachers are comfortable with the idea of not following a textbook that contains a set curriculum with questions at the end of the chapter (Kain, 1996).
- Student prior knowledge – The student population in one classroom may possess different knowledge than students in another classroom. Some teachers may lack the imagination to determine students' prior knowledge when working with many skills and to allow students to work at their own pace within their own levels.

- Student reactions – Students who have not experienced interdisciplinary PBL may react negatively when it is first implemented. For example, students may wonder, “why are we doing math in science?” These types of reactions can be reduced if the PBLs are well planned and teachers work collegially to implement interdisciplinary PBLs.

EXAMPLES OF INTERDISCIPLINARY PBLS

There are several different examples of interdisciplinary PBLs. Schooler (2004) developed a PBL called a “Chilling Project.” This PBL was the result of collaboration among mathematics, science, and technology teachers. The ill-defined task was to build an ice container. The teachers combined their classes once a week. Students worked in teams using their ideas about three-dimensional figures and technology in the design of the ice container. At the conclusion of the project, students’ ice container designs were evaluated based on guidelines that were developed at the start of the project.

Another example of interdisciplinary STEM PBL comes from collaboration among eighth grade mathematics, language arts, social studies, and science teachers. These teachers worked together to develop a matrix of activities on the topic of landforms. The collaboration among the teachers resulted in the creation of a lesson plan, activities and assessment strategies. The authors reported that their method was a fairly easy way to integrate multiple disciplines (Horton, Hedetniemi, Wiegert, & Wagner, 2006).

The final example of interdisciplinary PBL was based on the integration of mathematics and technology with the ill-defined task being to design a stairs system. There were a variety of skills addressed in this PBL. For example, students were required to use mathematical formulas and functions such as the Pythagorean theorem and slope in designing the stairway. The PBL also incorporated history as students were asked to write a short one-page paper on the history of stair designs. At the end of the project, students were assessed on their stair designs, educational visions, pictorial representations of the project and written papers describing the total project (Merrill & Comerford, 2004).

SUMMARY

Interdisciplinary STEM PBL has the potential to provide significant learning benefits to students in terms of building critical-thinking and problem-solving skills and bridging classroom learning with the real world. As demonstrated throughout this chapter, interdisciplinary PBL is much easier to implement and more effective when support structures are in place. Working and planning with colleagues, whether in a small group, PLC or SLC, can make the work of planning an interdisciplinary PBL much easier and more successful. Partnerships with local businesses, organizations or community agencies also provide additional opportunities for collaboration. It is important to keep in mind that there are advantages and disadvantages to every new approach and innovation, such as interdisciplinary STEM PBL. The process of planning and implementing STEM PBLs can be a radical departure from traditional practice for teachers and students, and therefore may elicit negative responses. However, given the benefits of interdisciplinary STEM PBL for students, this approach should be considered by administrators and teachers as they look for ways to provide students with learning experiences that will build deep conceptual understanding and increase students’ engagement.

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7. STEM PROJECT-BASED LEARNING: SPECIALIZED FORM OF INQUIRY-BASED LEARNING

INTRODUCTION

Project-based learning (PBL) is an instructional approach that utilizes student-directed inquiry processes to develop a product that has real-life connections and applications (Johnson, & Lamb, 2007). Specifically, PBL consists of *inquiry*-based tasks that help students develop important technological, social, and core curriculum content (Nastu, 2009). PBL has also been defined as a “special case of *inquiry*” (Slough & Milam, 2008, p. 19). Thus STEM PBL and inquiry-based learning go hand-in-hand in terms of student-centered instruction.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- understand how to use inquiry in implementing STEM PBL lessons
- understand how STEM PBL benefits from inquiry-based learning
- be aware of the advantages and limitations of inquiry-based learning

When you complete this chapter you should be able to:

- understand how inquiry-based learning has evolved through years to become STEM PBL.
- be ready to develop better STEM PBLs with the proper use of inquiry in lesson planning and implementation

WHAT IS INQUIRY BASED LEARNING?

Inquiry-based learning is an instructional method that was developed during the discovery learning movement of the 1960s (Bruner, 1961). It was developed as an alternative to traditional teaching methods in which students are taught largely by rote memorization. Inquiry-based learning is a learning and teaching approach that engages students to explore their own questions and interests by (1) Asking meaningful questions (2) Planning and executing investigative strategy (3) Gathering information from a variety of sources (4) Discussing information in a productive presentation (5) Reflecting on their own learning (see [Figure 1](#)).

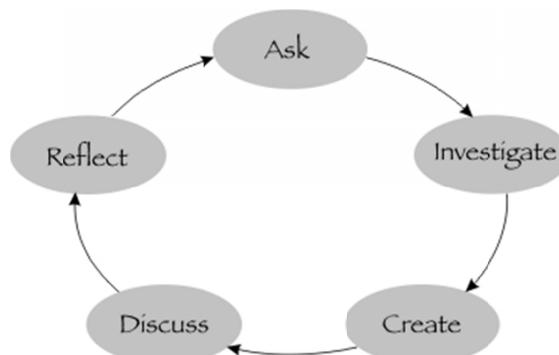


Figure 1. Illustration of Inquiry-based learning steps (Bruce, 2011, p.1).

STEM PROJECT-BASED VS INQUIRY-BASED LEARNING

Both PBL and inquiry-based learning are active learning methods that are grounded in the philosophy of John Dewey who believed that education begins with arousing students' curiosity. The following sections describe the differences and similarities between these two approaches.

In the inquiry based learning method, students' questions and curiosity form the central part of curriculum. Students are encouraged to ask questions and conduct research on topics they are interested in to make their own discoveries (Kessler & Galvan, 2007). Inquiry-based learning begins with a question (mostly from a teacher) followed by an investigation, which may involve data collection and student research to develop new knowledge. At the conclusion, students reflect on their newfound knowledge (Branch & Oberg, 2004). In contrast, STEM PBL begins with the end in mind. Students are introduced to the PBL through a well-defined outcome that relays clearly defined expectations and constraints for the completion of the task (Capraro & Slough, 2008).

During inquiry-based learning, students ask questions, conduct research, collect data, and make inferences. Through their research, students make their own discoveries as opposed to producing a product or artifact that has real-life applications. STEM PBL instruction differs from inquiry-based learning in its emphasis on students' construction of artifacts to represent what they have learned. Unlike inquiry-based learning, ill-defined task talks about an artifact or product that is going to be produced by students in the end, which is a solution to a real life problem. Also, the ill-defined task or driving questions requires multiple solutions constrained by the teacher so that easy or lazy solutions are not possible (Capraro & Slough, 2008).

STEM project-based learning is typically less structured than the inquiry-based learning approach because each group has to organize their own work, materials, individual duties, and manage their own time. Thus in STEM project-based learning, students take charge of their own learning and develop collaboration skills. At times, the less-structured nature of PBL, may make PBL classrooms appear to be unorganized, off-task, or out of control.

The inquiry-based approach is primarily used in science education where hands on activities are encouraged and scientific methods are studied on authentic problems (Savery, 2011). In contrast, STEM PBL is typically more interdisciplinary in nature (Serkan, 2009). Interdisciplinary/multidisciplinary lessons study one problem from the perspective of multiple disciplines to cover their individual learning goals and standards based on their needs and interests (Capraro, 2009). Teachers may also develop partnerships with professionals in the community to come up with better and more engaging projects.

Inquiry-based learning is driven by the questions that students care about the most. The role of teachers is to guide the students to find answers to their questions and encourage them to ask new questions. As students largely drive the lesson, teachers take on the role of a guide who makes sure that everybody is on task. As in inquiry-based learning, the role of a teacher in STEM PBL is similar to a coach or guide, who monitors students' progress throughout the project and make sure every group is working collaboratively towards one goal: completing the project. The main difference between the role of the teacher in STEM PBL is that STEM PBL teachers direct students to their groups to find answers to their questions. In contrast, inquiry-based teachers ask guiding questions to help them. Teachers in inquiry-based learning value students' prior knowledge, experience, and interests thus build the new learning or questions on top of it whereas this is not exactly the same in STEM project-based learning in which the project that students are supposed to study don't have to be built on their previous experience nor their interests but should be real world tasks and engaging.

Because students are assigned to solve problems/projects that are from real lives and have real life applications, students must investigate, record, analyze, and present their findings. Naturally, "the hallmark of [STEM] project [based] learning is greater independence of inquiry and ownership of the work on the part of students" (Houghton Mifflin, p. 6). In contrast to inquiry-based learning, STEM PBL grants students a greater degree of freedom to discuss, test, and create their own solution.

Assessment is an integral part of inquiry-based learning. Like STEM PBL, inquiry-based learning uses both formative and summative assessments to make sure students learn what they are supposed to learn. Formative assessment is an ongoing tool used throughout the lesson, and can take many different forms, such as student observations, taking notes, thus learning and assessment goes hand-in-hand (Annenberg Learner, 2011). In contrast, summative assessment focuses on overall learning outcomes. In inquiry-based learning, it is preferred to have narrative assessment as a summative assessment in which students provide a summary showing their learning to the teacher, family members, and others. Rubrics are also used to measure what students learn during and after group work. By using rubrics, students have started worrying about how much they learned instead of what they learned (Yoshina & Harada, 2009). Use of rubrics is also common way to grade students in both approaches.

Last but not least, one of the main differences between inquiry-based learning and STEM PBL is that engineering design principles (i.e. problem identification, research, ideation, analysis of ideas, testing and refinement, and metacognition and communication) are involved in each step of PBL. The use of engineering in solving real world problems, provides students with a great opportunity to use their mathematics, science, and technology curricula to illustrate concepts that otherwise may be difficult for students to visualize (Morgan, Moon, & Barroso, 2008). In contrast, the steps of inquiry-based learning (see [Figure 1.](#)) are more focused around a specific topic. However, inquiry-based learning does include elements similar to STEM PBL's design principles, such as investigation/research, create/ideation, discussion/analysis of ideas, and reflect/metacognition and communication.

Table 1. STEM Project Based Learning vs. Inquiry Based Learning

STEM Project-Based Learning	Inquiry-Based Learning
Student-Centered and self-directed	Student-centered and teacher guided
Learning and teaching method	Learning and teaching method
Learning through experience	Learning based on prior knowledge and experience
Produces Product	Don't have to produce a product
Collaborative learning	Collaborative learning
Cooperative and group learning	Individual or (not always) Cooperative and group learning
Ill-defined task and well defined outcome	Optional task and loosely defined outcomes
Driven by project	Driven by hypothesis/questions
Constructivism and constructionism	Constructivism
Less-Structured	Structured
Teacher as a facilitator	Teacher as a facilitator
Engineering Design steps is at heart of each STEM PBL lesson.	There is no product and no engineering design steps.
Assessment types: Formative and summative	Assessment types: Formative and summative
Students as question askers and determinant a real world solution to the ill-defined task/real life problem.	Students as question askers
Hands-on and minds-on	Hands-on and minds-on
Projects with real-life applications	Not always
Projects with constraints and within planned schedule	No constraints and specific time schedule
Questions are important part of PBL.	Questions are at the heart of inquiry based learning and teaching.
Multidisciplinary	Single Subject

HOW TO CONVERT INQUIRY-BASED LEARNING TO STEM PROJECT-BASED LEARNING

STEM project-based learning is often less structured than inquiry-based learning because groups may have different numbers of students working on various individual and cooperative tasks. Nonetheless, project-based learning has a more structured lesson plan format than traditional teaching and learning approaches.

The following section describes how to convert an inquiry-based learning lesson plan into a STEM project-based learning lesson plan. This section is based on the *teacher checklist* developed by the Aggie-STEM staff. STEM PBL lessons must include ten sections: 1. Teacher Introduction 2. Objectives 3. Connections 4. Well-defined outcome 5. Materials Used 6. Engagement 7. Exploration 8. Explanation 9. Extension 10. Evaluation /Assessment.

1. Teacher Introduction/Ill-Defined Task

In inquiry-based learning, teachers come up with a topic or theme to attract students' attention (Wells, 1999). Teachers begin the lesson with a short demonstration or instruction, thus setting the stage for the rest of the lesson, in which student questions take the central part. Next, students make a plan detailing how they will investigate their topic. The teacher then reviews and approves students' plans. Students use their journals to record their research. Finally, students publish their findings and share them with the class. To introduce a STEM-PBL lesson plan, the teacher provides some background information about the topic or content students are going to study and use to complete their projects. The teacher will also talk about the ill-defined task that students are going to complete. In STEM PBL the ill-defined task is introduced through a story format with real life context. This introduction has multiple goals: (1) to show that this task has a real life

connection; (2) to capture students' attention; (3) to give students motivation that they have a mission to complete, thus creating ownership of the project; (4) to create the idea that they have to work in groups to complete the task and be successful; (5) to define their tools and constraints to complete their project; (6) to talk about the product that they are going to complete at the end of the PBL; (7) the task is not easy to complete; and (8) the task students are going to complete will be linked to summative and formative assessments.



2. Objectives

STEM-PBL and inquiry-based learning are both based on local and national content standards. For example, in Texas, STEM-PBL lessons have to include TEKS standards for specific subject and grades for each lesson. Because STEM-PBL is often interdisciplinary, teachers have to identify objective for each discipline that is included in the PBL. In contrast, inquiry-based learning is typically used only in science classrooms. Therefore, teachers would only have to report the science objectives addressed in the lesson.

3. Connections

Inquiry-based learning targets to incorporate inquiry and scientific reasoning into the curriculum so the connection goes as far as it lets only for science. STEM PBL lesson plans make connections with other units in the subject you are teaching.

4. Well-Defined Outcome

There is usually no product-oriented outcome in inquiry-based lesson plans, because the goal of the lesson is investigation of content through inquiry and scientific reasoning. In STEM-PBL, the teacher's checklist or PBL lesson plan should include a well-defined outcome that describes a concrete outcome. This outcome may utilize a number of different formats, such as a speech, presentation, product, or model. In STEM PBL, it is important that the product also have real-life applications. There are three components: (1) the deliverable-

what students will produce at the end, (2) the constraints or limitations that keep the project within the boundaries, and (3) the learning students will own when they are finished (focus on the verb).

5. Materials

Both STEM PBL and inquiry-based learning involves the use of different materials. The primary difference between these two approaches is in the quantity and quality of those materials. While the inquiry-based learning uses limited materials provided by the teachers, STEM-PBL lessons require students to obtain their own materials depending on the size and scope of the project.

6. Engagement

In inquiry-based learning, the introduction to the project is designed to be very engaging to the students. This is very important as inquiry-based learning is based on student-generated questions. This is called the immersion experience (Etheredge & Rudnitsky, 2003) where students either complete a simple task or solve a problem. The immersion experience in inquiry-based learning and engagement in STEM PBL serve to the same goal of student engagement, but the difference happens in the types of engagement activities used in STEM PBL including YouTube videos, short stage-setting activities, writing assignments and games.

7. Exploration

In inquiry-based learning, students finalize their research questions to give a start to their research. During this process, teachers use guiding questions to help students develop appropriate research questions. The research questions should address variables they have learned about in previous instruction.

In STEM PBL, teachers first explain the conditions of their exploration and PBL experience. Students will have certain constraints and limitations (budget, time, materials) to complete their tasks. Formative rubrics are introduced here as well. Unlike inquiry-based learning, engineering design principles are at the heart of STEM PBL design process. Students have to go through all six principles in order to develop a testable project. This process begins with problem identification before each group starts doing research about what they are going to study. Once they come up with different findings, they start discussing, and refining those findings to finalize their final thought. This ideation process continues until all group members agree on the best ideas to test and modify. Once students complete all those processes, they start thinking about what and how they made and their learning steps to appreciate their hard work.

8. Explanation

Unlike in STEM PBL, inquiry-based learning lesson plans form their research groups in this step. Teachers usually decide how many students will be in each group and what group roles will be. Once the groups are formed, they begin conducting research. In order to address the discourse component of inquiry based instruction, teachers require all groups to answer the same question or conduct the same research. Once this facilitates the common language for talking about inquiry, other research can be done separately. The next step in inquiry-based instruction is to design a consequential task in which students find opportunities to show what and how they learned and what unanswered or new questions are.

In STEM PBL, as students understand what they are going to study, they begin using related content knowledge. At this point, teachers also start explaining the subject matter knowledge (theory behind), and the other issues to make the task clear. If teachers realize that most students have unsatisfactory knowledge of the content, they may stop whole class and reteach the related content before students continue their projects.

9. Extension

In both PBL and inquiry-based learning, the extension step includes additional short projects for students who finish early or who are capable of doing additional work. The extension projects will be more content related in inquiry based learning whereas it may include a product related project in STEM PBL.

10. Evaluation/Assessment

Both PBL and inquiry-based learning have formative and summative assessments. Formative assessments are based on content knowledge, skill developments, observational notes, and student conferences. Some of summative student assessment is ongoing throughout the investigation. Students are assessed in content knowledge, skill development, and habits of mind displayed. The tools available for teacher information

include individual student conferencing, observational notes during work time, the journals, the questioning techniques, and the presentation to the class. Unlike STEM PBL, science journals in inquiry-based learning are an excellent source for summative assessment. The use of rubric is respectively more common in STEM project-based learning than it is in inquiry-based learning.

SUMMARY

Project-based learning focuses on creating a product or an artifact by using problem-based and inquiry-based learning depending on the depth of the driving question (Johnson & Lamb, 2007). It is an extended inquiry in which students use inquiry each and every step of project completion due to its student-centered and self-directed side of it. But it is important to remember STEM PBL has been designed to hold students responsible for their own learning, thus, encourage students to develop the skills they need for the 21st century competitive world, such as technology skills, proficient communication and problem solving (Bell, 2010).

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8. TECHNOLOGY IN STEM PROJECT-BASED LEARNING

INTRODUCTION

Technology has penetrated almost every aspect of our lives. It plays an essential role in education, especially in Science, Technology, Engineering, and Mathematics (STEM) education. This role can be defined through two categories in STEM Project-Based Learning (PBL). In the first category, technology itself is a subject field that should be learned through integration within STEM Education. Technology is the visible face of STEM. Many types of 21st century skills and literacies such as information and communication skills, information literacy, mathematics literacy, and science literacy require effective knowledge and use of technology. In the second category, technology nurtures the teaching and learning processes. From this perspective we can define it as educational technology that offers and fosters opportunities for designing and implementing STEM PBL. Therefore, utilizing educational technology may yield more effective, efficient and attractive STEM PBL. This chapter includes a description of technology from the STEM PBL perspective, the important issues that should be taken into consideration while using technology, and the ASSURE model that enables the integration of technology with learning, and suggestions are made for possible technology that can be used through STEM PBL.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- the concept and scope of technology in STEM PBL
- some considerations for effective technology use in STEM PBL
- how technology can foster STEM PBL

When you complete this chapter you should be able to:

- explain the importance of technology in STEM PBL
- integrate technology in STEM PBL
- give examples of educational technologies that foster STEM PBL

DEFINITION AND SCOPE OF TECHNOLOGY IN STEM-PBL

In order to understand the role of technology in STEM PBL, first the concept of technology and its importance in STEM PBL should be explained. A functional definition is that, “technology is the making, usage, and knowledge of tools, machines, techniques, crafts, systems or methods of organization in order to solve a problem or perform a specific function” (Technology, n.d.). That is, technology, driven by human genius and creativity, aims to make the lives of people easier by solving problems, and offers a more efficient and productive life. That is why a concise definition of technology is what is human made (Yakman, 2010). In this context, do science, technology and engineering each have the same meaning? Or do they differ in some way or ways? Why do these fields meet in STEM? First, these questions should be answered in order to understand the role of technology in STEM.

Science is one of the concepts most likely to be confused with technology. Science and technology are two different fields; however, they are often used together. Thus, they have been considered complementary concepts (Brooks, 1994). Science explains the existence, objects and events, the laws and principles of these objects and events, and the relationships among them (Science, n.d.). Therefore, it can be said that the information required to develop a new technology can be provided by the results of scientific research. However, technology may sometimes move ahead of science. For instance, the desire to fly like a bird led people to invent many forms of aircraft. These ancient forms of aircraft were most likely invented without scientific knowledge, but all of them are examples of technology. However, the development of new technology today became possible with the contribution of science.

Technology is also confused with engineering. Engineering is research and development based on science in order to manufacture certain products to solve problems (Engineering, n.d.). Therefore, engineering produces technology to solve problems, but this does not necessarily mean that engineering creates all technology. A worker at a factory, with insufficient scientific and engineering knowledge, may invent new ways to make machines operate faster. In this case, what s/he invents is technology. After that, science can explain the operating principle of the invention that opens new avenues, and engineering uses them and generates the perfect operation of the invention. Moreover, new technologies developed by engineering may yield new opportunities. Therefore, technology makes a contribution to both the development of science and engineering and the invention of new technologies in science and engineering.

Mathematics is an abstract representational system used in the study of numbers, shapes, structure and change and the relationships between these concepts (Mathematics, n.d.). A more concise definition is that mathematics is the universal language of science (Adler, 1991). A scientist cannot prove and define a law or a principle, and engineers cannot design and develop technologies without mathematics. Mathematical equations, scientific rules or engineering design processes may be overlooked in daily life, but people are constantly faced with technological products. Therefore, technology can be described as the visible aspect of science, engineering and mathematics in daily life.

If science, technology, engineering and mathematics can be imagined as parts of the human body, science is the musculoskeletal system, engineering is the brain, technology is the hands, and mathematics is the heart and blood. Therefore, these separate disciplines actually have a close relationship with one another. Today, as in ancient times, it is impossible to manufacture supersonic aircrafts, robots or space shuttles without knowledge of mathematics, science and engineering. Moreover, new needs, aims and inspirations that result from the evaluation of the performance of these technologies contribute to the development of the fields of science, engineering and mathematics. All the projects that have contributed to the development of humanity, such as submarines, space shuttles, bridges, tunnels, cell phones and international space stations are realized with the use of the fields in STEM. Thus, an integrated approach is necessary in order to understand and learn about these fields that are so interrelated with each other in real life. This approach is provided by STEM. One of the most appropriate teaching methods for STEM education is PBL because it provides real-life like experiences for learning. PBL is a learning method that requires students to access multiple sources of information, apart from their teachers or textbooks, in order to solve complex real-life problems. It enables students to comprehend and use the information obtained through collaboration to learn one subject deeply, and to also learn multiple STEM subjects at the same time, adopting higher-order levels of thinking. It encourages, self-regulation, and the acquisition of life-long learning skills within the process. How can technology contribute to the STEM PBL learning process? In order to understand this, the considerations when using technology in STEM PBL should be explained.

CONSIDERATIONS IN USING TECHNOLOGY IN STEM PBL EDUCATION

How can technology contribute to the design and implementation of STEM PBL? STEM PBL aims to teach technology integrated with other fields, and to make the learning process more effective and attractive through the use of technology. Therefore, technology has two roles in STEM-PBL: 1) Technology education integrated with science, engineering and mathematics (Capraro, 2009), and 2) Using (educational) technology to foster STEM PBL (Cifuentes & Ozel, 2009). In the following section, the first role of technology in STEM PBL and the things that should be taken into consideration while using technology will be discussed. In teaching STEM PBL to students what would the desired student outcomes be regarding technology? There are many possible answers to this question. However, the most important outcome would be innovation, which is directly related to the definition of technology.

Using Technology in STEM PBL for Innovative Teaching and Teaching Innovation

Which events and movements most changed the course of history? The birth of the Messiah, the Renaissance and the Reformation, or the Industrial Revolution, might be the first things that come to mind. Considering history in terms of technological developments, it is obvious that there is a technological innovation behind every milestone event. The discovery of America depended on the invention of sailing ships that could travel over long periods of time. The Renaissance and the Reformation involved the spread of ideas and ideals among people. That spread of ideas depended on the invention of the printing press and the increase in the number of books and their availability.



People owe their use of many things that make life easier, such as motor vehicles, computers and plastics to technologies developed during the First and the Second World Wars. The fact that technology equals power, and that more developed technology equals more power was shown during those wars. The Internet, perhaps the most important technology today, was actually invented in order to enable a steady communication in case of a nuclear war. Consider the technologies invented courtesy of the Internet, with all their social, educational, economic and political effects. New technologies play an important role in the development of humanity and civilization, while creative thinking and *innovation* play an important role in the invention of these technologies. It is hoped that no more war will break out today or in the future; however, the competitiveness in many areas will continue. Therefore, the scientists, engineers, inventors and teachers of the future should be educated in a manner that encourages them to be innovative. This cannot be realized with teacher-centered teaching methods (President's Council of Advisors on Science and Technology, 2012). Students can only learn about innovation and adopt innovative thinking skills through an innovative teaching method. STEM PBL provides students with higher order level outcomes based on national and/or state standards (Yetkiner & Capraro, 2009). Therefore, technology integrated STEM PBL offers great opportunities for students to acquire innovative skills (Parker, 2011).

In STEM PBL, learners can find new and more practical ways to use technology depending on their own creative and innovative thinking, seek solutions to the problems, and even find new ideas to invent new technologies. For instance, in the robotics projects in which Lego Mindstorms sets are used, students can improve their innovative skills by designing a robot that can perform a task. PBLs, which require students to use the technology creatively may be designed, e.g. the students may not be given a thermometer or a temperature sensor but rather be asked to invent an alternative method to measure the temperature using other sensors or equipment of their choice. Thus, STEM innovators of the future (National Science Foundation, 2010) may be nurtured. STEM PBL offers a great teaching method that challenges students, develops their creative and innovative skills, and enables them to use or even invent new technologies within their own means. Therefore, teachers should design PBLs that will develop students' creative thinking and innovative skills, and allow them to make the best of their opportunities.

A true story about the creativeness and innovativeness of a learner can be accessed from the following link: <http://philosophy.lander.edu/intro/introbook2.1/x874.html>

Using Technology in STEM PBL for Developing Awareness of Sustainability and Environmental Protection

Air pollution resulting from manufacturing and industrial activities has become a severe threat to human health all around the world. Clean water sources have been polluted, rain forests damaged, and fossil fuels are both used up and continue polluting the environment [see <http://www.epa.gov>]. Why did these problems occur and why are they getting more severe every day? Most of these problems have resulted from people's use of technology, and new problems continue to arise; e.g. in nuclear power stations where electricity is produced; problems also occur in petroleum pipelines threatening the natural environment. Technology can

harm both the environment and people. Therefore, raising awareness regarding the negative effects of technology is vital. The use of technology in a way that has the minimum negative effects on nature is an important subject that should be learned; it should also become a philosophy of life. STEM PBL offers a great opportunity to learn about the caveats of technology use (Yakman, 2010). While teaching STEM PBL, teachers may ask students to choose and use technologies that will have the least negative impact on the environment and that support renewable energy. Students may prefer to use recycled or usable waste materials while developing new artifacts. Thus, a technology integrated STEM PBL may enable students to develop awareness and display increased sensitivity regarding environmental protection and sustainability.

Using Technology in STEM PBL for Developing Technological Literacy and I-Skills

The use of technology is almost a requirement of daily life. Today, people need to be technologically competent as well as literate for effective living. Technological literacy (TL) is one of the most important qualifications for a 21st century person to acquire (ETS, 2003), and STEM education is important for the acquisition of this qualification. Technological literacy is, “*the ability to responsibly use appropriate technology to: Communicate, solve problems, access, manage, integrate, evaluate, design and create information to improve learning in all subject areas, and acquire lifelong knowledge and skills in the 21st century*” (Technology Literacy Assessment Project, 2009, p. 1). One of the reasons why TL is a national target is that it enables competition and sustainable development in the fields of science, industry and the economy. Knowledge and skills regarding technology enable people to enjoy better careers, and these qualifications will be even more important in the future (International Technology Education Association, 2007). Therefore, providing students with ability to acquire TL is one of the important considerations while using STEM PBL. A technology integrated STEM PBL is an entirely appropriate method for students to acquire TL.

Another literacy, which is closely related to TL, is information and communication technology literacy (ICTL). ICTL incorporates peoples’ skills to handle information to solve problems and to think critically about information via digital environments (Katz & Macklin, 2007). These skills require people to know about technology and to be able to use it to define access, manage, integrate, evaluate, create and communicate information (Educational Testing Service [ETS], 2002; Katz & Macklin, 2007). Using information and communication technology is very important today (Tyler, 2005). Therefore, standard exams have already been prepared in order to measure ICTL (Katz & Macklin, 2007). I-skills, an exam like SAT, GRE and TOEFL, is applied by the ETS (ETS, n.d.). The I-skills test aims to measure the critical thinking and problem solving skills of post secondary students in the digital environment. Technology enriched STEM PBLs contribute to the development of the above mentioned forms of literacy and skills in learners.

Using Technology in STEM PBL: Considering Digital Natives & Digital Immigrants

Even Bill Gates, the owner of Microsoft, says that he finds it easier to use pen and paper to write something down, rather than using a computer (Gates, Myhrvold, & Rinearson, 1995). Today’s technology, that people are familiar with and use, may be replaced by many different technologies tomorrow and these are, perhaps, unimaginable. The technologies that teachers use today may be sufficient for them; however, they should constantly follow developments in the emerging technologies that can be employed in teaching and learning.

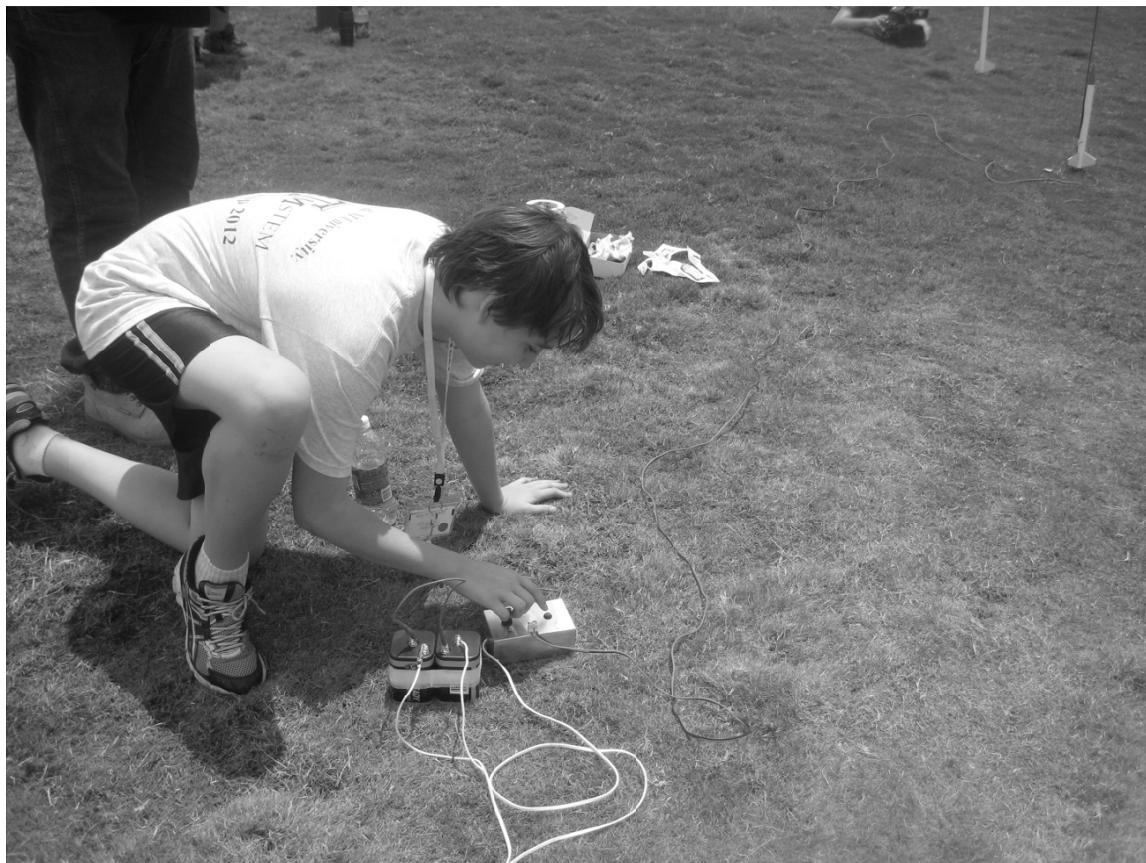
Educators should know about emerging technologies so they can gain understandings and be able to incorporate them efficiently. Research shows that teachers’ technology integration skills and the technology readiness is not sufficient for practice. These levels increase with professional development and practice (Baldwin, 2011). However, students use digital technologies intensively in their lives (Kamenetz, 2010). Prensky (2001) highlights the difference between the technological uses of the teachers and of students, and describes students as “digital natives” and teachers as “digital immigrants.” In all probability, the reader of this book never saw a multi-touch tablet while s/he was a student in elementary school. However, today’s students attending elementary school use applications such as Siri from Apple, or S Voice from Samsung and rich e-books for iPads. These technologies are not difficult to use today, but what if the new technologies and applications the students use in the classroom become unfamiliar to the teachers over time? That is, what happens when students use a digital application explaining the periodic table that is enhanced as compared to the teacher’s static wall poster of the periodic table. Teachers should react normally to this situation and keep abreast of the technological enhancements in their field. The fact that students adapt much better and more easily to new technologies and pedagogical paradigms, has changed the teachers’ role from that of “sage on

the stage” to that of “guide on the side” (Moursund, 1999). Therefore, teachers should let students bring new and appropriate technologies to the classroom in order to enable learning (Nikirk, 2012).

According to some researchers (Waycott, Bennett, Kennedy, Dalgarno, & Gray, 2010) the distinction between digital natives and digital immigrants is still controversial, and some researchers (Bennett, Maton & Kervin, 2008) regard this issue to be a “moral panic.” What matters is that teachers should not only trust their own knowledge today, but also follow the latest advances regarding the use of technology in STEM PBL. The professional developments offered by STEM centers, teacher forums, the small learning community (SLC) (Capraro, 2009), the professional learning community (PLC) (Maxwell, 2009) and library media specialists (Harada, Kirio, & Yamamoto, 2008; Plotkin, 2009) provide people with great opportunities to learn new technologies.

USING TECHNOLOGY FOR FOSTERING STEM PBL

What technologies should be implemented in classrooms? The answer may be computers, a projector, an overhead projector, iPads, calculators, an interactive white-boards etc. Most of these technologies were not invented for instructional purposes. However, they are used in educational settings because technology can contribute to teaching and learning, educational administration and planning, assessment, and guidance processes in education. As a result, all the technologies used for the purposes of education are called “educational technologies” (Lever-Duffy, McDonald, & Mizell, 2005). But it should be kept in mind that the scientific term “educational technology” is a science field that aims to increase learning efficacy and effectiveness through research into technology using appropriate methods and techniques. The terms “educational technologies” or “technology” used in this chapter do not correspond to the above mentioned science field but rather to technologies such as web sites, equipment for experiments, software, applications and sensors that will increase the efficiency of STEM PBL.



Research results indicate that the use of educational technologies in STEM PBL may increase success rates, interest and motivation, as well as improve students' attitudes (ChanLin, 2008; Cobbs & Cranor-Buck, 2012; Doppelt, 2003; Guzey, 2010; Harada et al., 2008; Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011). However, it cannot be said that the use of technology always increases the efficiency of education or enables a more successful STEM PBL (Freshwater, 2009). Technologies appropriate for the outcomes and characteristics of students can enable a successful STEM PBL. Otherwise, technology is costly in terms of excessive time and money can result in undesirable consequences, and produce negative effects on learning.

A useful article and video regarding the importance of technology in education can be accessed from the following link: <http://www.the21stcenturyteacher.com/member-articles/on-education/50-technology-in-education-why>.

Integrating Educational Technology into STEM PBL

Effectiveness, efficiency and attractiveness are three key components of a successful integration of technology into STEM PBL. These concepts are also regarded as the outcomes of instruction that use educational technology (Koper, 2005). Effectiveness, efficiency and attractiveness are related to the achievement of learning goals, students' learning levels, and appeal of the learning process. At least one of these components should be achieved through the integration of technology in STEM PBL. If the technology used in STEM PBL does not contribute to any of these components, the technology and implementation method should both be revised. Using a learning design model may help to provide effective, efficient, attractive, and well designed STEM PBL.

The ASSURE model which aims to guarantee technology integration, active student engagement and effective learning (Smaldino, Russell, Heinich, & Molenda, 2005) can be used in integrating technology into STEM PBL (see [Figure 1](#)). ASSURE is an acronym standing for Analyze learners, State objectives, Select methods and technology, Utilize technology, Require learner participation, Evaluate and revise. The processes that should be conducted in these stages are explained below (Smaldino et al., 2005).

In the 'Analyzing learners' stage, the ages, grades, socio-cultural or socio-economic situations, prerequisite skills, attitudes, interests, motivations and learning styles of the students are described. The technologies the students can use and their skills regarding technology use are defined. These characteristics are taken into consideration while choosing and designing the appropriate technology and STEM PBL, respectively.

In the second stage, 'State objectives,' the outcomes the students are expected to achieve at the end of STEM PBL should be well defined. Defining the outcomes, or examining the previously defined outcomes in the second stage, enables the evaluation of the appropriateness of STEM PBL to the target standards (national, state or local), and the determination of the assessment criteria for the projects (Yetkiner, & Capraro, 2009). Thus, what the students should achieve is clearly stated, and more appropriate teaching-learning processes and the integration of technology can be planned.

In the 'Select method' and 'technology' stage, pedagogical strategies and technology to be used are planned. The primary learning method is obviously STEM PBL. Various strategies such as demonstration and simulation can also be used in different stages of STEM PBL. In this stage, determining how the learning will take place and the roles of teachers and students enables a greater variety of appropriate technologies. While choosing the technology to be used, the characteristics of the students and the defined outcomes are considered. SLCs and PLCs help in choosing the most appropriate technology for the selected STEM PBL. When possible, students may also choose the appropriate application or software themselves under the supervision of their teachers if necessary. Technologies that will make the learning process more efficient by enabling active participation and social interaction is preferred (Nikirk, 2012; Tam, 2009). Modifying an existing artifact or material can also be used in STEM PBL; e.g. the modification of a robot previously made with Lego Mindstorms by the students in order to perform a new STEM PBL task. Students may be given some materials and asked to develop artifacts; that is, students may be asked to build a durable bridge that can withstand a particular load using spaghetti or to design a self-propelling car using waste materials. Modifying existing technologies or designing new ones make a significant contribution to creative thinking and to students' innovative skills (Smaldino et al., 2005).

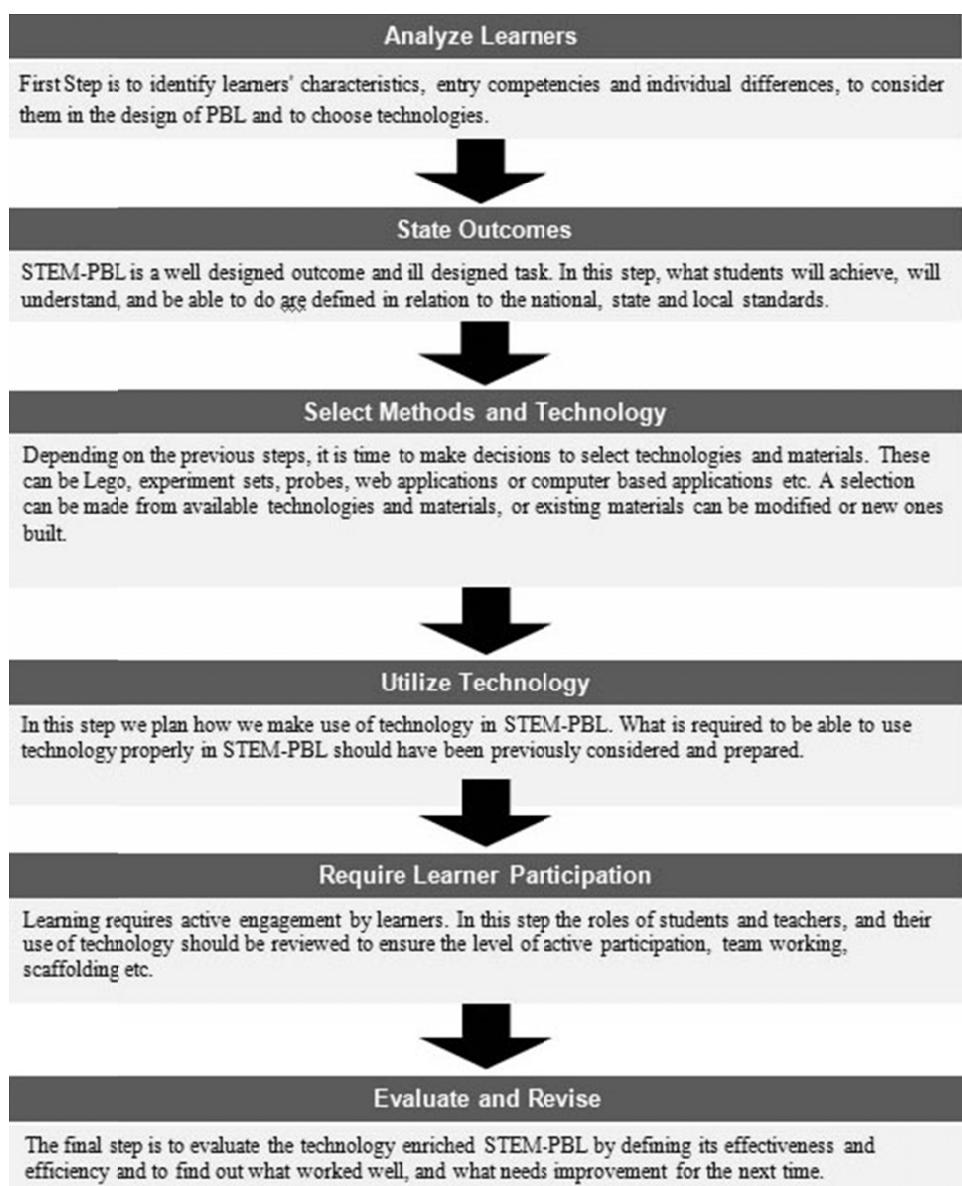


Figure 1. ASSURE Model for STEM PBL (Adapted from Smaldino, Russell, Heinich, & Molenda, 2005)

The fourth stage is to ‘Utilize technology.’ We should ensure that the technologies used in STEM PBL work properly and that the students use them appropriately. Teachers should gain a comprehensive knowledge of how to use the technology, including any negative aspects, before giving handing the equipment to the students. Using technology generally requires the use of other additional equipment. Equipment such as an extension cord, a charging device, and additional accessories or spare parts should be considered and prepared in advance. Some practical examples where supplemental equipment was ignored were: a video did not finish because the computer battery ran down and an electric robot motor broke down during a project presentation. Another important consideration when using technology is the level of student skills. For example, if the students are to design a robot for the first time, they should be given the necessary time and support (Cavlazoglu, Cetin, Erdogan, Akgun, & Stuessy, 2012).

In the ‘Require learner participation’ stage, students should be provided with a sufficiently rich learning experience and the opportunity for social interaction. STEM PBL is assuredly an active learning method. Students should undertake an active role and collaborate with other students while solving a problem or performing a task by using technology. Group study is both advantageous and disadvantageous in some respects. Teachers should always be wary that group work may be done by one person while some members

may abandon the task, or there may be an imbalance of power when a student who is more familiar with the technology than his or her teammates assumes leadership (Brown & Lara, n.d.).

The last stage is, ‘Evaluate and revise.’ This step is very important because the efficacy of technology-fostered STEM PBL is defined in this step and the results help to improve STEM PBL. In this stage, the following questions should be answered: “Was STEM PBL effective?,” “Did the technology contribute to the project?,” “What should be used in order to get better results and how?,” “What are the students’ opinions regarding the learning process, the teachers and the technology?,” and “Did the students achieve all the defined outcomes?” The answers to these questions may contribute to future technology-fostered STEM PBL in order to realize better designs and implementation.

Educational Technologies for STEM PBL

It can be said that educational technologies are almost limitless today. However, more options do not mean they all are useful for fostering STEM PBL. The effectiveness of technologies differs according to context including the subject matter to be taught, the teaching styles and the individual characteristics of the students (Smaldino et al., 2005). Teachers themselves should determine the most appropriate technologies according to the content that includes STEM PBL. Therefore, they should evaluate the efficiency of the technologies used in STEM PBL and make a special list for themselves. They should also update this list by following the new technologies and sharing it with their colleagues and communities. Some of these technologies’ descriptions and web addresses are provided in **Table 1**.

Table 1. Some Educational Technologies for STEM PBL

Description	Address / URL
STEM Center, bulletins, videos, downloadables	http://aggie-stem.tamu.edu/
Online PLCs	http://www.linkedin.com/groups?home=&gid=3391879&trk=anet_ug_hm
Digital resources and social media for teaching	http://ide29dayweb20challenge.blogspot.com/
50 awesome ways to use Skype in classroom for involving experts, parents, etc.	http://www.teachingdegree.org/2009/06/30/50-awesome-ways-to-use-skype-in-the-classroom/
Empowering teachers promoting innovation	http://www.digitallearningday.org/toolkits/
Siemens STEM Academy Teacher Resources	http://www.siemensstemacademy.com/index.cfm?event=showResourceLanding&c=37
Intel STEM Resources	http://www.intel.com/about/corporateresponsibility/education/k12/stem.htm
Intel PBL Resources	http://www.intel.com/about/corporateresponsibility/education/k12/projects.htm
PASCO STEM Modules and Probewares	http://www.pasco.com/family/pasco-stem-modules/index.cfm
Case Studies of Exemplary Using of Technology	http://www.nais.org/files/PDFs/NAIS_excellence_final2.pdf
Developing IOS or Android Applications	http://www.runrev.com/education/k12.html
Some exemplary PBLs	http://www.virtualschoolhouse.net/projects.htm
e-newsletter for STEM Connection and pals	http://linc.mit.edu/stem/2012-april.html
Online resources for STEM Educators	http://www.iteea.org/Publications/STEMconnections/STEMconnections.htm
Subject and Grade Based PBLs	http://blossoms.mit.edu/resources/
PBL for 21 st Century.	http://wvde.state.wv.us/teach21/pbl.html
What technology means to students	http://www.bie.org/
STEM-PBL Contests and Olympiad	http://www.youtube.com/watch?v=BHSehFV98TY
Science and Math Activities	http://siemens.discoveryeducation.com/
TED Education Lessons	http://www.isweep.org/
Classroom wireless collaboration tools	http://www.google.com/intl/en/events/sciencefair/
Semantic Networking (Concept Mapping) Tool	http://www.howtosmile.org/
21 st Century Skills	http://ed.ted.com/lessons
STEM Education Coalition	http://education.ti.com/calculators/products/US/navigator/
	http://www.inspiration.com/
	http://route21.p21.org/
	www.stemedcoalition.org

Classifications and taxonomies can be beneficial to discover which educational technologies might be used and how they can be used. According to the taxonomy of Levin and Bruce (2003), the use of technologies for learning may be examined under four categories. These categories are inquiry, communication, construction and expression. Bruce and Levin (1997) explain the technologies subsumed in these four categories this way: Technologies regarding inquiry enable the searching, finding, collecting, modeling and analysis of certain data; technologies regarding communication enable the presentation and collaborative working through any written, audio, visual or audio-visual form; technologies regarding construction enable the construction or building of new things through technology; and technologies regarding expression enable the sharing of the obtained results with other people in an aesthetically pleasing or artistic manner. These technologies may be

e-books or online encyclopedias which give students direct access to the primary sources of information; probes, sensors and experiment sets which enable data collection; social networking or net meeting web sites which enable access to experts or cyber meetings via online communication tools; presentation or video editing software which facilitate making presentations; and recording or analysis software which extend the mental capabilities of students (Moursund, 1999). Mind tools such as micro worlds, graphic design software and concept mapping tools that enable students to learn better and to develop critical thinking skills (Jonassen, & Carr, 2000), and problem-solving skills (Jonassen, & Reeves, 1996) can be used efficiently in STEM PBL. The students may also use technologies from daily life such as smart phones or digital cameras or waste materials such as the electric motors of discarded toys, and unwanted CDs and DVDs.

Technology can also be used for implementing STEM PBL and also for teacher professional development. One of the goals of STEM Education is teacher development (United States Government Accountability Office, 2012). Teachers should be qualified for a successful delivery of STEM, and STEM PBL. There are many technologies to help teachers update their knowledge, design better PBLs and be better facilitators for their students. Teachers can join web-based forums where they can keep up with the changes regarding STEM PBL, and explore relevant websites (see Table 1). The sample PBLs, lectures and technologies may be helpful for designing and implementing successful STEM PBLs.

SUMMARY

Technology plays an important role in STEM PBL. Through the use of technology in STEM PBL, students can learn about innovation, develop technological literacy, acquire I-skills, and learn about the effects of technology on the environment and sustainability.

Additionally, the educational technologies offer great opportunities in terms of supporting STEM PBL. These technologies should be used effectively in both professional development activities and in the teaching-learning processes. In order to do this teachers should know how to select and use the appropriate technologies for STEM PBL. In this regard, personal experiences, PLCs and SLCs may help. The ASSURE model can be used for effectively integrating educational technology into STEM PBL. Making a list of the most appropriate technologies for the selected STEM PBLs, taking suggestions into considerations from PLCs and SLCs, and evaluating each STEM PBL will result in more successful technology integration for better learning.

Moreover, encouraging students to use technologies during the STEM PBL with active engagement and social interaction is important. The fact that students use technology in a self-directed way in STEM PBL makes a great contribution to their gaining self-regulated learning skills. Also, via the modification, and adaptation of technology, or by developing new artifacts may importantly and significantly improve their creative and innovative skills.

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9. AFFORDANCES OF VIRTUAL WORLDS TO SUPPORT STEM PROJECT-BASED LEARNING

INTRODUCTION

Unquestionably, throughout this text, authors have built a strong case as to why engaging students in science, technology, engineering, and mathematics (STEM) learning is so important. Perhaps topping the list, are the prominent shortages that we are faced with nationally related to the preparation and early recruitment of K-12 students into various STEM fields. Equally alarming are the disparities in recruiting underserved groups (e.g. women and minorities) in STEM (Bayer Corporation, 2010). In addition, the gaps in achievement across STEM areas between white students and students of color are an ongoing challenge (Flores, 2007). In addressing these challenges, two prominent and immediate needs appear to bubble to the top. First, various stakeholders agree that students must be immersed in authentic real-world projects that actively engage them in mathematics and science learning. Scholars uphold the STEM project-based learning (PBL) tenet that integrating engineering design principles into K-16 curriculum, can enhance the real-world applicability (Capraro & Slough, 2008). Second, the combination of deep and specific content knowledge and a thorough understanding of diverse learners are necessary for preparing teachers to close the achievement gaps in STEM. Exploring new ways to prepare teachers to engage *all* students in rich and effective learning experiences in STEM, offers promise in addressing these parallel needs. Innovative technological resources like virtual worlds are available which can support both STEM-focused PBL, and STEM teacher development, in novel ways.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- background perspectives on simulations and virtual worlds
- the affordances of using virtual worlds to support STEM PBL
- teaching and learning examples in Second Life
- where to find getting started resources for educators interested in exploring 3-D VLEs

I join other scholars in the belief that when students are immersed in authentic real-world projects that actively engage them, deeper learning occurs (Scheurich & Huggins, 2008), along with a host of other benefits. This belief is at the core of making the case for PBL. Capraro and Slough (2008) frame STEM PBL approaches eloquently in their discussions on the design of PBLs. They remind us that STEM PBLs, particularly the examples highlighted in this book, all start with a well-defined outcome. They also remind us that ill-defined task(s) are essential to the inquiry process in PBL. It is my belief, and I will attempt to offer some support through illustrative examples, that the affordances of three-dimensional (3-D) virtual worlds can provide a rich environment for STEM PBL.

BACKGROUND ON SIMULATIONS AND VIRTUAL WORLDS

Three-dimensional virtual learning environments like the virtual world of *Second Life* are available which can support STEM learning and teacher preparation in emergent ways. Many concepts and competencies that are foundational across various STEM fields require unique understandings. Computational thinking and problem solving, for example, are critically important across various fields, with an emphasis in technology, engineering, and mathematics certainly. Similarly, various concepts across the field of science require the understanding of spatial relationships (Merchant et al., 2012).

Simulations as a subset of computer-assisted learning have been around since the late 1980s (e.g. SimCity) (Wright, 1989). These earlier programs typically simulated real life places and scenarios. They provided opportunities for learners to interact in environments even when they were not able to physically

visit them. In this way, three-dimensional virtual learning environments were an effective alternative, and fostered experiential and situated learning approaches (Davis, 2012, in press). In the last decade virtual worlds like *Second Life* have been on the leading edge of a new set of technological and experiential applications that have the potential to impact how people communicate, play, work, and learn. Advances in educational theory and cognitive science mean more is understood about the process and impact of learning than ever before. Much of the work on learning in virtual worlds has been exploratory. There are many exciting possibilities for using *Second Life* as a learning tool (Goodband, Bhakta, & Lawson, n.d.).

Hew and Cheung (2010) reviewed empirical research studies on the use of three-dimensional immersive virtual worlds in K-12 and higher education settings and found that they are being utilized in three overarching ways as: (1) communication spaces, (2) simulation of space (spatial), and (3) experiential spaces ('acting' on the world). All three utilizations have great potential for supporting STEM PBL. Dalgarno and Lee (2010) in their review of published research on applications of 3-D virtual learning environments spanning two decades, identified a series of learning affordances that include:

- *Affordance 1: 3-D VLEs can be used to facilitate learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain (p. 18).*
- *Affordance 2: 3-D VLEs can be used to facilitate experiential learning tasks that would be impractical or impossible to undertake in the real world (p. 19).*
- *Affordance 3: 3-D VLEs can be used to facilitate learning tasks that lead to increased intrinsic motivation and engagement (p. 20).*
- *Affordance 4: 3-D VLEs can be used to facilitate learning tasks that lead to improved transfer of knowledge and skills to real situations through contextualization of learning (p. 21).*
- *Affordance 5: 3-D VLEs can be used to facilitate tasks that lead to richer and/or more effective collaborative learning than is possible with 2-D alternatives (p. 23).*

In their review of literature, Dalgarno and Lee reviewed a range of proposed and actual applications of 3-D virtual environments for learning. The affordances identified represent the theoretical learning benefits of 3-D VLEs that were explicitly and/or implicitly purported by the authors included in the analysis.

While being actively engaged in experiential and situated learning in virtual environments, learners can be afforded ubiquitous opportunities to authentically develop an array of skills: new literacies (Jenkins, Clinton, Purushotma, Robinson, & Weigel, 2006), problem-solving or mathematics skills (National Council of Teachers of Mathematics, 2000), scientific literacy skills, and computational thinking and information and communication technology (ICT) skills (Barr, Harrison, & Conery, 2011; ISTE, 2007). Sample skills include but are not limited to: collaboration, problem solving, simulation, critical thinking, and negotiation. The new literacies, for example, almost all involve social skills developed through collaboration and networking (Jenkins et al., 2006).

Bell (2008) tried to synthesize all the elements of virtual worlds and came up with the comprehensive definition of a virtual world as "a synchronous persistent network of people represented as avatars, and facilitated by a network of computers" (p. 2). According to Caprotti and Seppala (2007), the design of 3-D learning activities in the virtual world of *Second Life* (SL) is not hard, although activities that focus on modeling and working out mathematics problems may require different approaches or instructional planning. For example, with recent developments in SL such as extended use of displays that project an array of formats including audio, video and web-based media, and now the availability of interactive pen displays (i.e. *Smart Podium* solutions) working in concert with streaming applications, mathematics concepts, symbolic representations and problems can be presented with greater ease (Davis, 2012, in press).

Slightly different from simulation, role-playing requires more specific concepts on interactive point of view for enhancing interpersonal relations and social transaction among individuals (Tompkins, 1998). Role-playing, as Scarella and Oxford (1992) defined it, is acting out a character represented somehow by everyday life experiences. To achieve the goals for the target topics the participant needs to follow the intended *mission* and responsibilities in order to immerse him/her -self in situations directed toward the ultimate goals (Jones, 1982).

TEACHING AND LEARNING EXAMPLES IN SECOND LIFE

The affordances of using 3-D virtual learning environments to foster rich instructional settings have been briefly discussed in this chapter. Utilizing features of immersive 3-D virtual worlds can support various learning outcomes and tasks in STEM PBL. Virtual world projects and simulations across STEM subjects that

engage learners in new and different ways are highlighted below. These projects help to illustrate two approaches - using virtual worlds to prepare STEM teachers and using virtual worlds to learn STEM content in highly participatory and immersive ways. *Second Life*, an internet-based virtual environment allows its users to create digital self-representations (or avatars). Users (or learners) can interact in the environment in countless ways (see [Table 1](#)). They have the ability to build 3-D virtual objects, move the objects around, view them from all vantage points, or program the objects, as needed, to do a multitude of things. Immersive, hands-on, STEM PBL can be situated within a host of user-designed virtual simulations or spaces in *Second Life* (e.g. students can engage in PBL within a virtual scientific testing center designed by a physics instructor). A variety of STEM PBL design and experimentation activities can take place that are not easily accessible by learners in face-to-face settings. Instructional designers and practitioners can expand the notion of "project" to include PBLs situated within virtual learning environments. Through a wide array of STEM PBL designs, individual learners or design teams can become immersed in authentic real-world learning tasks, with an emphasis on making connections to what STEM professionals might do on the job (Capraro & Slough, 2008). *Second Life* makes possible high representational fidelity (Dalgarno & Lee, 2010) within authentic STEM learning tasks. Moreover, interdisciplinary groups of STEM experts can comprise PBL instructional design teams or serve in advisory roles. STEM PBLs can then be evaluated for authenticity.

Table 1. Features of Virtual Worlds to Support STEM PBL

<i>Sample Features of Virtual Worlds</i>	<i>Possibilities to Support STEM PBL</i>
Communicate and Collaborate with Peers or Experts [Locally/Globally]	Learner has the ability to communicate or work collaboratively with peers or experts during all stages of the PBL
Engage in [3-D] Spatially and Visually-rich Learning or Problem-solving	Learner has the ability to examine and manipulate 3-D objects, zoom in and out on objects, move objects around; learner can investigate complex problems and issues
Access and Experience Authentic Places, Simulations, and Objects in Immersive Environment. Learners experience presence or co-presence in participatory virtual space.	Learner has the ability to intimately examine 3-D virtual objects and places (e.g. City of Paris 3-D Sim, Space Shuttle Simulations) they may not have access to
Engage in [unique] Experimentation	Learner has the ability to engage in simulated innovative experimentation
Engage in Role-Playing	Learner has the ability to engage in role playing (with authentic diverse teams, or small/large collaborative groups)
Design and Build in 3-D Spaces	Learner has the ability to design 3-D virtual objects, inventions, buildings, or spaces
Design Simulations or Games	Learner has the ability to design 3-D simulations and games for diverse audiences
Share or Exhibit Work/Findings to Broader Global Learning Community	Learner has the ability to share project work and findings with peers across their classroom or across the world

Although there are growing numbers of higher education projects and simulations in *Second Life*, there is still room for greater penetration in STEM or integrated STEM learning approaches, particularly designed for secondary students. If one explicitly conducts a search on STEM in *Second Life*, it will yield two prominent results, *STEM Island* (which houses a virtual STEM exhibition) or the *Marshall University Virtual Campus and STEM Academy*. Searching across STEM areas will yield additional results. Caprotti and Seppala (2007) report that searching for mathematics in *Second Life* yields very few locations or projects that focus solely on mathematics. However, as one looks to the literature there are examples of empirical work on teaching and learning mathematics in virtual worlds. Some studies suggest, mathematics explorations in virtual worlds not only provide students visual information to see the mathematics logic (e.g., 3D geometric construction) (Kaufmann & Schmalstieg, 2003), but also have the potential to increase students' engagement and effectiveness in learning mathematics (Harrell et al., 2008).

Sample *Second Life* project examples follow:

- The *Knowledge for Algebra Teaching for Equity (KATE)* project enriches the education of STEM teachers by using emergent technologies like *Second Life* to provide preservice middle school mathematics teachers, early teaching experiences that address topics in problem solving, and equity. Preservice teachers engage in a series of culturally relevant activities in *Second Life* throughout a semester long course. The culminating project for the semester is for preservice teachers to design and lead lessons with a group of middle school student actors (avatars) in the KATE virtual classroom in *Second Life* (see [Figure 1](#)) (Brown, Davis & Kulm, 2011).

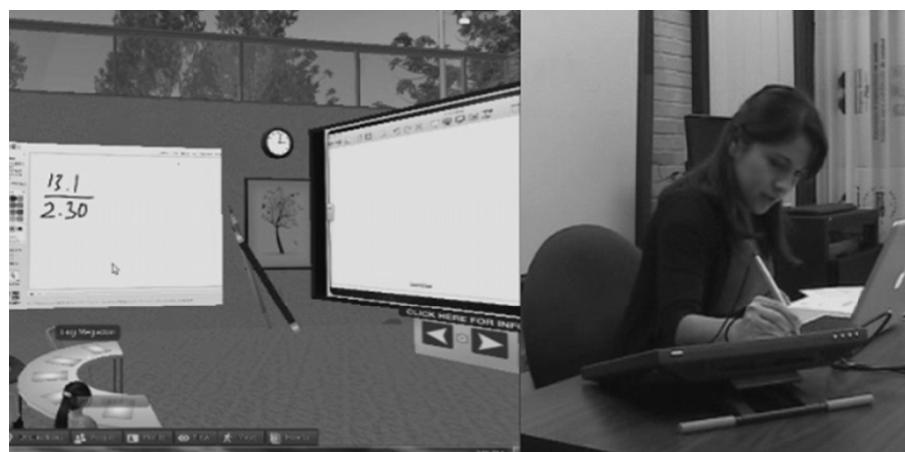


Figure 1. Preservice teacher giving problem-solving lesson in Second Life

- The *Oddprofessor's Museum and Science Center*, and *Oddprofessor's Testing Center* provide innovative examples of how physics students are immersed in hands-on PBL within these instructor-designed elaborate virtual learning spaces in *Second Life*. As one (my avatar) walked around the *Oddprofessor's Testing Center* for example, I was completely pulled in by well-designed experimentation areas and labs that can engage learners in a host of exercises or projects (e.g. interactive vector exercises or “level air track” experiments). As my avatar walked through the space, I was offered a notecard. The instructional notecard shared information like the *Level Air Track* was a model of a very common piece of physics education equipment, used to model 1-dimensional motion at constant speed. The air track does a good job of modeling frictionless motion over short distances. There were two photogates over the track (one red, one blue). Students were instructed to measure the time it took the glider to move between them. Similarly, the *Oddprofessor's Museum and Science Center* housed an interactive virtual workshop for developing demonstrations in Newtonian mechanics for use in teaching physics. The Oddprofessor's virtual learning spaces were very dynamic. It was like visiting a physics Disneyland with various facilities, museum buildings, labs, 3-D models, rich activity areas throughout, inside and outside.
- *Dr. K's Chemistry Corner* (see [Figure 2](#)) provides another powerful example of how *Second Life* is being used by students in a core introductory chemistry course to explore molecules. Prominent simulations in this space include *The Molecule Game*, *The Chemist as Artist*, and *The Tower of VSEPR*. *The Molecule Game* was designed for students to explore molecules in a 3-D space. They can rotate the molecule to view it from different perspectives. This virtual space has been designed to allow the learner to manipulate the molecules, and link or unlink the atoms to explore the molecules in greater detail (Merchant et al., 2012).



Figure 2. Activity stations Dr. K's Chemistry Corner

Merchant et al. (2012) described the *Molecule Game* simulation as allowing students the opportunity to view molecules with their bond angles from various perspectives, among other learning tasks. Learners were able to use the zoom in and zoom out features in *Second Life* to gain multiple views. They were able to readily examine bond relationships between atoms within a molecule using different capabilities within SL; this included rotating and manipulating various molecules. The *Chemist as an Artist* learning activity was also designed to further develop students' ability to see molecules from various vantage points in an immersive environment. Learners were able to photograph themselves next to different orientations of the molecules (using the SL Snapshot feature). They also constructed 2-dimensional drawings (representations) of the various orientations.

GETTING STARTED RESOURCES

There are active professional networks, as well as, resources available for educators interested in learning more about using virtual worlds to support STEM PBL. Professional organizations like the International

Society for Technology in Education (see **Table 2**), Virtual Environments Special Interest Group (SIGVE), provides outstanding venues for educators interested in connecting with other educators that are actively using virtual worlds in their classrooms. Most of these organizations offer several ways to support new and returning users as they begin to explore *Second Life*. They host virtual socials, professional development sessions, and other informal learning experiences throughout the year. SIGVE and the ARVEL SIG disseminate research and best practices through journals and member communication outlets. They also have comprehensive lists of the various virtual worlds that are being used in addition to *Second Life*. The SLED listserv, an extremely “active” SL Educators Listserv, provides a good venue for posting technical questions to the SL education community at large, or finding others to collaborate with on instructional or research projects. Various invitations and events are announced daily. Attending sessions virtually or face-to-face at conferences are helpful in learning more about how others are using virtual worlds.

Table 2. Resources for Educators Using Virtual Worlds

<i>Resources for Educators</i>
Second Life – http://www.secondlife.com
The SL Educators List (SLED List) – https://lists.secondlife.com/cgi-bin/mailman/listinfo/educators
Virtual World Best Practices in Education – http://www.vwbpe.org/
ISTE Virtual Environments Special Interest Group (SIGVE) – http://www.iste.org/connect/special-interest-groups.aspx
Applied Research in Virtual Environments (ARVEL) SIG – http://arvelsig.ning.com/

CONCLUSION

One can explore engaging simulations in the virtual world of *Second Life*, which can provide powerful opportunities for STEM teaching and learning. As educators gain greater skills and experiences using the features in virtual learning environments like *Second Life*, they can begin to discover how to effectively design STEM PBLs for their students. Access to innovative simulations that support learner-centered design or experimentation that may not be readily available in classrooms, show great promise within a virtual learning environment context. As education budgets stay on a continual decline, virtual simulations can offer unique alternatives for immersing learners in STEM PBL. University-school partnerships and professional development programs with local school districts can provide multiple venues for employing STEM PBL approaches in virtual learning environments. Preparation programs should also include parallel experiences for preservice teachers. Stakeholders at every level should have opportunities to explore the power of using simulations and games, steeped in effective practices that can facilitate STEM PBL. Ultimately, when students are immersed in authentic real-world projects that actively engage [and inspire] them, deeper learning occurs.

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10. STEM PROJECT-BASED LEARNING AND TEACHING FOR EXCEPTIONAL LEARNERS

INTRODUCTION

Today's classroom is a heterogeneous grouping of students with diverse backgrounds and with disabilities or special challenges in learning and behavior. This chapter focuses on how to reach these students through the use of Project-Based Learning (PBL). Although the strategies and issues presented here are, "best practice" for the instruction and management of students with enriched backgrounds, extensive vocabularies, strong self-advocacy, and self-management skills, these types of students may learn well without them. However, students with diverse or disabling conditions require these strategies for successful participation and learning. Students who are diverse, disabled and/or normative will benefit from a learning environment where these practices are used skillfully. This chapter begins with a section on the characteristics and learning considerations for exceptional and diverse learners followed by a section on the key elements of STEM PBL and concluded with a section on how these elements can address learner characteristics to improve student participation and performance.

CHAPTER OUTCOMES

When you complete this chapter, you should better understand:

- the characteristics and issues of exceptional learners
- recognition of the essential elements of STEM PBL
- the ability to utilize strategies to facilitate STEM PBL with learners who are diverse or disabled

WHO ARE EXCEPTIONAL LEARNERS?

Today's classrooms are filled with exceptional students varying in culture, language, abilities, and many other characteristics (Gollnick & Chinn, 2002). To meet this challenge, teachers must employ not only theoretically sound but also culturally responsive pedagogy. Teachers must create a classroom culture where all students, regardless of their background, are welcomed, supported, and provided with the best opportunity to learn and succeed.

Students from culturally and/or linguistically diverse backgrounds, as well as those who learn in atypical ways, bring diverse perspectives, skills and experiences to the educational process and this diversity enriches education but can challenge singular methods of instruction. Educators and educational systems have evolved to understand and better address the changing population of students in public schools and our communities.

A variety of terms are used to describe or characterize children for purposes of providing services, organizing instruction and better understanding learner characteristics. Although there are many children with diverse and/or disabled characteristics, each is individual and should be first recognized as such. However terms do help to identify and define the "types" of student groups, which will be discussed in this chapter. For our purposes here, we will discuss students currently and typically described by the terms English Language Learners (ELLs), children with Learning Disabilities (LD), children with Emotional and Behavioral Disorders (EBD).

As more and more students from diverse backgrounds populate 21st century classrooms, efforts continue to identify effective methods to teach these students. This effort includes *all* students: children from multicultural backgrounds, children from homes in which English is not the primary language, and children with disabilities (Gonzalez, Yawkey, & Minaya-Rowe, 2006; NCLB, 2001; IDEA, 1997). If all children are going to reach their full potential, teachers must be sensitive to and familiar with the diverse needs of the children and families they serve, and must be cognizant of using inclusive and developmentally appropriate practices on an ongoing basis in their classrooms.

CHARACTERISTICS OF STUDENTS WHO HAVE LEARNING DISABILITIES

Definition

Learning disability (LD) is a legal term that schools use to classify a range of students for service provision under federal mandate. A learning disability is identified by a discrepancy in intelligence scores and performance or as a failure to respond to effective instruction and repeated intervention. LD is commonly demonstrated as a deficit in one or more of the following skill areas: language, reading, writing, listening, speaking, reasoning, and mathematics. Researchers think that learning disabilities are evidence of basic psychological process disorders. The Federal definition further states disorders included are such conditions as perceptual disabilities, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia. Learning disabilities do not include a learning problem that “is primarily the result of visual, hearing, or motor disabilities, of mental retardation, of emotional disturbance, or of environmental, cultural, or economic disadvantage” [34 Code of Federal Regulations §300.7(c)(10)].

Prevalence and/or Incidence

In the United States, as many as 1 out of every 5 people have a learning disability. According to the National Institute for Literacy, 30-50% of the population has undiagnosed learning disabilities. Almost 3 million children (ages 6 through 21) have some form of a learning disability and receive special education in school. In fact, over half of all children who receive special education have a learning disability (Twenty-fourth Annual Report to Congress, U.S. Department of Education, 2002).

Characteristics

Students with learning disabilities usually demonstrate needs in a variety of areas such as: performing consistently, following and understanding directions, reading, comprehending, writing, organizing and sequencing thoughts, retaining information, following more than one step instructions or directions, interacting with peers appropriately and often struggle with self-esteem and confidence.

Special Considerations

Learning disabilities are not always “identified” formally and some students may struggle with issues that remain unidentified. Because LD cannot be seen, they often go undetected, are misunderstood and their impact underestimated. Students with slower processing but strong adaptive skills may be hidden but still struggle with academic tasks and school performance demands. Government and Institutional guidelines for identification also vary and the term and definition itself is under scrutiny from the field. Regardless of identification or “status” students who struggle will benefit from best practice instruction.

CHARACTERISTICS OF STUDENTS WHO HAVE EMOTIONAL AND BEHAVIORAL DISORDERS (EBD)

Definition

The term Emotional and Behavioral Disorders reflects a large heterogeneous group of students who have emotional and or behavioral disabilities that interfere with school and learning. The federal definition of EBD includes the demonstration of severe social, emotional or behavioral functioning that is significantly different from generally accepted, age appropriate ethnic or cultural norms and these differences must appear for extended periods of time, across a variety of settings. These social, emotional or behavior functions include social relationships, personal adjustment, classroom adjustment, self-care and vocational skills. (Code of Federal Regulation, Title 34, Section 300.7(b)(9)).

Prevalence and/or Incidence

The MECA Study (Methodology for Epidemiology of Mental Disorders in Children and Adolescents) estimated that almost 21 percent of U.S. children ages 9 to 17 had a diagnosable mental or addictive disorder

associated with at least minimum impairment (Shaffer et al., 1996). The number of children and youth ages 3-21 receiving special education services was 6.5 million in 2009-2010, or about 13 percent of all public school students and approximately 407,000 children and youth were receiving services under the eligibility emotional disturbance to address their individual needs related to emotional disturbance (US Dept. of Education, 2012). Boys out number girls somewhere between 2 to 1 and 10 to 1. Costello, Messer, Bird, Cohen and Reinherz (1998) found “there were no clear ethnic differences” (p. 411) and poverty doubled the risk of SED.

Characteristics

By definition, students with Emotional or Behavior Disorders have many characteristics that interfere with school learning. Not surprisingly, many students with emotional disturbance experience poor academic performance. They fail more courses, earn lower grade point averages, miss more days of school, and are retained more than students with other disabilities (Kauffman, 2001; Nelson & Rutherford, 1990; Nelson et al., 1991). Fifty-one percent leave school before graduating (US Department of Education, 2002, 2006) although more recent data indicate that the overall dropout rate of students with disabilities has been cut in half, it has remained the same for students with EBD (Wagner, Cameto, & Newman, 2003). At two years post high school, 58% of youth identified as EBD have been arrested at least once and 42% are on probation or parole (NLTS2, 2005). This is a stunning figure that is even more disturbing when one considers that experts in law enforcement estimate that there is, on average, only 1 arrest for every 10 “arrestable” offenses committed. Additionally, students with EBD reported use of alcohol (54%), illegal drug use (36%), marijuana use (33%), and smoking (53%) at rates higher than all other disability categories (NLTS2, 2008).

Special Considerations

Many children who do not have emotional disturbances may display some of these same behaviors at various times during their development. However, when children have an emotional disturbance, these behaviors continue over long periods of time and are not typically expected reactions. Their behavior thus signals that they are not coping with their environment or peers. A student who is depressed due to the death of a parent is not an EBD student, although they certainly are in need of special considerations. A student who is depressed and aggressive given no precursor needs a different level of intervention and has a different trajectory for recovery.

For students who are EBD, services beyond strong academic programs are needed in addition to but not instead of. Students with EBD should not be removed from the academic instruction and content to receive counseling or behavioral supports, instead, ideally the environment will support the student and provide opportunity for additional services to occur with academics rather than present an “either or” scenario where struggling students become further behind academically.

Students with EBD may lack the social or parental support to accomplish aspects of projects that require sustained resources, access to community or innovative approaches to problem solving. Sometimes students with inadequate coping skills or a history of trauma and neglect are part of a family system struggling with the same issues as the child and without the mental health or behavioral supports to cope.

KEY ELEMENTS OF PROJECT-BASED LEARNING

PBL is an approach for classroom instruction that utilizes learning activities that are child-centered, have well defined outcomes are long-term in nature, and include interdisciplinary missions. In this section, we identify the key elements of STEM PBL and articulated examples for how these elements facilitate improved learning opportunities for diverse and disabled students.

The context for where STEM PBL typically takes place is a heterogeneous classroom. Rarely are students grouped by perceived ability level or heterogeneous learning environments. More than likely, students with different maturity levels, development levels, language and disabilities are in the same classroom; which can add pressure to a stressed system or single instructor. What are needed are effective efficient opportunities for learning content across disciplines in a way that is meaningful and allows individual strengths to be utilized and demonstrated.

Students need to be able to successfully interact with an increasingly heterogeneous society. Since heterogeneous classrooms are a mix of various abilities and traits, students will have opportunities to work with others of various languages, intellectual, emotional, and physical developments. These skills and

experiences generalize beyond individual projects. Heterogeneity allows students to socialize with, model, and adjust to a variety of peer influences (Spear, 1992).

Settings for STEM PBL vary but the nature of the task has child centeredness, extended time, well-defined outcomes and interdisciplinary mission as essential elements. STEM PBL is child centered and as such reflects the experience and values of individual students while accomplishing the goals and objectives of the instructional leader. Extended time allows for deeper exploration and more opportunity for engagement. Well-defined outcomes make expectations explicit and provide structure to encourage student participation, interdisciplinary missions allow for repeated exposure to content, explicit connections and generalization of skills opportunities.

Child Centered

Definition. A child-centered learning environment is structured to facilitate independence, self-direction, and autonomy to encourage critical thinking and problem solving. STEM PBL is an instructional method centered on the learner. Instead of a lesson plan that directs learner activity specifically toward learning outcomes or objectives, the outcome of objective is directed but the activities to get there are not. The child or learner (rather than the instructor) directs his or her activities toward that end.

Relevance and significance. STEM PBL allows in-depth investigation of a topic worth learning more about (Harris & Katz, 2001). Through the building of artifacts, learners represent and demonstrate what they have learned (Harel & Papert, 1991; Kafai & Resnick, 1996). Potentially learners demonstrate more autonomy and

Example: An example of how child centered is illustrated in PBL might be demonstrated in this science example. Students independently or in groups organize by interest and are asked to develop “science for mankind” projects. Students using their interest, expertise, strengths and experiences to first identify and then solve a community problem. One student from Tijuana who crosses the border to attend school in San Diego may identify that trash blows both directions across the border and that neither town wants to “pick it up” in his words because no one feels like it is theirs. Other students join this “team” to brainstorm solutions and decided to write an ad campaign called “Wind and waste have no borders” “El viento y el desecho no tienen las fronteras” and to write letters to city leaders to add more trash cans along the pedestrian walks, and within a 1 mile radius. They also determine to sponsor a trash pick up weekend once a year and find adult service groups to help make tortillas and face paint children. T-shirts with the slogan in English and Spanish are designed and sold and the classroom donates the money to fund more trashcans and a billboard on both sides of the border.

A teacher’s role and responsibility is to create a “concept” rich classroom providing materials, tools, opportunities and guidance, encouraging children to make choices, of interaction with the environment and other children. Students learn to gain and demonstrate knowledge and skills through meaningful experiences. Play and experimentation are valued as context in which learning takes place. The elements that make child centeredness successful with students who are diverse or disabled are 1. Create an environment that is risk tolerant and safe for “un-success”. 2. Maintain active engagement. 3. Scaffold for success, 4. Encourage self-reliance, problem solving and critical thinking.

self-determination over how they learn and sometimes what specifically they learn. This is theorized to facilitate maintaining interest and motivating learners to take more responsibility for their learning (Tassinari, 1996; Wolk, 1994; Worthy, 2000) and be more actively engaged. More independence allows learners to “shape their projects to fit their own interests and abilities” (Moursund, 1998, p. 4) or accommodate their difference and disability.

Extended Period of Time

Definition. Extended period of time (EPT) is a characteristic of STEM PBL and means a task or assignment, objective or outcome that requires multiple distributed efforts to complete. Extended time might also be conceptualized as extended task. A project as part of its nature has multiple components, each requiring time to complete and all of which lead to the well-defined outcome.

Relevance and significance. Learning is related to time on task or engaged time. The more time that students spend with opportunities to learn, lead, think, direct, respond, plan and execute is time well spent. Rather than a discrete task with no explicit connection to the following task or the one that came before, extended time to complete a project compels the understanding and application of one set of knowledge and skills to the next. Extended time projects teach students the same content typically taught through lecture and discussion but adds a relevant and extended engagement time to the learning. STEM PBL teachers find that they do considerably less “busy work” activities in the classroom. And, though projects take time to plan, teachers have more time to work with students once a project is under way.

Example of STEM PBL that demonstrates extended time. Traditional research papers quickly come to mind but school publications in all their variations are also examples of extended time projects. Yearbooks, school papers, newsletters, campus blogs or calendars are some of the variants. Let’s look at a science class newsletter this could be as relevant for a high school freshman class as a group of 4th graders. Emma and Jack are creative story tellers, Fisher and Dalton are strong spellers, Lo Lo, Bart and Mike like to know everybody’s business and frequently sneak food from the cafeteria. Barry is an organizer while Ally and Ben are more social than academically minded. The teacher, Mr. Bowen, decides to create and have an ongoing science class newsletter. Students are assigned roles based on teacher observed interest. With an organizational chart established, this assignment takes place every Friday. Science facts and new science spelling words are incorporated, some students collect and or write fiction, others edit, a student with significant disabilities contributes a joke of the month, while others distribute papers, some are responsible for counting and tallying words and space, some are responsible for “management and organization” other students keep track of science experiments and one or two do interviews with science related people in a “guess who” section that is a favorite of students. Weekly tasks are related to monthly publishing, ongoing features are carried forward and certain students develop strengths in writing up the news while others learn to motivate their peers.

The extended time and ongoing nature of the science newsletter allows students to remain on task even when not specifically engaged in writing assignments, as students go about their day on campus they think of new story ideas or ways to make the newsletter better. Some jobs might be rotated based on interest and skill or as a reward for contribution. On the board there is a list of story ideas and the enduring brainstorming keeps kids involved and interested. Jaclyn decides to add cartoon humor when he notices a Sunday paper at home. Elaine wants to add “dress for weather” tips for each month as a regular feature. Barry asks about charging parents a quarter for the newsletter and paying students for stories. Sadie adds recipes from the cook at school and Lauren loves to get asked how to spell science words. Mr. Anderson, a mathematics teacher, even has a regular section on “solving the latest math jumble”. State standards in science, mathematics, spelling, reading, reading comprehension, writing, and problem solving are addressed each week in the curriculum and revisited recursively as the class publishes one newsletter each month for the academic year.

The elements that make extended time especially beneficial for students who are diverse or disabled are the repeated opportunities to engage with the material, the explicit connections, and the increased time on task.

Well-Defined Outcome

Perhaps the most challenging key element in STEM PBL is the idea of a well-defined outcome. “Without a destination, any road will take you there” is a good adage for the use of STEM PBL. Well-defined outcomes ensure two things, explicit expectations for the student and an appropriate outcome for measurement and evaluation. Learning is ultimately a change in behavior and the child who says, “I know that” but cannot demonstrate how they know it, is in an unfortunate position. Demonstration of skills and knowledge is ultimately what teachers have to go on until such time as other technologies for measuring learning and academic performance are available.

Definition. Well defined is not the same as predetermined. A well-defined outcome is a clear articulation of purpose and expectation. For example, a teacher may assign an artistic representation of the voyage of the pilgrims that includes 3 factual depictions and 1 illustration of causation. However, it does not predetermine that the project must show a model ship or Plymouth Rock, or reflect oppression and religious freedom. The desired outcome is selected first and the curriculum is created to support the intended outcome, in this case facts about the voyage and to create an understanding about causation.

Relevance and significance. Investment in long-term significant learning, is prompted by relevant tasks that are meaningful to students not because of the need to learn them from a test but because engaging in the activity will help them learn, produce opportunity to be stimulated, demonstrate skills and attain success. Clearly defined outcomes reflect the notion that having outcomes articulated is not stifling but supportive. Well-defined outcomes produce structure, goal and mutual understanding about purpose. This concept promotes three basic premises (1) All students can learn and succeed, but not all in the same time or in the same way, (2) Successful learning promotes even more successful learning, and (3) Schools (and teachers) control many of the conditions that determine whether or not students are successful at school learning.

Well-defined outcomes allow diverse and disabled learners to have appropriate levels of scaffolding, to make choices about task relevance and to better understand teacher expectations for performance.

Example that demonstrates Well Defined Outcomes. There are three levels of defining outcomes 1. Global outcome descriptor, 2. Outcome with required components, 3. Outcome, components and valuation.

Table 1. Levels of defined outcomes

Global Outcome Descriptor	Outcome with Required Components	Outcome, Components and Valuation
Produce a slide show of native plants	Produce a slide show of native plants Show 5 plants in one genus Use text from 2 sources Use photos from surrounding flora	Produce a slide show of native plants Show 5 plants in one genus (25 pts, 5 each) Use text from 2 sources (20 pts, 10 each) Use photos from surrounding flora (25 pts, 5 each bonus for more plant examples additional sources, creativity (up to 5 pts)

Interdisciplinary

There is also an interdisciplinary aspect of STEM PBL (see Chapter 6 for further information on interdisciplinary PBL). The interdisciplinary nature of STEM PBL allows students to learn horizontally across curriculum rather than only vertically. Interdisciplinary projects also allow for instructional collaboration, cross pollination of ideas and the repetition of concepts in new and different applications to understand the relevance of learning and to facilitate fluency, mastery, and generalization of skills.

Definition. Interdisciplinary teaching involves a conscious effort to apply knowledge, principles, and/or values to more than one academic discipline simultaneously. The disciplines may be related through a central theme, issue, problem, process, topic, or experience (Jacobs, 1989). The organizational structure of interdisciplinary/cross-curricular teaching is called a theme, thematic unit, unit, or project, which is a framework with goals/outcomes that specify what students are expected to learn because of the experiences and lessons that are a part of the unit.

Relevance and Significance. According to the *National Assessment of Educational Progress*, while students are learning the basic information in core subject areas, they are not learning to apply their knowledge effectively in thinking and reasoning (Applebee, Langer, & Mullis, 1989). Interdisciplinary/cross-curricular teaching provides a method by which students can use knowledge learned in one context as a knowledge base in other contexts in and out of school (Collins, Brown, & Newman, 1989). Clarity on the relationship of content to standards provides opportunities to articulate relevance in instruction and assignments. In this way teachers better ensure that the students learn a concept necessary for a project. Teachers working together can develop ways to tie projects in with their curriculum goals (Bottoms & Webb, 1998).

Many of the important concepts, strategies, and skills taught in the language arts are "portable" (Perkins, 1986). They transfer readily to other content areas. The concept of perseverance or conflict of ideas for example, may be found in literature and science, mathematics, geography, history, vocational arts and fine arts. Strategies for monitoring comprehension can be directed to reading material in any content area. Critical

thinking can be applied in any discipline. Cause-and-effect relationships exist in literature, science, and social studies. Interdisciplinary/cross-curricular teaching supports and promotes this transfer by providing different applications and practice opportunities that are relevant and more naturally occurring.

STEM PBL offer teachers a useful, logical, and flexible way to organize for interdisciplinary teaching over a block of time (Tchudi, 1991). Throughout the project, teachers are able to integrate content area study and engage students in meaningful and functional learning activities (Tompkins & Hoskisson, 1991). Interdisciplinary units should comprise activities that promote and support the *active construction of meaning* for students (Pappas, Kiefer, & Levstik, 1990). These include such things as projects in which students work independently or cooperatively to solve “real world” problems (Ward, 1988); opportunities to read and respond to authentic literature; discussions with peers and the teacher about what has been read or heard; teacher-led lessons for the whole class or small groups that focus on a needed concept, strategy, or skill; and self-selected student activities such as books to be read or activities to be done.

Example of the interdisciplinary nature of problem based learning.

Juniors with undeclared majors at a high school take two standard electives each fall, Home Economics and Intro to Business. These two teachers, one in a high school home economics department and the other in the Business department develop a joint class project where students will operate a student store selling baked goods and sandwiches. Students rotate tasks of manager, sales, accounting, distribution and maintenance while in the business class and these same students use the budgets and funds to plan menus, purchase ingredients, and produce the food items for sale. Back in the business class different mathematics applications are used to count money, deposit money, staff schedules are completed, “pay” is earned and profits are distributed. The class sells stock to teachers and charges extra for premium delivery service. Adding menu items is determined based on sales and decision-making based on data as an outcome for both the home economics course and the business class.

Teachers dedicate some days a month for “block” classes that run back to back so that students can work in groups. As the semester progresses the speech class has students become involved in “arbitration” and disputes about pay and management style. The science teacher uses the opportunity to collect bacteria samples from old chicken salad and students see and participate in interdisciplinary learning opportunities.

With this interdisciplinary approach, students synthesize and collaborate their learning while responding to the project question by pulling evidence or previous knowledge from multiple disciplines.

COMMON FEATURES AND CHALLENGES FOR DIVERSE LEARNERS

For teachers, success in the classroom is not just a matter of knowing your subject; it is a matter of knowing your students. Having a working knowledge of the characteristics of development and difference or disability of students is critical to the success of the teaching and learning experience. Each key element and common features of STEM PBL has its own challenges for diverse learners.

In this chapter, we first identified characteristics of diverse learners, and next articulated some key elements of STEM PBL with examples for heterogeneous classrooms. These two things, characteristics of learners and elements of STEM PBL can work together in a powerful way to address the needs of diverse and disabled learners and assist in ensuring successful participation and performance of all students.

Certain characteristics of students who are diverse or disabled pose particular challenges for the classroom and learning. This section will articulate some of the most common characteristics in students that create challenges for instructors.

Language and Cultural Differences

Differences and disabilities in language knowledge and skills can make traditional lecture inaccessible. Heterogeneous learning environments provide opportunities to gain background knowledge if peers are utilized for peer-tutoring and small cooperative grouping. Working on group projects in heterogeneous learning environments provides an opportunity for both ELLs and native English speaking students to be immersed further in a topic, to take more time to comprehend a topic by peer explanation and recursive activities. Extended time to engage when language may interfere with understanding provides more opportunity for learning. Child centeredness can facilitate all students' interest and motivate engagement and can take advantage of cultural capital. The interdisciplinary nature of PBL provides repeated opportunity to engage with the vocabulary and concepts in new and different contexts.

Further, instructors can accommodate the lack of background knowledge often faced by ELLs by creating opportunities for experience and language acquisition to provide more background knowledge through active participation and physical experience rather than lecture or text. PBL offers an alternative method for demonstrating knowledge and skill by including assignments that use model presentation, visual presentation, graphs, maps, and pictures.

Below Grade Level Reading Ability

Many diverse disabled learners read below their age or grade level making text inaccessible as a method of learning. STEM PBL can enhance student's ability to access content through the introduction of a variety of "scaffolding" techniques (learning aids, models, training strategies). Teachers can provide schematic maps, visual aids, charts, and graphs, simplify text, pre-teach key vocabulary, and provide audio supplements. Other strategies to teach students include the skill of breaking down tasks, creating models, content mapping, highlighting, and looking for cues in text. Teachers in class can use prompting, and coaching to teach strategies for thinking and problem solving.

Deficits in Processing Speed

Slower than typical processing can occur as a disability or due to second language-learning conditions. Teachers can address the variation in the speed with which students perform cognitive activities by utilizing the extended time of PBL's and can modify their instruction to include writing down the well defined outcomes, adjusting the pace of instruction, providing more time for asking and answering questions.

Motivation

Students with disabling or diverse backgrounds may find much of what we do in schools to be irrelevant or students may have experienced lack of success to the extent that they are no longer willing to try, risk, or engage. STEM PBLs can address this in several ways. The child-centered nature of the task can address relevancy and interest to propel motivation. The extended time and interdisciplinary nature of STEM PBL may provide context for students to be willing to risk participation by having the ability to pull from a strength area of content knowledge to assist in the demonstration of skill in another content area. Well-defined outcomes can provide safe and structured environments where students understand clear expectations and are willing to engage. STEM PBL can feel more palatable and be motivating for students as the pace, topic, and level of difficulty can be individualized with projects broken into smaller, manageable assignments with extended periods of time for completion. Lack of motivation in diverse learners is an issue. Students tend to "check out" when they do not understand the task at hand. STEM PBL can be created around themes that students help choose. Students who are exposed to pro-social peers and might find high interest child-centered projects motivating thus increasing attendance. Needed problem solving skills and social support are taught and modeled throughout the process. Projects that have depth, duration, and complexity will challenge students and motivate them towards construction of knowledge. They will acquire problem solving, communication, collaboration, planning, and self-evaluation skills.

Off-task Behavior

Off-task behavior is a term used to describe occasions when the child is engaging in a behavior that is not related to the activity set by the teacher. Students are off task for a variety of reasons: to escape the task, or biologically a learner becomes distracted and is attending to other things in the environment. Some strategies

that increase on-task behavior are the use of self-monitoring, the tangible rewarding of on-task behavior, and prompting students with visual or physical cues to return on task. For off-task behavior that is escaped driven, students may need breaks contingent on task engagement. PBL can engage these learners in an activity that may be more rewarding by identifying parts of the project that the child is responsible for and able to complete. This can increase confidence through successful engagement.

Impulsivity

Some children have difficulty staying with the task at hand. Their verbalizations seem irrelevant and their performance indicates that they are not thinking reflectively about what they are doing. STEM PBL can assist by providing a rubric of the project expectations; assist the student in setting long-range goals but breaking that goal into realistic parts. STEM PBL tends to work from well-defined outcomes and allows one to probe irrelevant responses for possible connections to the questions. When introducing a new project the teacher can begin by having the children generate questions about it before providing them with much information, allowing student to tap into previous knowledge and backgrounds.

Lack of Organization

Diverse and disabled learners, in particular, can demonstrate difficulty in organization. This is evidence both in work completion and in memory (storage and retrieval). Organizing an extend time project will require scaffolding and task break down with additional monitoring help for these students, time management may also be an issue and will interfere with task completion or organizing and managing the smaller steps needed to accomplish the larger project. Students may miss “team meetings” or forget where their materials are, who their other group members are, or what the purpose of the assignment was. Learning new knowledge, skill, abilities or attitudes and applying them to a subject matter is particularly challenging with organizational deficits.

Teachers can facilitate organization through memory cues, ignoring repeated forgetfulness, and increasing visual reminders or teaching self-cuing skills. Teachers can use a variety of techniques to make the input comprehensible, including scaffolding and a variety of graphic organizers to draw on background knowledge. Teachers can also make sure the students have weekly or monthly assignment sheets, list of materials needed to complete the daily assignment of the project.

BENEFITS OF STEM PBL AND ACADEMIC SUCCESS FOR DIVERSE LEARNERS

The essence of STEM PBL lies in the engaging experiences that involve learners in complex and real world projects through which they develop and apply skills and knowledge. [Table 3](#) provides an outline of common features and how to set up a project for learners of all skill levels using best instructional practices.

Table 3. Common Features of Project Based Learning (Grant, 2002)

Features	Description
Introduction	Use an introduction that includes “The Big Ideas” or anchor, for the project. This often contributes to motivating learners, provides focus and increases performance.
Task	The task and guiding question scaffold and explain what will be accomplished and embeds the content to be studied. The tasks should be engaging, challenging and doable. This allows the learner to choose, plan, design based on previous knowledge, background, and skills on how to obtain new knowledge. Students need frequent opportunities to respond and variations in how to respond.
Investigation	The process and investigation include scaffolding the steps necessary to complete the task and reinforcing participation at each step including answer the guiding question. The process should include activities that require higher-level and critical thinking skills, such as analysis, synthesis and evaluation of information. Students at a variety of cognitive and language levels may need alternative methods to demonstrate comprehension and performance at appropriate levels.

Resources	Resources provide data to be used and can include hypertext links, computers, scientific probes, compasses, CD-ROMs, eyewitnesses, etc. Resources should be provided in an environment that students can access. Internet access is not available to all students, neither are computers for typing or materials for projects or adult help in problem solving.
Scaffolding	Guidance and scaffolding are needed at different levels for different students and may include organization, social, planning, resource help, student-teacher interactions, practice worksheets, peer counseling, guiding questions, job aides, project templates, etc.
Collaborations	Many projects include groups or teams, especially where resources are limited. But, cooperative learning may also employ rounds of peer reviews or group brainstorming sessions.
Reflection	The superior examples of project-based learning offer an opportunity for closure, debriefing, assessment or reflection. These may include relevant in-class discussions, journal entries; follow-up questions about what students have learned or even an assessment over learning.

Introduction

The most essential aspect of planning a project begins with the introduction. While there is great variation in motivational levels from learner to learner, the importance of high motivation for diverse learners is clear. Start with the big ideas or anchors, which will provide the conceptual focus and activate prior knowledge.

In addition to activating prior knowledge and generating interest, teachers need to prepare students conceptually for big ideas and concepts. Teachers must seek concrete ways: visuals, objects, metaphors to represent the concepts and big ideas their students do not already know. Since many students do not learn best through tasks requiring literacy or numerical representation, both the experiential and conceptual introduction should incorporate diverse modalities and precede grade-appropriate literacy or abstract mathematical tasks. The goal is for students to understand key concepts and big ideas prior to reading about them or solving abstract problems.

Task

It is imperative that educators identify and teach the big ideas. These key principles and generalizations (statements of the relationships among important concepts) point in the direction for all instruction. Once the essence of instruction or steps is clearly stated, teachers can more readily identify critical concepts to be taught and develop lessons that have a strong conceptual focus. When identifying lesson objectives, the content objectives state what students will do to demonstrate understanding of the big ideas. Related language objectives reflect how students will access and express the big ideas and key concepts. Once the instructional essence has been stated as big ideas, teachers need to create an experiential base for instruction. It is important to first build on prior knowledge of the students and to create common experiences that generate emotional responses. The purpose of these activities is not only to provide relevant experiences but also to also generate curiosity and motivate diverse learners.

Investigation

During the investigation phase of the project students, will task analyze and be able to complete the steps necessary to complete the project. Teachers must seek every opportunity to promote higher-order thinking. Students who think analytically and creatively and who develop strategies for learning, always seem “head and shoulders” above the rest. Teachers need to provide mental challenges and specifically teach the strategies that enable all students to more effectively develop the thought processes and procedures for meeting their thinking goals.

There are multiple ways to promote higher-order thinking, but the procedures used should be related to the big ideas being taught. For example, students can engage in activities that enable them to construct meaning and discover those important ideas for themselves. Graphic organizers are particularly valuable for helping students process the tasks and organize related details. To that end, educators choose organizers that match the thinking required for understanding the big ideas being taught. In a lesson, teachers need to also include

student objectives that are related to the project outcomes. Teachers need to define what students will do to demonstrate use of the strategies or knowledge taught.

Resources

Too often instructional decisions are based on the materials available, rather than insightfully selecting materials that are the most appropriate for the educational goals of the population being taught. Educational materials take a lot of work and often need to be cut, shaped, strengthened and polished. It is rarely possible to purchase a program that would be an exact match for the curriculum in any discipline. Resources to consider:

- Graphic Organizers as the visuals, manipulative, and other materials needed to preview the concepts in concrete ways
- Text-like materials and trade books
- Multiculturalism that include: choice of themes and topics of investigation, multicultural literature, texts that incorporate diverse perspectives, materials designed to reduce bias and promote cultural sensitivity, authentic sources, the Internet, and personal interviews
- Many resources generated by the students themselves that can be used for multiple educational purposes
- Materials that reflect the interests and experiential backgrounds of the students
- Materials that match the range of students in the class (for example, materials with different reading levels) as well as materials for any specialized needs, such as, materials in the native language or materials for the blind
- The Internet brings many resources from around the world into the classroom. In addition, students generally move beyond the classroom as they use parents, community members, businesses, and organizations as educational resources.

Scaffolding

Diverse learners usually have difficulty working independently and require extensive guidance at first. “Scaffolding” refers to the personal guidance, assistance, and support that a teacher, peer, or task provides to a learner. One way to scaffold instruction for diverse learners is to differentiate learning tasks and materials and provide a variety of verbal and academic supports, from both teacher and more proficient peers, so that students are able to meaningfully engage in content area learning and acquire the necessary language and academic skills necessary for independent learning. Successful scaffolding includes a variety of components:

- First, teachers must provide continuity in the classroom. In this way, teacher’s present tasks that are repeated throughout instructional sequences with variations and that are interconnected to each other and the curriculum.
- Secondly, teachers must also provide support from context. Students should be encouraged to explore topics in a risk free learning environment and be provided with a variety of ways to meet learning goals and objectives.
- Finally, teachers must create learning contexts where learners increase their autonomy as their skills and confidence increase.

Continuity of tasks will facilitate learners being able to take over portions of the task and become independent learners.

Collaboration

Collaboration of student groups provides diverse learners with essential opportunities to use language in meaningful, purposeful, and interesting ways, build self-esteem and self-confidence, and develop academic, communication, and social skills. The students are responsible for one another’s learning as well as their own, which requires group interdependence, motivation, persistence and flexibility (Abrami, 1995). Collaboration methods to consider for project-based learning:

- Classroom arrangement
- Grouping practices are organized in a variety of ways including mixed academic achievement, interest, language, project, language, and friendship.
- Small group work is structured so that students need to be concerned about the learning of all group members as well as themselves. Groups are expected to help and encourage their members to master academic content.
- Each student in the group is individually accountable for their learning.

If collaborative skill instruction occurs regularly, teachers can consistently process how effectively groups work and learn together.

Reflection

Reflection and assessment is an integral, ongoing part of instruction and becomes more visible in the older grades. Although reflection and assessment generally comes last in the STEM PBL phase it is considered at each phase of planning. Assessment enables us to meaningfully report learning, provide feedback, determine needs and improve instruction. Different methods for reflection include:

- Journaling interest inventories and classroom observations to demonstrate what students know, can do, and how they feel.
- Student-initiated authentic reflections of learning and as well as self-assessment and assessment by peers
- Assessment of the classroom climate for learning
- Allow student to verbally demonstrate their understanding of the big ideas and key concepts
- Allow students to transfer skills by applying what they have learned to unique situations and act on their learning in personally meaningful and socially relevant ways

SUMMARY

A project is an extended inquiry into various aspects of a real-world topic that is of interest to students and judged worthy by teachers. Because of its real-world appeal, students are motivated to investigate, record, and report their findings. The hallmark of project learning is greater independence of inquiry and "ownership" of the work on the part of students. When contrasted with more formal instruction, it allows students a greater degree of choice and capitalizes on internal motivation. When students participate in experiences they see the value of what they are learning and become more actively engaged (Resnick, 1987).

As with any teaching method, STEM PBL can be used effectively or ineffectively. At its best, STEM PBL can help you as a teacher create a high-performing classroom in which you and your students form a powerful learning community focused on achievement, self-mastery, and contribution to the community. It allows the teacher to focus on central ideas and salient issues in the curriculum, create engaging and challenging activities in the classroom, and support self-directed learning among students. It assists in overcoming the dichotomy between knowledge and thinking while supporting students in learning and practicing skills in problem solving, communication, and self-management. But most of all, STEM PBL can create positive communication and collaborative relationships among diverse groups of students.

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11. CLASSROOM MANAGEMENT CONSIDERATIONS: IMPLEMENTING STEM PROJECT-BASED LEARNING

INTRODUCING CLASSROOM MANAGEMENT

The issue of classroom management in a Science, Technology, Engineering and Mathematics (STEM) Project-Based Learning (PBL) classroom is really two distinct issues; the first issue is how to design a PBL activity to maximize learning and the positive behavior of the learner; the second issue lies in a variety of topics related to the management of a classroom with groups of students working together. There is a mistaken perspective that STEM PBL simply involves creating an open-ended question and letting the students do all of the work, but this could not be further from the truth. Our definition of a *well-defined outcome* and an *ill-defined task* for STEM PBL has profound implications for classroom management. Although it may sound oxymoronic, a well-designed, ill-defined task does more than promote student learning. It promotes student motivation and engagement and when paired with a well-defined outcome, eases teacher and student concerns related to classroom management. Students are still expected to be on-task; restrict conversations to planning, investigating, problem solving, and communicating results; work in groups and individually; and follow procedures and routines (Wong & Wong, 2004). This chapter first deals with the design of a STEM PBL, as a good design will solve a great deal of the classroom management concerns for both the teacher and the students. Secondly, it will deal with the issue of managing students working in groups because the implementation of projects in a class works better when both teachers and students are comfortable with the dynamics of a cooperative learning environment.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- the issues related to students working in groups or teams
- the dynamics of a cooperative learning environment
- the features of an effective project

When you complete this chapter you should be able to:

- design ill-defined tasks that encourage student learning and minimize classroom management concerns
- form, develop, train, and manage student groups
- develop effective STEM PBL activities

DESIGNING ILL-DEFINED TASKS TO PROMOTE LEARNING AND MANAGE BEHAVIOR

It is important to remember that the primary justification for STEM PBL is that active engagement generally leads to improved learning outcomes (Hake 1988), which is fully supported by our definition of PBL as a *well-defined outcome* and an *ill-defined task*. Classroom management in a STEM PBL environment is based on increasing active engagement and controlling the chaos. The first decision that promotes active engagement and control of chaos is the design the STEM PBL itself. The well-defined outcome includes expectations for learning and behavior – even if the behavioural expectations are not explicitly stated. The ill-defined task is included to increase student motivation and engagement. Boredom, repetition, confusion about expectations, and easily completed tasks are a teacher's enemy. It is a teacher's responsibility to set the tone that is expected of students, namely to learn and to behave during PBL, just like the rest of the year. You do not get a second chance to make a good first impression. Well-established procedures and routines that allow students to actively engage in the task are critical and must be designed with as much care as selecting the learning objective. Remember the focus in a STEM PBL is on what the student knows and is able to do, not

what the teacher covered. Therefore, instead of procedures that emphasize listening to the teacher and following predetermined steps to problem solve, procedures that emphasize student engagement, decision making, and problem solving need to be designed, and implemented. Eventually, students internalize procedures into unprompted routines. For a full discussion of procedures and routines see Wong and Wong (2004).

Examples of some procedures for students to follow that are specific to STEM PBL include:

1. Check the board to see who is initiating project work today – the teacher or the students.
2. Record *all* design ideas in your lab notebook/journal.
3. Record *all* trials in your lab notebook/journal.
4. Keep in mind how you are going to communicate your results to others.
5. Keep in mind how you are going to answer your own questions.
6. Work cooperatively, not competitively.
7. All students are responsible for all phases of the project, regardless of their temporary roles within the group (see discussion on groups and roles below).

In addition to the STEM PBL-specific routines that support increased student engagement, motivation, and problem solving, specific routines that deal with working in groups need to be developed as well. The scariest part of adopting an active, inquiry-based pedagogy for many teachers is the potential loss of control of individual students and control of the classroom. Consistent application of traditional and STEM PBL-specific procedures will go a long way towards managing the behavior and learning of individual students and the class as a whole. Many teachers have been surprised by the increased attendance that accompanies team activities in class (students are sometimes willing to disappoint teachers but less willing to let down their classmates/team). Many techniques are listed in the active-learning literature; all are simple, some are silly, but most require agreement in advance and practice to be effective. Some examples include:

- *Touchdown signal* – the teacher makes a touchdown signal. Students seeing the signal raise their hands in a touchdown signal; students seeing this signal raise their hands in a touchdown signal, and so on. It is surprising how quickly a classroom becomes quiet – students who do not see the signal notice that room is getting quiet and look up from their work. Of course, the students have to be informed that the signal means to (1) raise their hands, (2) stop talking, and (3) turn their attention toward the teacher.
- *Single raised hand* – this method works much the same as the touchdown signal except that the teacher raises only one hand.
- *Air horn, bell, or buzzer* – the signal is audible and (if neighbors are not nearby or if they are very understanding) can be either loud enough or at a frequency that will be noticed by even the most engaged students.
- *Blinking classroom lights* – this method is silent and very effective; however, it must be used with caution if students are up and moving around or if there are obstacles in the room.
- *Other* – many teachers may simply move to the middle of the room and quietly giving verbal instructions; nearby students notice and become quiet; the teacher repeats the instructions; more students notice and become quiet, and the sound of silence propagates throughout the room.

All of these procedures work if explained in advance, consistently applied by the teacher, and complied with by the students. Usually, students recognize the advantages to active participation versus passive learning and are thus willing to learn new procedures and routines as they solve new problems in more authentic learning environments.

Beyond the development, implementation, and reinforcement of new procedures and routines, care must be taken to design projects that are in fact motivating and engaging to the students, not just the teacher. As such, projects that engage students in higher levels of learning through authentic tasks often result in the emergence of various learning outcomes in addition to the ones anticipated. Often, such projects include the characteristics of student-centered learning, students as teachers, teachers as coaches or facilitators, students working in groups, and performance-based assessment.

There are a variety of sources with lists of attributes of a good project. Although these lists are not the sole answer for designing good projects, they do provide a useful checklist. Outstanding projects commonly:

- Recognize students' drive to learn,
- Make project work central rather than peripheral,
- Lead students to in-depth exploration of important topics,
- Require the use of essential tools and skills, self-management of learning, and projects,
- Incorporate investigation, research, or reasoning,
- Include frequent feedback (opportunities to learn from experience),

- Include high expectations and performance-based assessments, and
- Encourage collaboration through small groups, student presentations, or peer and class evaluations of projects (Thomas, Mergendoller, & Michaelson, 1999).

This list provides a convenient checklist when developing a project, converting problems into projects, or converting learning objectives into projects. The following sections give tips on modifying other STEM PBL activities; modifying other inquiry activities; and modifying more traditional lesson plans to a STEM PBL format.



Modifying Other STEM PBLs

A well-designed STEM PBL will have a *well-defined outcome* and an *ill-defined task*. If one is lucky enough to inherit a well-designed PBL, then modification consists of assessing student prior knowledge, providing adequate resources, continuous individual and small group scaffolding, and the occasional whole-class discussion or direct instruction on an as-needed basis. Starting with a well-designed STEM PBL is an excellent way to develop the procedures and routines you will implement in future STEM PBLs.

Modifying Other Inquiry Activities

The first task in modifying an inquiry activity into a STEM PBL is to develop a *well-defined outcome*. This assures that the activity is aligned with the local, state, and national standards and communicates clear expectations for learning and behavior to the students. The second task is to check or modify the inquiry task to make sure that it meets the definition of *ill defined*. This ensures that the primary elements of the STEM PBL are in place, which will minimize off-task behavior.

Modifying Teacher-Centered Instruction

Modifying teacher-centered instruction requires the same emphasis on designing *well-defined outcomes* and *ill-defined tasks*. Good teacher-centered instruction should have easily modifiable learning objectives; the primary task at this point is to consider new behavioral objectives. Converting a teacher lecture or verification lab into an *ill-defined task* is quite another task. The first priority for creating *ill-defined tasks* is to find a problem that has multiple, reasonable solutions or multiple paths to a single solution.

The connection between the *well-defined outcome* and the *ill-defined task* is as important to student behavior as it is to student learning. The consistent application of these two elements is the first routine that teachers should establish for themselves as they design STEM PBL. As teachers and students become more comfortable with this new style of learning, most of the new procedures will become routine. Teachers have to learn to trust themselves enough not to provide all of the answers, and they have to learn to trust that the students will be able to get to the place teachers want them to be without a step-by-step procedure. Although it does not matter how they get there, *it is essential that they do get there*.

Communication in STEM PBL

A final component of the design of the well-defined outcome that is essential to managing learning and behavior is the constant communication of learning and communication to learn. Students are communicating their conceptions, ideas, problems, and observations constantly within the STEM PBL. The teacher must support the active learning represented by this communication process or it becomes chaotic. It is important to share or post intermediate and final results of a project. This can be done by having different teams share their work or by the teacher summarizing the different approaches used by different teams of students. Either way, it is important to connect the projects back to the learning objectives; often, students can solve a problem or submit a good project and not realize that they used algebra, geometry, trigonometry, physics, and/or English (even though all are present in their solution). It is up to the teacher to help them celebrate their accomplishment and build self-confidence in applying the concepts that they have mastered and will need to demonstrate on the test.

Mrs. Gonzalez's Ninth Grade Integrated Physics and Chemistry (IPC) Vignette

In a PBL on Non-Newtonian Fluids (see Appendix A) Mrs. Gonzalez introduces the following ill-defined task while playing with a large ball of silly putty at the front of the class (engagement 5E model):

*What effect does %water have on the viscosity of silly putty . . .
and how can the general forms of functions help us interpret this relationship?*

The students are then given time to explore how to make silly putty, what exactly is viscosity, how is it measured, what is the general form of a function, what do we have at the school that can be used to make silly putty and measure viscosity, and why is Mrs. G using math terms in a science class? The classroom becomes a blur of motion, and the noise level increases. As an experienced teacher, Mrs. Gonzalez seems to ignore the noise and student motion. But, closer inspection shows us that she is moving from group to group checking progress, providing suggestions—never “the answer”—and keeping students on-task. After the initial exploration phase (5E model), Mrs. G has the students share ideas with the whole class before full-scale testing occurs.

Day 2

Mrs. G is still working the room. Students have found various recipes for making silly putty, GAK, and a host of other substances on the Internet. Mrs. G has provided a limited set of materials, so the students are forced to chose the recipe that includes glue + borax + water = silly putty. After all of the groups have experimented with the mixture, Mrs. G again has a whole-class discussion to make sure that all of the students are on-task and to remind them how important taking good notes and multiple trials will be in the next phase of data collection.

Day 3

Students are wrapping up their explorations and beginning explanation (5E model). Mrs. G is focused today because she knows how critical today's transition is... without good data, the

students' explanations will be weak. She has really taken a risk by requiring that the students use functions to explain their science, but as she checks the students notes she only needs to make gentle reminders as the groups have all recorded good data. As the students begin to analyze data, questions about what type of graph to use and how many points it takes to make a graph and a variety of questions about functions start to permeate the room. After she conducts several small group interventions, Mrs. G decides to have a short, whole-class review on functions and graphing. She takes the time to find out where each group is at and facilitates an exchange that is largely student driven because she knows where the groups and individuals are in the process. The students return to their groups and work well to complete their analysis and start with their presentations.

Day 4

It is the fourth day in a multi-day PBL, and Mrs. G is rewarded by students coming into class and starting immediately on their projects. Most of the students are really focused on completing graphs and placing them in PowerPoint presentations. Mrs. G notices that although the students were able to collect good data and were able to determine the equation on their lines, they really had not focused on answering the question. From experience, she had expected this and had planned some extension activities (5E model) that would hopefully prompt the students to think beyond just the graph and to understand how the shape or form of the line was critical to differentiating between linear and non-linear flow. Examples of appropriate extensions include: what would the data for a Newtonian fluid look like? Or how do engineers take advantage of nonlinear flow?

Parts of this vignette are also shared in Chapter 3 to illustrate why PBL works.

The vignette above shares a brief introduction to how an experienced teacher and well-trained students are able to perform in a STEM PBL environment. Not all procedures for active learning and student problem-solving are readily apparent, but they are present as students are comfortable with Mrs. G checking their work rather than giving them the answers. Students are able to transition from group work to full class discussions and direct teacher instruction without devolving into chaos. Students have taken good data and are planning their presentations. They even demonstrate a transition from a teacher-driven procedure to a student-driven routine by starting the fourth day without prompting from Mrs. G. Was this classroom quiet for the four days? Certainly not! Was this class engaged for the four days? Apparently yes! Did chaos ever rule this class during the four days? Probably not! Can regular classroom teachers and professors implement a few new procedures and routines to effectively manage student learning and behavior? Absolutely yes!

STUDENTS WORKING IN GROUPS

The purpose of cooperative learning is cooperating to learn, not learning to cooperate (Wong & Wong, 2004). There is a wealth of information on the issues related to effectively using student groups in a classroom. These issues range from maximizing student learning to balancing individual and team activities to controlling the classroom. In addition to these issues, it is sometimes important to consider the difference between a student group and a team of students.

The distinction between student groups and student teams is largely one of longevity. Groups of students are often assigned on the fly for in-class cooperative activities and also can be used in STEM PBL. Projects often take longer, so in STEM PBL it is important to deal with the interpersonal dynamics that may affect team performance such as:

- Training
- Roles
- Goals and rules
- Monitoring team progress
- Accountability
- Regaining order from chaos

Additional information, hints, and techniques can be borrowed from research on active learning, collaborative learning, and cooperative learning (Bonwell & Eison, 1991; Johnson, Johnson, & Holubec, 1986; Johnson, Johnson, & Smith, 1991; Katzenbach & Smith, 1993; Seat & Lord, 1999).

Training

Although orientation to group work is a good idea in any cooperative learning environment, it is essential in STEM PBL. Like anything else, teachers should train students as they would at the introduction of any new concept. Even those who have played successfully on a sports team will not naturally apply their experiences to a classroom environment. The process of teaming is not instinctive but can be learned.



Team training should include a clear set of expectations: the *forming, norming, storming, and performing* team development cycle (Tuckman & Jensen, 1977); what makes a good team player (i.e., *expectations*); and how performance will be evaluated (teacher only, peer evaluation, or both). Training also should include tools such as how to set an agenda, how to run a meeting, verbal and non-verbal communication, and decision-making processes (consensus is much better for a team than voting – rarely do the students think past voting unless prompted to do so). When groups are expected to work outside of the school environment to complete a project, they need to develop additional procedures to follow. One example might be to include agendas with the following elements:

- Agendas need to include a few essential items:
- ▲ When and where will the meeting take place?
 - ▲ What is the purpose of the meeting?
 - ▲ What resources do we need?
 - ▲ Who will bring what to the meeting?
 - ▲ When will the meeting end? (Some of us have a life outside the team and need to be able to plan for living it.)

Figure 1. Essential items for agendas.

Roles

In a team environment, it is often desirable to have students take on a variety of different roles *and to rotate* these roles. Different roles are desirable because efficiency can be obtained through dividing the work and because it reduces the time when one or more team members are watching the others work and waiting for someone to tell them what to do. Rotating roles is desirable because some jobs are more/less desirable than others *and* because students often do not know which jobs they will be good at until they have a chance to experience the role (*and improve performance when they repeat the experience*). Although there are many possible roles, common roles include the following:

- Facilitator – preferable to leader – this person facilitates team meetings and discussions and makes sure everyone knows where meetings will occur, when they will start/end, what to bring, and so on.
- Recorder – this member keeps notes of action items (minutes of meetings are rarely necessary), that is, a list of who agreed to do what by when. This record needs to be shared with all members of the team to minimize any misunderstandings.
- Time keeper – this person is in charge of keeping track of the timeline (both for the project as a whole and for individual team meetings or activities), keeping the team on task, and reminding team members of when items are due and how much/little progress has been made towards completion of the deliverable.

- Gatekeeper/encourager – this person is responsible for making sure everyone has an opportunity to participate in team discussions and activities by noticing that one member has not said anything and asking his/her opinion or gently reminding a vocal teammate that others may have something to share.

Roles can be combined, and additional team roles are possible. However, teams larger than three or four are generally less effective because of the decreased accountability and corresponding increased likelihood of someone disengaging or slacking off. Depending on the complexity of the project, teams of two are possible, but teams of three or four are generally ideal. It is important to note that these roles are *not* “for the duration of the project”; *roles should be rotated on a daily (or at least weekly) basis*. All students deserve the opportunity to practice each role multiple times – *this cannot be stressed too much*. Also, be certain that students do not see different roles as opportunities to not participate in the project.

Goals and Rules

It is important for project teams to establish goals and rules within the larger classroom-based procedures and routines. These could be viewed as shared norms for the team and should be available to each team member and to the teacher at all times. The goals should include the *teacher’s goal* that all members of the team master the learning objectives included in the project as well as whatever goal the team wishes to set (*winning the competition, finishing ahead of schedule, everyone passes, etc.*). In addition to goals, the team needs to set rules; these are called ground rules, codes of cooperation, rules of engagement, and other things. Rules are simply an agreement among team members about expected behavior and agreed-upon penalties. Often rules include unrealistic promises such as *everyone will give 110% and put the team first above all things*. It is a good idea to have teams revisit and revise the rules on long projects. On shorter projects, classroom procedures and routines can suffice. *REMEMBER:* a good set of rules (see Appendix H and I), which have been agreed to by all members of the team, goes a long way towards avoiding problems as the team struggles to approach the deadline.

Team Ground Rules

1. All meetings will begin and end on time
2. Sarcasm is left at the door
3. All members will participate in group decisions
4. Conflict will be managed and resolved before irritations become overwhelming
5. All debates are no-fault discussions
6. State the purpose of the meeting
7. Only one conversation at a time
8. No cheap shots or personal attacks

Figure 2. Team ground rules.

Some are not comfortable with the concept of *rules*; this can easily be handled by using an *agreement to cooperate*.

Sample Agreement to Cooperate

1. All members will attend meetings or notify the team by email or phone in advance of anticipated absences.
2. All members will be fully engaged in team meetings and will not work on other assignments during meetings.
3. All members will complete assigned tasks by agreed-upon deadlines.
4. Major decisions will be subject to group discussion and consensus or majority vote.
5. The roles of recorder, facilitator, and timekeeper will rotate on an agreed-upon timeframe (all members will take their turn—NO EXCEPTIONS).
6. The team meetings will occur only at the regularly scheduled (weekly) time OR with at least a two-day notice.

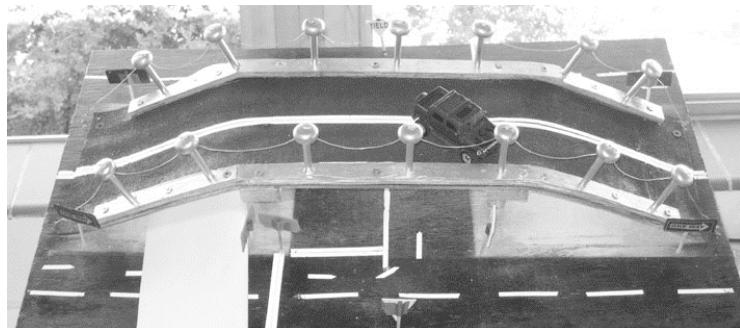
Monitoring Team Progress

The primary job of the teacher/coach/facilitator is to monitor learning and behavior, not to solve all of the problems or transmit the knowledge. The teacher needs to balance student frustration and motivations. Give the students the answers and they will not try to solve the problem on their own; ignore legitimate questions and they will become so frustrated that they will quit. Although the students need to find their own way through the winding path of discovery, they must occasionally be guided gently down the proper path. See Appendix J and K for examples of gentle reminders. Frequent questioning, whether formal or informal, is the best way to monitor progress. Sometimes the answers to these questions will lead to helping a team re-engage. Other times, a question will help the team avoid a brick wall or discover that they learned something in this or another class that might be helpful. Answers also might allow the teacher to discover that the team is making progress (perhaps on an unexpected path). Communication and participation within the group is essential and must be monitored and supported by the teacher.

Accountability

The issue of accountability is both an issue of motivation and an issue of fairness. Students are more engaged if they have a clear understanding of expectations and know they will be held individually accountable. Students are more engaged if they know that the members of their team will be held accountable (even if only in part) for their individual failure. Everyone is less concerned with fairness if they know that at the *end of the day, week, project, or semester*, more credit will be received by those who deserve more credit (see Appendix M), and less credit will be received by those deserving less (see Appendix L).

Most accountability systems include both observations by the teachers and peer assessments of performance on the team (Felder & Brent, 2001; Kaufman, Felder, & Fuller, 2000). Peer evaluation aids the perception of fairness – those who work harder usually get more credit, and those who slack off get less credit. In addition, in most classes, the team component of the course grade is rarely the major factor. Those who depend mostly on teammates to carry the load do not typically achieve the learning objectives and therefore do not do well on the individual quizzes, tests, and exams. On the other hand, the high engagement associated with STEM PBL, combined with peer pressure to participate, results in fewer disengaged students and fewer students failing exams.



Possible alternative questions for a peer evaluation include questions about whether a teammate:

1. Contributes to group discussions
2. Welcomes comments from others
3. Listens even when he/she disagrees
4. Comes prepared to meetings
5. Works hard
6. Makes our work FUN!

Figure 3. Possible alternative questions.

CONCLUDING THOUGHTS

Classroom management in a STEM PBL environment is based on increasing active-engagement and controlling the chaos. The central components of our STEM PBL definition, the *well-defined outcome* and the *ill-defined task*, help support proper management of learning and behavior. The thoughtful identification and implementation of appropriate procedures and routines are essential to the well-defined outcome and when paired with the motivating and engaging components of ill-defined tasks, provide a framework to actively engage and control. It also is important to realize that different methods can be used to satisfy the requirements of a project – *all can be correct approaches, and all are valuable learning opportunities!* Students can learn a great deal from each other, from the process of struggling to find the information needed to complete the project, and in applying the concepts they have learned in the class (and previous classes).

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12. CHANGING VIEWS ON ASSESSMENT FOR STEM PROJECT-BASED LEARNING

INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) Project-Based Learning (PBL) integrates assessment methods across different aspects of learning experiences. While STEM PBL shifts the focus of attention from summative to formative assessment, a greater attention is given to the interpersonal domain. Because of the nature of STEM PBL, which is centered on developing real-world projects where students can apply their understandings of various concepts, authentic assessment underlies both formative and summative assessment tasks through technology, such as classroom response systems, and rubrics. Authentic assessment in STEM PBL helps students transition from an authority-imposed regulation to the self-regulation of their learning. Therefore, assessment in STEM PBL is inextricably interwoven with pedagogy through integrated assessment methods that develop the whole person, stimulate creativity, and foster individualized group responsibility.

The major focus of this book has been on the practical integration of knowledge so that students can demonstrate what they learn in meaningful ways to be academically successful. This chapter is concentrated on determining what students can do and on facilitating students to do more than what they think they can. The particular emphasis of this chapter is on formative assessment; though, making connections to grading and evaluating knowledge products are discussed as a necessity in the current age of accountability.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- the nature of STEM PBL assessment
- various rubrics used in the development of STEM PBL
- complexities teachers face when assessing STEM PBL

When you complete this chapter you should be able to:

- develop an assessment plan that matches your selected learning outcomes for your STEM PBL activity
- communicate clearly with administrators and parents about valuing student learning and not just evaluating it
- assess student learning in terms of academic progress instead of meeting arbitrary decision points (e.g. 90, 80, 70, 60).

OVERVIEW OF ASSESSMENT

The Role of Assessment

STEM PBL requires a whole new perspective on what assessment means. As an integral component of STEM PBL, assessment holds the project components together, maintains student motivation for learning (Brophy, 2004), and provides both the teacher and the student with useful information about each student's learning (Kulm, 1994). In STEM PBL assessment, teachers need to change their focus from summative to formative assessment. When the focus is formative, (1) assessment is not seen as simply quantifying a product but is more concerned with the learning process (Ashcroft & Palacio, 1996), (2) test scores or grades have minimal impact on the summative assessment of the students (Wright, 2008), and (3) students are keenly aware of their own learning processes.

Students are not accustomed to encountering the STEM PBL assessment. In typical teacher practices, assessment is synonymous with grading, which determines the success or failure at school. This typical

approach to assessment leads students to strive to do well on tests in order to get a good grade rather than develop learning strategies through self-improvement and understanding. For students, an authority-imposed regulation of learning through grading precludes the interpretation of assessment as a means of feedback towards the desired learning objectives. For teachers, the typical approach to assessment emphasizes the common belief that teachers need to understand what students do not know so that teachers can adjust teaching content, teaching style, or the ways they assess learning to improve student understanding. Over the course of their education, students have already developed a preconceived notion of what assessment is and how it is done. Sometimes breaking the mold requires confronting student conceptions as well as shifting the practices of teachers.

Teachers need to be prepared for helping students with STEM PBL assessment. Based on our experiences with teachers, it is common at the beginning stages of PBL projects that teachers are faced with student reactions, asking for further clarification to their checkpoint assessment. To those teachers, our response is that students have to be taught how to interpret a rubric, how to interpret the teacher's comments, and that a formative assessment is meant as a checkpoint rather than a grade. It is also common that students are often turned off by poor grades at the initial stages of STEM PBL, so it is paramount that the teacher set the stage by discussing how formative rubrics are used and that rubrics are designed to help students identify the areas for improvement rather than to evaluate their success or failure. STEM PBL's new perspective on assessment requires a change in both teachers' and students' views on assessment.

Formative and Summative Assessment

There are two broad categories of assessment: Formative and Summative. Formative assessment provides students with regular feedback to regulate their own learning processes, whereas summative assessment primarily concentrates on evaluating the learning that has taken place following a predetermined instructional period. In the most general terms, almost any assessment can be used in a formative or summative way, albeit, some assessment tasks, such as multiple-choice tests, provide only limited information.

Summative STEM PBL assessment tasks are ideally planned concurrently with lesson development. It is, however, not unusual that preplanned rubrics are modified or new rubrics are created during the later stages. In this perspective, summative assessment is not relegated to the last day of the instruction. They can occur in smaller increments throughout the instruction. Teachers may choose to use short summative assessment tasks to guide students toward an improvement in collaboration with other team members by emphasizing the sense of individual accountability or toward a development of their content knowledge. Yet, such short summative assessment tasks should be accompanied by an advanced preparation of the students to the tasks rather than come as a surprise. As teachers would not be happy to have their teaching assessed without preparation or without knowing the criteria on which their teaching was assessed, using surprise summative assessment demoralizes students, diminishes their intrinsic motivation, causes discontinuity in group and individual learning, and can even break down the learning process extensively. Summative STEM PBL assessment should only be used after closely aligned formative assessment tasks are introduced to the students.

The formative STEM PBL assessment encompasses an accumulation of learning artifacts, which are assembled by students through clear and explicit directions from the teacher. Teacher-driven directions align the expected learning outcomes to the STEM PBL projects, while the artifacts are used as summaries of student knowledge or are knowledge products that depict a richer and more complete picture of what students have learned. In this regard, formative STEM PBL assessment should be a means for helping students apply their knowledge, thereby owning the knowledge rather than acing the tests. Thus, the formative STEM PBL assessment must move beyond evaluating student success in spitting out formulas.

In the age of accountability, success in multiple-choice tests still continues to be an important benchmark, measuring the effectiveness of teaching for tests. By focusing on critical assessment of students' progress in thinking through writing about what they learn and why they believe that they learned, formative assessment, which is empowered by such writing and reflection tasks, is more likely to lead students to be flexible with their knowledge (Boaler, 1998). Being flexible with their knowledge may help students develop certain test-taking skills, such as critical-reading skills that may help students develop the ability to better comprehend the readings presented in multiple-choice items on high-stakes state tests.

STEM PBL assessment evaluates both individual and group performance. It is important to match the formative assessment to the learning activity and the setting in which the learning takes place. For instance, individualized formative assessment of a group activity is less productive than a more encompassing and group-based assessment of learning. If students pursue learning individually, the group-based assessment may create dissonance with individualized learning and, thus, have a negative impact on student learning. For group-based assessment, if group membership is heterogeneously assigned, less customization of the

assessment is required. When students are randomly or self assigned to groups, the assessment needs to be modified for each group's personality and academic idiosyncrasies. In cases where a high degree of customization occurs, groups may only demonstrate one specific learning goal of the STEM PBL as compared to students with less customization, who may be able to produce more comprehensive artifacts (see [Figure 1](#)). Similarly, the content is an essential variable that should be accommodated when designing the assessment. Some content is more easily assessable by some methods than others. For example it is a challenge to assess knowledge level content through creative assessment tasks. Thus, it may be difficult to assess content at the analysis or evaluation levels.

In short, formative assessment can differ based on several aspects of the STEM PBL environment, including:

- The setting (e.g. group or individual)
- The content
- Outcome expectations
- Allotted time frame
- The time students spend on the activity
- Constraints in the design brief
- Criteria

Authentic Assessment

Authentic assessment is the most complicated assessment method compared to other formative and summative schemes. Despite the lack of an agreed definition, there is a consensus among educators that authentic assessment tasks should focus on the knowledge products, which make the assessment relevant to the learner through real-world applications. Authentic assessment matches the content being learned and knowledge products with student interests guided by clearly defined outcomes. Examples of authentic assessment can include tasks as simple as students listing what they learned to get to a certain stage of the project or may be as complicated as filing a report of their progress and the steps involved in solving the problem. Authentic assessment fits into various aspects of STEM PBL in different degrees. For example, when assessment of procedural skills is the focus, authentic assessment is less relevant compared to the situation when the goal of assessment is to understand how students apply those procedural skills in real-world contexts. Another example is the “just in time assessment,” which is a form of authentic assessment that utilizes technology. In one “just in time assessment” model, the tablets (e.g., iPads or Android-based mobile technologies) can be used, casting in the role of a data collector. The tablet easily captures student performance as a video and audio file, which can be used by the teacher to digitally record information into rubrics and made immediately available to the students. Just in time assessment is instantly performed by the teacher with minimal delay between the time that the assessment is performed and the time that students received information regarding their progress. Another just in time assessment example is the classroom response systems or classroom clickers (Duncan, 2005). Clickers provide the teacher with the opportunity to carefully play assessment, be it alpha numeric (the students type in a response), multiple choice, or numeric. With the help of the clickers, all students simultaneously participate in the learning process through both group and individual feedback. The group feedback can help the teacher make decisions about how the rest of the lesson will proceed. In return, students get a firm understanding of what the whole class understands and their corresponding learning level compared to peers. Because the identities of each individual are masked, students can only see the individualized feedback provided to them while the feedback to their peers remain anonymous. These forms of just in time assessment can be powerful in differentiating STEM PBL instruction from more traditional practices in a cost-effective way (Cavanaugh, 2006). Just in time assessment methods clarify the utilization of authentic assessment methods in the digital domain (see Chapters 8 and 9 on technology).

The Venn Diagram in [Figure 1](#) categorizes the assessment methods explained in this chapter, some of which are more closely aligned to the intent of PBL than those peripherally associated.

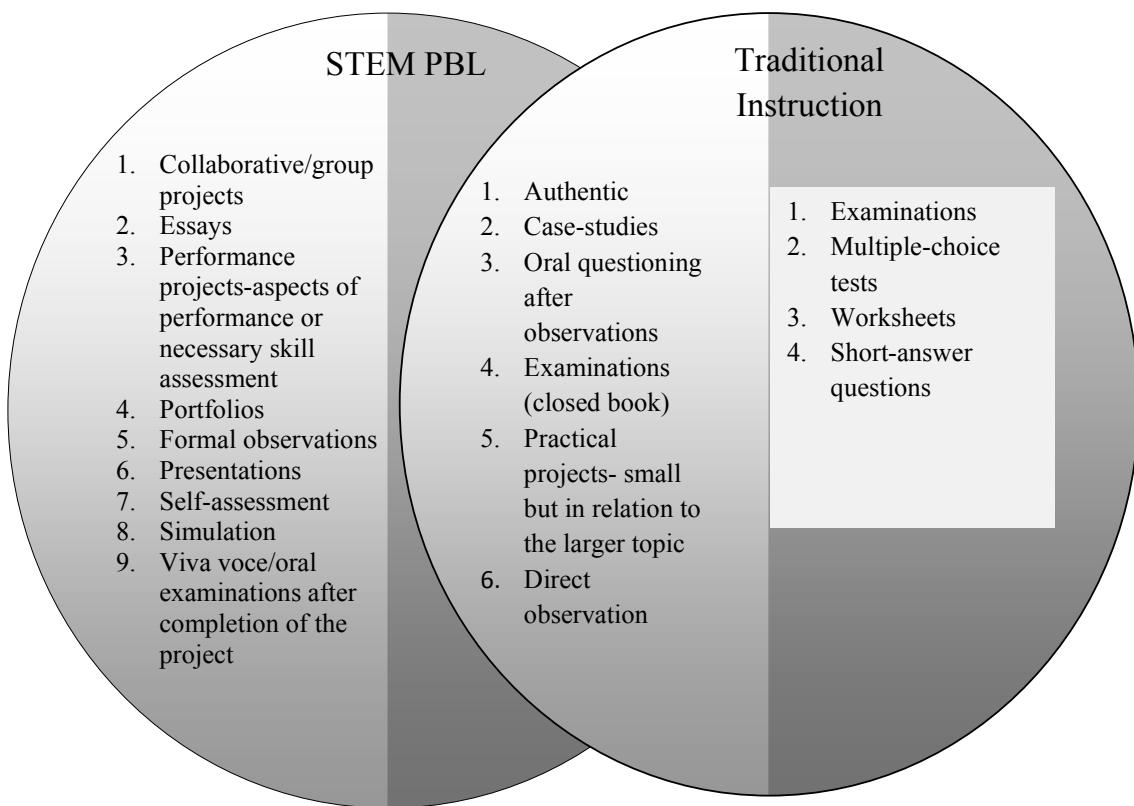


Figure 1. Comparison of assessment methods in STEM PBL and traditional instruction

STEM PBL ASSESSMENT

It is essential to integrate assessment and instruction in each STEM PBL lesson (Solomon, 2003). In the practical design of STEM PBL, the standards are clearly delineated so that assessment and instruction are intertwined. If teachers are keenly aware of the standards in their content area, then they can base their students' expectations on these standards and develop a STEM PBL environment that addresses these expectations. It is not necessary for the teacher to predetermine every aspect of the assessment methods to be used with the STEM PBL at the onset. Different assessment methods may be chosen after the initial selection of standards and perhaps even during the actual STEM PBL activity because assessment needs to be aligned with the learning environment. For instance, teachers can adjust the assessment method based on the setting because the assessment of the same content or standard can differ depending on whether learning occurs in groups or individually. When students learn in group settings, it is important to respect the group intelligence and assess in group settings with individual accountability. We present some examples of common rubrics as well as other examples and helpful tools in the Appendix of this chapter, which might be helpful to teacher in setting up their STEM PBL environments.

Individual Accountability

There are several accountability strategies that attenuate and facilitate group intelligence, yet encourage individual accountability at the same time. Peer assessment is one of those strategies that can provide the teacher with valuable insights about individuals' contributions to group intelligence. Further, setting up requirements, where students are randomly or pseudo randomly selected by the teacher, may explain the group's results so that the team's score is in part based on that person's individual responses. Reflection is another way to gain insights into individual performance. When the teacher uses reflection strategically,

students can respond to questions about what would have improved the project, what would have improved the group's product, and how could their performance have changed to improve the quality of the deliverable. These questions can yield surprising insights about both the respondent and the team members. There are several examples contained in Appendix Q and R.

To help guide individual accountability, teachers may consider the use of contracts, both social and intellectual to establish common goals (common to the teacher and students) that clearly articulate expectations. The contracts can be agreed between groups when it is group behaviors (whether those behaviors are social or intellectual), between a group member and his or her group, or between the teacher and an individual group member or some members. Appendix O provides an example of a completed contract and several other contract types that can be used or modified to meet specific classroom and instructional needs.

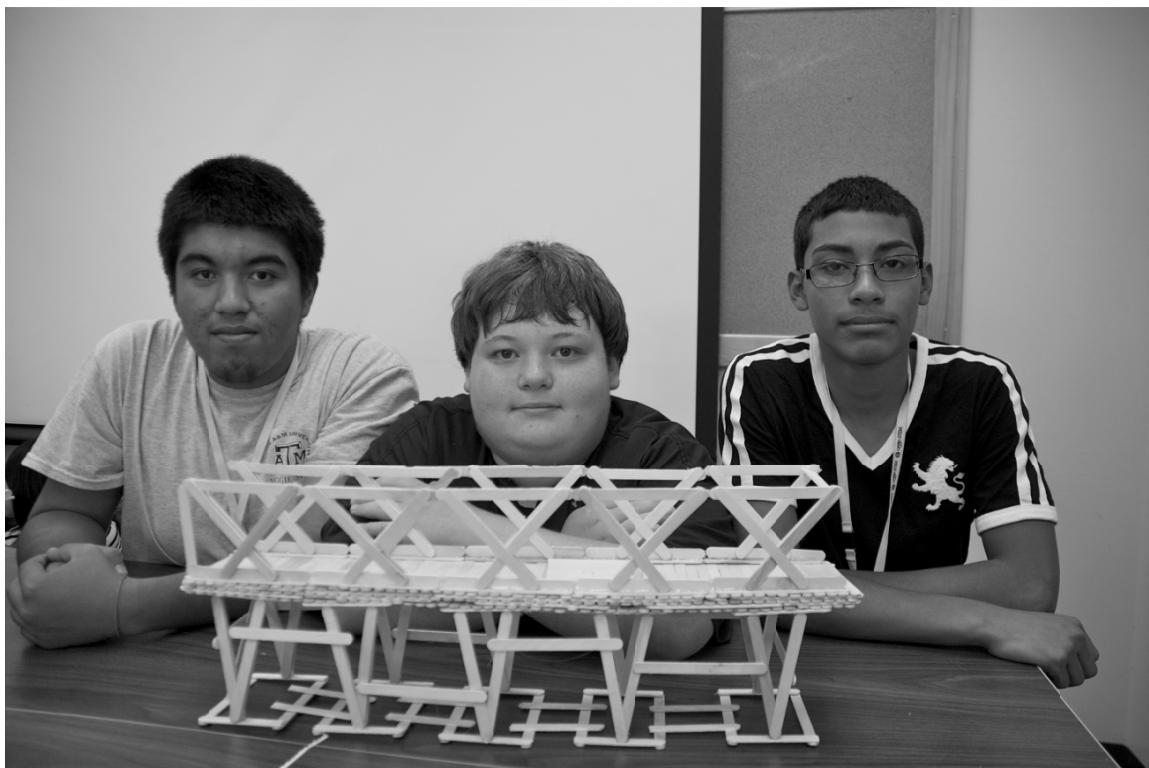
Additionally, it is important to use individualized assessment that mirrors assessment tasks at the state level because students need to be able to demonstrate their learning on high-stakes testing formats, too. As long as schools, teachers, and student performances are measured with high-stakes tests, any educational innovation that fails to provide measurable impact on high-stakes assessment is doomed. Therefore, it is paramount to achieve an equilibrium between authentic and high-stakes assessment when considering the individual accountability. In a STEM PBL environment where the instruction focuses on designing, constructing, and synthesizing, it is important that assessment is similarly focused and that sufficient weight is given to these concepts as opposed to the high-stakes variety. One effective way to reflect student accountability in authentic assessment is through the careful design and application of rubrics.

Development of Rubrics

This book contains many rubrics, which are designed to provide educators with important guidance. Some of the rubrics are tried and tested for many years while some are newer. However, all are developed, used, and shared by the teachers we work with. Rubrics should be used with an important principle in mind that teachers should always prepare students before they use rubrics in class. Rubric use and grading has to be taught just like any other classroom practice so it can become the routine and not the exception. It is our honest goal that the included rubrics are viewed as intellectually stimulating and they prompt you the reader to try your hand at developing the rubrics you will use in your classroom to facilitate student learning and to stimulate creativity and in-depth STEM learning.

Rubrics are one means for providing students with formative and summative feedback about their learning processes. Rubrics can help teachers to evaluate students' learning efficiently (Andrade, 2000). Rubrics also provide guidance for students throughout the self- and peer-assessment processes (Andrade, n.d.). The specific and clear criteria identified in rubrics are particularly helpful for those professionals who are not teachers and thus not familiar with assessing student performance as they evaluate projects. A well-designed rubric contains components that reflect the specifics of the standards and conceptual generalities of an activity as well as intangible aspects like those reflected in the Secretary's Commission on Achieving Necessary Skills Report (2000). Various attainment degrees of the learning goals are specified in the rubrics (Andrade, n.d.). Rubrics should also provide sufficient information to help students understand what they know and do not know and some guidance about what they need to learn (Zimmaro, 2004).

Rating	Brief Description
1. Nascent	Student displays preliminary knowledge and skills related to the learning task.
2. Constrained	Student displays limited knowledge and skills related to the learning task.
3. Developing	Student displays a developing level of content and concepts related to the learning task.
4. Commendable	Student displays functionally adequate attainment of the content and concepts related to the learning task.
5. Accomplished	Student displays mastery of the content and concepts related to the learning task.
6. Exemplary	Student displays a novel or personal level of mastery of the content and concepts related to the learning task.



The rubric's scale can be closely related to the grading system or be one that obfuscates the relation between the scale score and the A to F grade equivalency. For example, a rubric can either be interpreted by point value and the points converted to a percentage score, or the six-point mastery rubric can be interpreted directly from A+ to F. Contrarily, a rubric can be based on a three- or four-point scale that does not align well with the conventionally-based A to F grading scale. An even number of ratings (such as four or six) precludes a midpoint decision on the part of the rater. This is often considered desirable. What is most important when designing a rubric is to assign more weight to the critical and important aspects of the task while placing less emphasis on things tangential to the clearly-defined outcomes.

SAMPLE GENERIC RUBRIC

Note. This rubric meets some of the tenants of rubric design, but from this rubric, the student would not have sufficient information about the knowledge gaps but just that he or she has gaps. To improve the rubric one could replace the words *knowledge and skills* or *content and concepts* with specific knowledge and/or skills necessary to the learning outcome.

Rubrics are an essential component of PBL that serve different purposes for those who are involved in the assessment process both at the stage of the rubric's development and its utilization during the evaluation. There are many stakeholders involved in the assessment process and the whole group should have some level of responsibility in the development of rubrics, including students, peers, the supervisor (teacher), and possibly even external evaluators such as other content-area teachers, administrators, coaches, or interested community members. When all stakeholders are involved in rubric development, they not only understand the criteria but also own them.

The use of rubrics by students through teacher modeling can help them develop important self- and peer-assessment skills. However, in urban schools it is often difficult to enculturate self- and peer- assessments and teachers can find the enculturation process to be time consuming to attain the positive impact that these assessments are intended to achieve. However, some groups of students and/or school cultures are less resistant and teachers can be surprised by how rapidly students own the self- and peer-assessment methods. Sometimes students may be overly critical whereas at other times they are overly accommodating. It is important to model critical feedback (Falchikov, 1995) that is both honest and constructive. Students should understand that to identify a weakness without an accompanying suggestion for improvement does not foster intellectual development. To foster the development of self- and peer-assessment, it is important for students

to (1) be involved in the development of rubrics, (2) be reflective by learning to self-assess, (3) receive critical commentary on their assessment of peers.

The enhanced understanding of learning goals and assessment criteria help students to develop metacognitive awareness and an intrinsic motivation (Peckham & Sutherland, 2000). Students who regularly engage in PBL activities should be able to thoughtfully answer:

- How can I tell if I have learned _____ well enough?
- Does the learning serve my current needs?
- Did I learn it in a way that I will be able to use it in the future?
- Will I be able to transfer this learning to new situations?
- Do I know what I do not know?
- Do I have the necessary foundation to learn more?

Self-Regulation

Explicit assessment helps students to self-regulate their behavior. Two different levels of self-regulation are present when students are integrally involved in the assessment process. The first level of self-regulation emerges as students co-develop rubrics for assessing various aspects of the PBL. Through involvement in the development of the rubrics, students establish ownership of the assessment model and clearly understand of what aspects of learning will be evaluated and how (Bray, 2001). This process will allow students to decide the degree to which their artifact meets expectations. This thorough understanding of the rubric can guide students as they implement self-regulation to plan their learning activities to achieve the objectives of the rubric. Thus, involving students in the development of rubrics fosters a sense of self-determination as they feel the agents of their own learning.

The second level of self-regulated behavior takes place when students learn peer- and self-assessment through the application of the rubrics they develop. As students do self-assessment, they get to know their areas of weakness and strength and allocate their effort to different areas of the learning objectives accordingly, thus holding themselves responsible. Students also start to align the requirements of the rubric with their learning process and desire to meet the requirements for their own benefit and purposes rather than merely meet the requirements of the teacher. Peer-assessment also could be a function as an information for their own learning, especially when assessment focusses on the development of particular skills in a non-competitive environment. Informational feedback could further enhance students' self-regulation. This implementation of this second level of self-regulation may require several attempts and clarification by the teacher. Although the application of the rubric to assess a student's own learning and behavior may be difficult initially, repetition will lead to success and the student will eventually develop an appreciation for the assessment and value for the learning task.

Formative Assessment of Teacher Enactments of PBL

It is important to include the teacher in a chapter about assessment. The teacher too, should participate in being formatively assessed in his or her enactment of STEM PBL. We have included a sample document, which was developed by Aggie STEM team. The Aggie STEM teacher assessment instrument follows from our STEM PBL model as well as professional development training program. However, this teacher assessment instrument should never be used as a summative assessment of teachers. The document is designed to provide criteria specific information (Stearns, Morgan, Capraro, & Capraro, 2012).

In order to improve the quality STEM education classes, which are designed to encourage conceptual development (i.e. PBLs), teachers need feedback and support, too. "There is considerable evidence from different studies suggesting that how teachers behave in the classroom, the instructional approaches they employ, significantly affect the degree to which students learn (Van Tassel-Baska, Quek, & Feng, 2007, p. 85). In fact, research shows that ineffective teachers can depress student achievement in mathematics by as much as 54% regardless of students' abilities (Sanders & Rivers, 1996). Without some form of classroom observation, teachers' assimilation of professional development ideas cannot be assessed and continuous improvements may be compromised (VanTassel-Baska et al., 2008). Observations can be either peer or professional in nature, but the observer needs to provide feedback to the educator so he or she may evaluate and adjust their teaching to benefit students (Patrick, 2009). See Appendix S for an example. Therefore, to ensure translation of any professional development into classroom practice, assessment must be present in some form during actual teaching activities. When carefully aligned with the professional development, a

classroom observation instrument can be an effective tool for providing feedback about assimilation of PD teaching strategies.

An effective way of evaluating teaching behaviors is with the use of a specifically designed observational instrument (Guskey, 2002; O’Malley et al., 2003; Simon & Boyer, 1969). An observation tool can yield a descriptive account of targeted performances. This can be achieved with a conceptual rubric that contains a numeric range of descriptors for each predetermined objective. Observational data can also be structured with a frequency-counting system, or coding system (Taylor-Powell & Steele, 1996). Observational tools can serve to monitor progress toward increasing a desirable trait or diminishing an undesirable behavior based on some theoretical framework. For example, The Aggie STEM teacher assessment instrument includes a category: “The teacher worked with members of all small groups,” noting that a teacher who did this well, a score of 4 or 5 would likely provide confirmation that the actions were noteworthy and meritorious and might likely reinforce the practice. However, assigning a low score of 1 or 2, and noting in the discussion with the teacher that “Too much time was spent only one single group, resulting in not checking in with or visiting with other groups. This resulted in some students not making as much progress as others toward the completion of the project,” would likely to identify the issue, describe the condition, and the effect. Thus, with all these points taken together, the teacher has a solid structure for altering instruction to meet the intent of the category. The information gained through an observation tool can also be used for teacher reflection and to customize subsequent professional development. See Project-Based Learning Observation Record (Stearns et al., 2012) in Appendix T.

The Aggie STEM teacher assessment instrument was specifically created to evaluate observable teaching and learning objectives when teachers develop and implement STEM PBL activities in their classrooms. Teachers being evaluated with this instrument should have participated in sustained professional development (5 or more full days) focusing on STEM PBL. The professional development should focus on each of the measured objectives. Both the observers and the teachers should be trained on the components and purposes of the instrument. The instrument contains twenty-two items organized by six objectives. The objectives include: (a) PBL Structure, (b) PBL Facilitation, (c) Student Participation, (d) Resources, (e) Assessment, and (f) Classroom Learning Environment. The number of indicators under each objective varies. Each indicator is evaluated on a scale ranging from 1 (no evidence) to 5 (to a great extent) with the observer justifying every score assigned to each item. Occasionally, an item will not apply to what is taught during a particular observation. When this happens or when the observer is only present for part of a PBL activity, a well-documented lesson plan can provide insights and further details. The observer may still choose to indicate that a particular behavior was not applicable or not observed during the class period. Finally, the authors of the instrument at the Aggie-STEM Center encourage you to seek professional development prior to using it and to participate in an observers’ workshop for teachers, who are already expert STEM PBL implementers, to learn to provide constructive-formative feedback and to carefully rate the teaching enactments.

GUIDING THOUGHTS FOR TEACHERS ABOUT PBL ACTIVITIES AND ASSESSMENTS

- Think about the content you teach. Think about what makes your content area and the assessments you traditionally use distinct from assessments in other content areas. Consider the changes that PBL requires in both teaching practices and assessments (Moursund, n.d.). A sample project development rubric is included in Appendix U.
- Think about how students learn. Much is known about the value of metacognition, self-assessment, and reflection on student learning. Do you think self-assessment is a valuable attribute for students who enter the workforce in a field related to your content area? How important is it in your content area of field to learn to assess one’s own work and learning and that of peers or co-workers (Moursund, n.d.)?
- Think about your PBL. Critically examine your PBL and the lessons or activities and comprise it. Did the PBL cover the standards and objectives in your curriculum? Did you align assessment with your standards and objectives? Did you balance formative versus summative assessments? Think about provide useful formative feedback within the constraints imposed by the length of your instructional time allotment. How will you ensure the feedback is timely so students’ efforts can reflect this information before the next assessment occurs (Moursund, n.d.)?
- Think about PBL versus traditional instructional practices. Consider the substantive adaptations or modifications you need to make in the structure of your curriculum and teaching practice. What aspects of PBL attracted you to make the effort and go through these changes (Moursund, n.d.)? If you are satisfied with the results of your current teaching practices, then one reason to implement PBL is to infuse the social responsibility so prevalent in PBL. Perhaps you are ready to try something new that will provide you a new challenge and add rigor to your activities to build on previous successes. You may have considered that times

have changed and students will need to be prepared to thrive in a STEM world where the ability to creatively solve problems in dynamic and fluid situations abound. Regardless, students who are preparing to enter college will benefit from their experiences with PBL, and those students who do not participate in post-secondary education will develop a deeper and more salient understanding of the working world that they will enter. All students will have the opportunity to develop the cooperation and collaborative skills that are in demand regardless if they become factory workers or engineers.

PBL SAMPLE AND ASSESSMENTS

In the “Who Killed Bob Krusty?” PBL (see Appendix V), the scenario contains all the salient information that a student needs to successfully engage the problem. The activity integrates calculus and science with a forensic science and criminology spin. There are important skills need to be assessed before the start of the project and then again after the completion of the project. In this PBL, students are given the same assessment form before and after the activity. The pretest serves as one formative assessment. It provides students with a structure about what they are expected to be able to do upon completion of the PBL. For teacher, the assessments provide insights about students’ strengths and weaknesses so that the teacher can adjust the PBL process to meet students’ needs, such as providing whole-group instruction on specific topics. The posttest provides a direct measure of how much improvement was achieved through the PBL. Another summative assessment may be included, such as asking students to keep a daily journal where students can reflect on their learning, record their thought processes during the PBL, and discuss what mathematics they need to employ or learn more about.

This activity can facilitate incorporation of knowledge from additional disciplines. For example, a drawing of the crime scene can be useful to determine if the conditions are aligned with falling from the window or being thrown. This aspect of the activity may involve the contribution of the engineering or CAD design teacher. Geometry and trigonometry as well as physics and chemistry topics may easily be integrated into the PBL. Nevertheless, it is always essential to foster scientific process skills in any PBL, such as those employed by medical examiners during a death investigation. That is, they rule out the cause of death based on death scene characteristics, medical history, and other factors, and whatever is left that cannot be ruled out as the cause of death. Additionally, in real life, coroners, forensic examiners/investigators, and police officers are included in the process as case reporters; therefore, within this activity students should also be expected to write reports to meet learning objectives, thereby facilitating connections to the language arts class. At periodic intervals during the activity to check on learning, students should provide forensic reports that rule out possible causes of death. The final report should incorporate these preliminaries and provide a detailed hypothesis and a conclusion, so that students can demonstrate a clear final explanation, incorporating the mathematical and scientific processes to support their hypothesis and the conclusion.

UNDERSTANDING PBL

Given that this chapter is focused on assessment, it is important to connect the discussions in the book through an assessment model. The PBL Refresher Quick Quiz (see Appendix W) should be considered as a formative assessment task. Some answers are not obvious initially from just reading this book. In fact, PBL is much like riding a bicycle. No matter how many technical manuals one reads about riding a bike, one must still get on, fall off, and reflect on both actions and suggestions in order to master the task. What makes riding a bike so complex? It is not just one task. It is composed of many small tasks that must be mastered to enjoy success. You must be able to balance, coordinate your peddling and steering, remembering that maintaining your balance is easier as long as you are moving forward. Thus, remember how to brake and understand that loose gravel can result in a painful lesson. Just like riding a bike, PBL is not just one task but the interaction of several smaller tasks, including choosing learning outcomes, planning content, determining a scenario, writing the scenario, developing formative assessment tasks, creating rubrics, and designing summative assessment tasks. Then, once the PBL starts, two new tasks arise: managing the materials and students. Therefore, as one reads and implements their PBL, one will gradually be more confident about the answers to the PBL Refresher Quick Quiz. It is the only iterative process of reading about PBL and implementing it in the classroom required to make it a second nature. Only through practice is it possible to perfect one’s teaching because it is the teachers’ own experiences and reflections that offer the best opportunities to improve student achievement.

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13. ENGLISH LANGUAGE LEARNERS AND PROJECT-BASED LEARNING

INTRODUCTION

For many students in American schools today, the language of the classroom is not the language they use in their own homes. These students come from many different cultural and linguistic backgrounds. In addition to learning English, these students must also master the content of mainstream classes, such as math and science. Even if these students can use English for basic communication, the academic language required in a content classroom proves to be a much greater challenge.

Today, many educators are looking to Project-Based Learning (PBL) as a way to help students attain greater levels of understanding in their classrooms. Teachers of Science, Technology, Engineering, and Mathematics (STEM) are using STEM PBL to motivate students to see the value of these fields and raise achievement as well. For English Language Learners (ELLs), STEM PBL can be an excellent way to help them build their knowledge in these content courses, while also providing opportunities to become more proficient in English. This chapter describes how teachers of STEM classes can use STEM PBL to meet the content and linguistic needs of their ELL students.

CHAPTER OUTCOMES

When you complete this chapter you should better understand:

- the demographics of ELLs
- the language and cultural issues ELLs face in a STEM classroom
- strategies to use with ELLs
- ways that STEM PBL can meet the needs of ELLs

When you complete this chapter you should be able to:

- plan STEM PBL for a classroom with ELLs
- adapt STEM PBL to the needs of ELLs

ENGLISH LANGUAGE LEARNERS

Demographics

English Language Learners (ELLs) are increasing in numbers all over the United States, with some states feeling the increase more than others. In 2008-2009, there were 5,346,673 ELLs in K-12 schools in the U.S.A., almost 11 percent of all public school students. California had the highest number of ELLs (1,512,122), with Texas (713,218), Florida (257,776), New York (229,260), and Illinois (208,839) as the next highest states (National Clearinghouse for English Language Acquisition and Language Instruction Educational Programs [NCELA], 2012). In 2008, the Office of English Language Acquisition, Language Enhancement, and Academic Achievement for Limited English Proficient Students [OELA] reported that in the previous ten years, the percentage of Limited English Proficient (LEP) students had increased nationwide by 60 percent, while the overall student population had only increased by 3 percent (p. 8).

While the highest populations of ELLs are in states with historically high numbers of immigrants, such as California and New York, most states have seen an increase in the number of ELLs in their classrooms. During this time, many states have experienced an increase of over 200 percent in the number of ELL students in their schools (OELA, 2008). Also, although the majority of ELLs reside in a small number of districts across the country, many districts do have at least some ELLs in their schools (OELA, 2003, p. 5). It can be challenging for states such as Oregon and Michigan, where ELLs have increased by more than 100

percent, and even more so in states such as Georgia and Virginia, where ELLs have increased by more than 200 percent, to be ready for the rapid change in student demographics in the classroom (NCELA, 2011).

One of the challenges for states dealing with ELLs in their classrooms is the great linguistic diversity of these students. ELLs in U.S. schools speak more than 400 languages as a first language. The vast majority of these students (about 80 percent) speak Spanish. Four Asian languages, Chinese, Vietnamese, Hmong, and Korean, make up another 5 percent of the ELL student population. No other language by itself reaches one percent of the ELL population (OELA, 2008).

These students differ in much more than the language they are accustomed to speaking. A number of other factors separate these students. As Echevarría, Vogt, and Short (2008) note, these students vary in their “educational backgrounds, expectations of schooling, socioeconomic status, age of arrival, personal experiences while coming to and living in the United States, and parents’ education levels and proficiency in English” (p. 7). They may come from families and cultures where formal schooling is a high priority or schooling may be a very new experience for both parent and child. If the student comes from a migrant family, they may have experienced schooling only sporadically, and may have difficulty adjusting to a new school environment. The student may even have been born in the United States, but not feel comfortable culturally and linguistically with the setting. Any of these factors may be in play when working with ELLs.

Specific Concerns with ELLs

Cohen (1986) points out that “the dedicated classroom teacher of a bilingual or English as a Second Language (ESL) classroom faces a scene of enormous complexity-linguistic, academic, and cultural” (p. 128). These students approach the classroom with certain expectations and understandings. However, these expectations may not line up with those of an American classroom, particularly in STEM courses like science (Lee, 2005). ELLs may not have the necessary background knowledge to know how to act in a classroom setting or how to complete an assignment in the way that a teacher expects (Moje, Collazo, Carillo, & Marx, 2001). This mismatch in schema can cause confusion and frustration for both the teacher and the student.

Part of the problem for ELLs comes from not knowing the academic language and key vocabulary for different content areas (Echevarria, et al., 2008). In classrooms involving ELLs, a multitude of different ethnic, home, and peer discourse styles interact. Teacher and students can be using the same words to talk, read, and write about topics in content-areas, yet still not communicate effectively if teachers don’t make explicit the discourse styles and ways of using language of the content area (Moje et al., 2001).

Two things must be stated regarding the importance of an ELL’s proficiency in English in a content-area classroom. First, an ELL’s lack of proficiency in English means that it will be harder to learn the content of the class (Lee, 2005). While this might seem obvious, there is another part of this that is not as intuitive to teachers. Cummins (as cited in Butler-Pascoe & Wilburg, 2005) points out that the language of the content area is more abstract, more complex, and takes more time to learn than conversational language. A student may be fluent in conversational English, where there is a rich amount of context included and it is not cognitively challenging. However, this student may not be able to negotiate in a content-area environment where there is little context and it is more cognitively demanding. Therefore, teachers cannot assume that because a student can speak with them in English also means that they can understand and perform at the same content level as other students in their class.

Sometimes, in recognition of students’ challenges with the language in classrooms, educators may be tempted to simplify or water-down the curriculum for these students. The danger here is that the curriculum will become “so narrow that it limits the students’ intellectual development” (Cohen, 1986, p. 142). By focusing solely on their linguistic needs, ELLs do not receive the content-area instruction they also need, and fall even further behind their native English counterparts in school. Furthermore, the reauthorization of the No Child Left Behind (U.S. Department of Education, 2010) requirements makes it clear that ELLs, like all other students, need to be prepared for standardized assessments, with new assessments for content areas such as science to begin in 2015. Educators must find ways to help students succeed in both language proficiency and content-area knowledge.

What do English Language Learners need to succeed?

First, ELLs need clear, explicit objectives and expectations. It is difficult for students to learn specific content and acquire certain abilities if they are not sure what they are supposed to be focusing on in the first place. Many ELLs struggle in content-area classrooms because teachers may not give specific objectives to students, or they may only give them orally, requiring ELLs to process information too quickly (Echevarria et al.,

2008). Also, students who do not know how to navigate through school culture need teachers “to make that culture’s rules and norms explicit and visible, so that students learn to cross cultural borders between their home and school” (Lee, 2005, p. 506). This clarifying of expectations and objectives for ELL students allows them to work with a clear purpose and provides the framework they need for moving through curriculum.

Next, because ELLs often lack the necessary background knowledge for content classrooms, teachers need to bridge this gap in their students’ knowledge. First, they can relate the new content information to experiences in the students’ background. Moje et al. (2001) point out the importance of teachers “explicitly connecting and integrating ‘Discourses’, experiences, and funds of knowledge” of the students to the content (p. 491). Doing this enables ELLs to understand the language and knowledge of the content classroom, as well as feel that their own knowledge and experiences are valuable in the classroom.

Teachers can also help students build background by emphasizing key vocabulary. Teachers should introduce the vocabulary, write it down for students to see, repeat it often, and highlight it when it is being used (Echevarria et al., 2008). Zainuddin, Yahya, Moales-Jones, and Ariza (2007) suggest a number of different ways to teach key vocabulary to students of different proficiency levels. These include using word walls, mnemonic devices, flash cards, songs, games, the dictionary, or analogy. By helping students learn the key vocabulary, teachers enable students to use the content-specific language and ideas that they will need to move in the classroom.

Another aspect of teaching that is important with ELLs is that the work and activities they do in the classroom should be meaningful to their learning. By doing activities that reflect the way things are accomplished in the real world, students have a more authentic experience that connects the language and content they are learning to everyday life (Echevarria et al., 2008). Omaggio-Hadley (2001) notes “students need to learn language in logical contexts, either through authentic discourse-length input or through language learning materials” (p. 161). Without these meaningful contexts, ELLs struggle with content that is abstract and far away from what they can relate to. One way to make learning concepts less abstract is through the use of manipulatives and hands-on learning. Reid (1987), in a study of preferred learning styles, “showed that ESL students strongly preferred kinesthetic (physical involvement) and tactile (hands-on) learning styles” (p. 7). These can take a number of different forms, including models, experiments, building blocks, or small pieces of food to count (Hawkins, 2005; Reiss, 2005). Moving objects by hand can aid ELLs in understanding complex ideas that might not otherwise be clear.

Scaffolding techniques can be used to improve reading comprehension. Scaffolding is based off of Vygotsky’s (1997) ideas of a zone of proximal development. This zone is the distance between what the child can accomplish solely through its own development, and what the child can accomplish through some type of assistance. Vygotsky said that this assistance can come through the direction of an adult, such as a teacher, or through collaboration with a peer who is more expert. Teachers can help students move through this zone by scaffolding instruction, or supporting a student’s learning in some way (Greening, 1998).

Echevarria et al. (2008) list three main ways of scaffolding for ELLs. These are verbal scaffolding, procedural scaffolding, and instructional scaffolding. Verbal scaffolding involves using different techniques to elicit more language production from the student. These techniques include prompts, questions, and elaboration. In addition to moving students to higher proficiency levels, these techniques also help students with comprehension and thinking skills. Other examples of verbal scaffolding include paraphrasing and providing correct pronunciation. One other, very powerful form of verbal scaffolding is when teachers change how they speak to students. These changes can be in the rate of speech, word choice, the pauses that are provided, the complexity of the sentences, and its length. Procedural scaffolding consists of a number ways of showing and demonstrating to students. One common way for teachers to give procedural scaffolds is through modeling to students what is to be done (Butler-Pascoe & Wiburg, 2005). Teachers can explicitly teach about a process, model it for them, and then do it with the students. After having scaffolded the process, students are able to move through the steps by themselves. Finally, instructional scaffolding helps students to organize and comprehend content. Reiss (2005) describes a number of different tools to help with scaffolding instruction. These include diagrams, charts, sequenced pictures, graphic organizers, Venn diagrams, and matrixes. When scaffolding is used properly, students can move through the zone of proximal development (Vygotsky, 1997).

Yet another way that ELLs can be helped, particularly in their language development is through interaction and group work. Cohen (1986) points out that group work offers teachers a powerful tool in assisting students in increasing their proficiency in English and bringing their basic skills up to grade level. Group work also takes advantage of using language as communication to accomplish the objectives of the classroom. Finally, the ways that students are grouped and paired is important. Pairing a lower-proficiency student with a peer who is more fluent can help students improve together (Foulger & Jimenez-Silva, 2007).

WHAT IS PROJECT-BASED LEARNING?

Project-Based Learning (PBL) is a form of constructivist teaching which presents students with a specific problem or challenge, but no specified way of solving it (Greening, 1998). The Buck Institute of Education describes Project-Based Learning “as a systematic method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks”(p. 4; Markham, Lamar, and Ravitz, 2003). STEM PBL is known for increasing students’ motivation for learning as well as giving a less constraining environment for students to work in than traditional teaching methods (Greening, 1998).

PBL can be applied to a classroom setting in many ways. Some projects may be short, taking only one class session, while others can two weeks, two months, or half of the school year (Alan & Stoller, 2005). In planning a project, it is helpful to review the five key criteria of a PBL project, as identified by Thomas (2002). The first is that in PBL, projects are central to the curriculum. Second, driving questions are at the heart of all PBL projects. Third, students investigate the question. Fourth, these projects are student centered and involve a great deal of student control. Fifth, projects are authentic, real world challenges.

Thomas (2002) makes it clear that in PBL, projects are not just part of the curriculum, but that “projects are the curriculum” (p. 3). In PBL, the material that students will learn comes through the creation of the product. Assessment in PBL is organized to critique the product(s) that students create, since it is through the products(s) that students demonstrate their learning (Marx, Blumenfeld, Krajcik, & Soloway, 1997). Assessment in PBL can be done in a number of ways, but is often done through rubrics. It is important to create the right criteria for the rubric, and to make it clear to students what the criteria are. When planning and deciding on criteria, Markham et al. (2003) suggest using the framework that Jobs for the Future uses with PBL. They look to the six A’s: Authenticity, Academic rigor, Applied Learning, Active Exploration, Adult connections, and Assessment practices. Markham et al. (2003) also recommend looking to Bloom’s Taxonomy when creating rubrics for examples of verbs to use when describing what students must be able to do or perform.

Markham et al. (2003) explain that in PBL, there must be a driving question, which “makes a project intriguing, complex, and problematic” (p. 37). Driving questions should come from issues faced in the real world, particularly students’ own lives, rather than just from the back of the textbook. This gives students greater internal motivation to find answers to the driving question. Finally, when crafting the driving question, teachers need to take in to account the abilities and skills of their students to investigate the question (Marx et al., 1997).

In PBL, students investigate new knowledge. They are not merely rediscovering knowledge through controlled activities, but going out into the world to discover solutions to problems and propose new ideas for dealing with issues (Thomas, 2002). Rather than activities that require only lower-level processing, such as simply recalling information, students using PBL are to participate in complex processing of class content (Marx et al., 1997). Students in PBL are not just to work in groups to practice, but are to collaborate in ways that can bring groups and sources of information from outside of the school community in as well. Therefore, many projects done in classrooms do not qualify as PBL.

Because PBL projects are more student-centered than traditional teaching methods, students work more on their own, without the supervision of the teacher, and make choices for how they feel the project should go (Thomas, 2002). Because of this added autonomy, “students will have many questions about what to do next or what is important to know” and teachers should “be prepared to direct their efforts clearly” (Markham et al., 2003, p. 98) acting as “a colearner and guide” in the inquiry process” (Marx et al., 1997, p. 343). This direction will help guide the students, but will not simply be telling students what to do for the project.

To make projects authentic, teachers must start with the end in mind. That is, teachers must think of what they want their students to create. Possible products that students might make for a project include designing an exhibit for a museum, recommending a new law to solve a problem in a community, or inventing a new device or machine. Students could also be asked to make an oral presentation to a local governing board or make a multimedia presentation to a company. They could also write a magazine article (Markham et al., 2003; Marx et al., 1997).

HOW IS PROJECT-BASED LEARNING USED IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATH (STEM) CLASSES?

Classrooms involved in science, technology, engineering, and mathematics (STEM) are turning more frequently to PBL to teach their content areas. One reason is because of STEM PBL’s increased focus on the learner and its ability to adjust to a multitude of learning styles. Also, STEM PBL improves students’

communication skills and ability to think critically (Hadim & Sven, 2002; Marx et al., 1997). Students in these classes appreciate and are motivated by the real-life uses they see as they use STEM PBL (Hadim & Sven, 2002). Amaral, Garrison, and Klentschy (2002) suggest a number of reasons why inquiry-based science models like STEM PBL may benefit students in science and other STEM classes. First, students have time to build context. Also, STEM PBL builds common experiences for group measures and cooperative learning skills. In addition, STEM PBL aids students in developing thinking skills. Lastly, students are able to work at a level that is appropriate for them, which leads to positive attitudes towards future learning in STEM classes.

HOW STEM PBL CAN HELP ELLS IN STEM CLASSROOMS

How Can ELLs Benefit from PBL in a STEM Classroom?

Using PBL with STEM curriculum has been shown to help ELLs in many ways. First, it can improve their proficiency in English by using the language in class for a specific, meaningful purpose (Mathews-Aydinli, 2007). Structured group work can also help students develop greater proficiency in English, enabling them to use the language of STEM classrooms. They also increase their knowledge of English vocabulary, grammar, and scientific genres. In addition to this, students use STEM PBL to communicate “in a variety of formats, including written, oral, gestural, and graphic” (Lee, 2005, p. 515). STEM PBL can even “accommodate a purposeful and explicit focus on form”, if teachers feel that their students need more practice with specific language features (Alan & Stoller, 2005, p. 11). PBL is an effective way for teachers to assist students with functional language learning (Beckett, 2002).

Another benefit of using STEM PBL with language learners is that students are more motivated to learn and continue working when the task is more authentic (Alan & Stoller, 2005). In a study on ELLs’ writing, Foulger and Jimenez-Silva (2007) reported that teachers could see that students were more engaged in the writing process when they had the opportunity to write for an audience besides their teacher (through publishing their writings online). Mathews-Aydinli (2007) has also noted that problem-based learning, another inquiry-based learning curriculum, increases students’ motivation and leads to more learning outside of the classroom.

ELLs also can make gains in cognitive skills through PBL. Students develop these higher levels of thinking by attempting to understand and answer complex, original problems. Students also acquire higher-level skills and processes, such as planning and communicating (Markham et al., 2003). These higher cognitive skills are reflected in students’ achievement as well. Amaral et al. (2002) studied the relation between ELLs in schools that used inquiry-based science instruction (such as STEM PBL) and student achievement in different content areas. Their study showed a positive correlation between the length of time that students were in this program and their achievement. The more time students spent in this kind of program, the more achievement went up in content areas like math and science. Lee (2005) has articulated similar findings, pointing out that when teachers are able to connect to ELL students’ cultural and linguistic backgrounds, these students are able to show higher academic achievement than they would otherwise.

One of the best features of STEM PBL for ELLs is its ability to bring so many different components together. STEM PBL connects the process of learning with the final product, and integrates skills throughout the process, culminating in a reflection of the entire process at the end (Alan & Stoller, 2005). Beckett (2002) has also emphasized this theme of integration, arguing that STEM PBL can improve language, content knowledge, and cognitive and social skills at the same time.

Organizing PBL for ELLs

To form a theoretical framework for STEM PBL within second and foreign language teaching, Stoller (2006) has organized what PBL supporters see as the main benefits of this approach into four main areas. These areas are motivation, expertise, input/output, and learner centeredness. These four areas can apply to STEM curriculum as well. Students will be motivated to learn concepts in STEM through projects. They will increase their expertise of the content. They will improve their ability to comprehend the language and produce it themselves. They will also be able to accomplish this work with less reliance on the teacher.

Beckett and Slater (2005) have created a Project Framework. They explain that “the primary purpose of the Project Framework is to show the students the language, content, and skill development which occurs through project work. It has two key components: the planning graphic and the project diary” (p. 110). Teachers can use the planning graphic to help students visualize the purpose of the project. Seeing how the elements of language, content, and skills come together can help them to see the bigger picture. Teachers can change the

specifics of the graphic according to their needs. The project diary is intended to help students keep track of what they have and have not accomplished in language, content, and skill development that week.

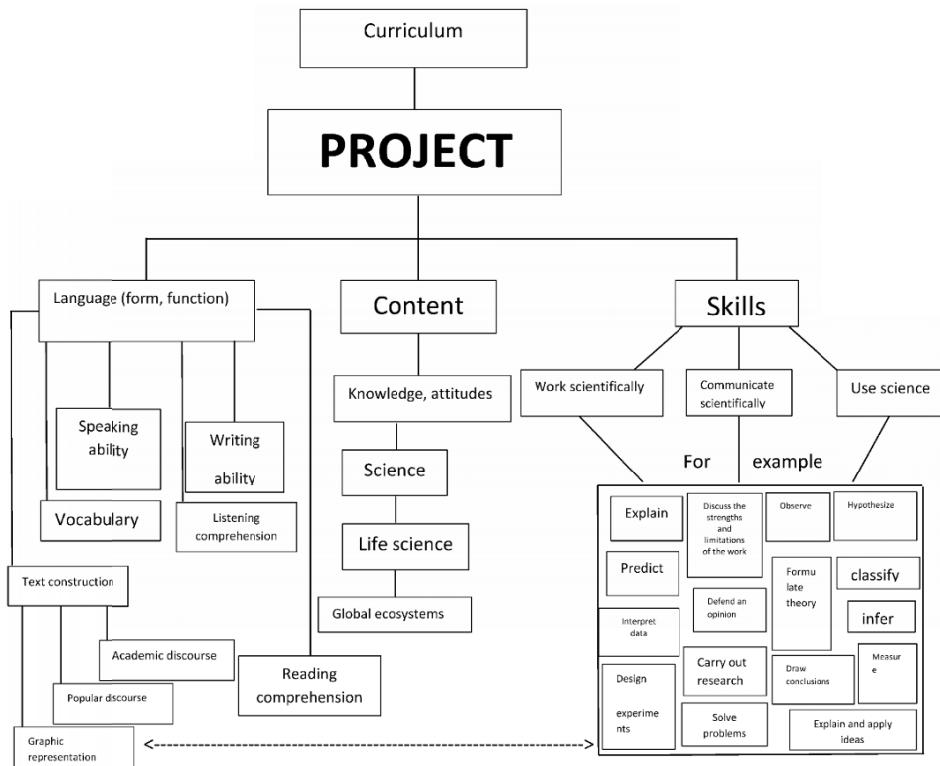


Figure 1. Planning graphic in the project framework (Beckett & Slater, 2005, p. 110)

Week _____	Project Diary		Name _____
Activity	Knowledge and skills		
Things I did this week	Things I learned this week.		
I spoke English to	Language (e.g. vocabulary expressions, grammar)	Content (new information about your topic)	Skills
I talked English			
I read			
I looked for and found			
I looked for and didn't find			
I wrote	Things I hoped to learn this week, but didn't. (State reasons for not learning.)		
I observed			
I created a key visual about			

Figure 2. Project diary in the project framework (Beckett & Slater, 2005, p. 111)

Beckett and Slater (2005) state that their framework helps “students to see the value of project-based instruction by making explicit the various components” (p. 115). Stoller’s (2006) theoretical framework mirrors the benefits that the students in Beckett and Slater received. These students were self-motivated to follow their goals (motivation), increased knowledge and proficiency as they met the content component (expertise, input/output), and controlled the process themselves (learner centeredness).

Mathews-Aydinli (2007) lists five things for teachers to consider when preparing for project-style learning with ELLs. These are: preteaching, introducing the problem and the language for the problem, grouping students, providing them with the necessary resources, observing and supporting the students, and following up and assessing their progress (p. 3). In assessing progress with PBL, Markham et al. (2003) suggest that there should be both formative and summative assessment. This gives students feedback both during and at the end of the process.

In using rubrics for the assessment, Markham et al. (2003) state that “all rubrics share three common features: elements, scales, and criteria” (p. 53). Elements describe the “various aspects of a product, and become the framework for the rubric” (p. 54). Scales on a rubric help to rate the level of quality present in the elements. It is through the scales that teachers say how well a student has done on a science or math project. Criteria denote the specific instructions that a project must meet to pass the assessment. In other words, criteria indicate the rules of the project. These three features must be explained well to ELLs so that they understand what must be accomplished.

PROJECT-BASED LEARNING AND ENGLISH LANGUAGE LEARNERS: THINGS TO CONSIDER STUDENTS’ CULTURE OF LEARNING

While STEM PBL is an excellent tool to use with ELLs, research has shown that if the purposes for using PBL are not made explicit, some ELLs may not like this form of instruction. This is due in part to how some cultures view the learning process. Mathews-Aydinli, 2007 points out that:

for students who are accustomed to more traditional, teacher-centered classrooms, it is critical that they know they will be given direct, follow-up instruction, but that during the problem-solving phase, the teacher’s role is to observe and support. (p. 3)

Beckett and Slater (2005) have commented that teachers and students may have different learning goals in mind when working in a classroom. While a teacher might be excited about the prospect of giving their students more autonomy, students from some cultures may question why the teacher is abandoning his or her responsibility to lead the class. Beckett (2002) shares that if ELL students are expecting to use solely repetitive practice of grammar rule with no context, memorization of vocabulary, and writing, using projects as the curriculum makes them feel that effective instruction is being taken from them.

These fundamental differences and beliefs in the purposes of education, if not clarified and resolved, can create problems in the classroom. Students will not feel greater motivation to do the work if their underlying views say that the STEM PBL is not an effective way of learning English or content knowledge. Teachers must be careful in explaining and showing students how STEM PBL can be effective for their learning. This should be done before the project starts if possible. A good way to introduce STEM PBL is to do so through a framework that will help the students see the benefits of trying another way of learning language and content (Beckett, 2002). Markham et al. (2003) propose that “one of the most effective strategies you can use is to share the goals and context of the project with your students as early as possible” so that they will understand what can be accomplished (Markham et al., 2003, p. 98). Alan and Stoller (2005) also warn that teachers must find a balance between giving students autonomy and knowing when to exert more control of the class as the teacher.

LANGUAGE AND DISCOURSE STYLE ISSUES

Moje et al. (2001) highlighted the difficulty that can occur when teaching ELLs in a content classroom, particularly a STEM course like science. These researchers highlighted the difficulty of multiple ‘Discourses’ within a project-based science classroom. These ‘Discourses’ included that of the students’ home culture and language, the text for the class, and the science discourse that the teacher used. The teacher tried to relate the everyday experiences of the students to the science curriculum. However, the teacher used these experiences to discuss scientific discourse, without scaffolding to make concepts clear for the students or to help them apply key vocabulary correctly. It was difficult for the ELLs in the classroom to switch back and forth between scientific and everyday ‘Discourse’. This led to moments in which the teacher and students were

using the same language and words, but were confusing discourses, so that the students would incorrectly interpret what the teacher tried to say. The teacher had difficulty bringing together the competing ‘Discourses’ of science and everyday activity. He did not just want them to complete a creative writing assignment. He wanted the students to complete the fictional account from the perspective of a scientist.

Moje et al. (2001) explained that the problem was a lack of scaffolding in both the curriculum materials and the directions from the teacher. The ELL students experienced frustration in trying to go from one style of ‘Discourse’ to another without having the connection between the two made explicit. The authors argue that four characteristics are needed for bridging the gap between the student’s home or everyday discourse and that of the content-area classroom. These are:

- (a) drawing from students’ everyday ‘Discourses’ and knowledges, (b) developing students’ awareness of those various ‘Discourses’ and knowledges, (c) connecting these everyday knowledges and ‘Discourses’ with the science discourse genre of science classrooms and of the science community, and (d) negotiating understanding of both ‘Discourses’ and knowledges so that they not only inform the other, but also merge to construct a new kind of discourse and knowledge. (p. 489)

Merging and constructing this discourse between text and student and teacher is crucial to helping ELLs in a STEM classroom. To do this, there must be a sufficient amount of scaffolding present.

The Importance of Scaffolding to ELLs in a STEM Classroom

As was seen from the previous section, lack of scaffolding in a STEM classroom can adversely affect ELLs. Lee (2005) comments that, “the education system often fails to provide adequate instructional scaffolding for ELLs in science classrooms” (p. 511). This can include not taking into account ELLs’ development in oral skills and writing. Moje et al. (2001) say that because instructional ‘Discourses’ are so complicated, “that without scaffolding, [these ‘Discourses’] may constrain learning opportunities for English Language Learners” (p. 473).

To help scaffold learning for ELLs in STEM classes, particularly those who come from cultures where questioning in the classroom is not encouraged, “teachers may move progressively along the teacher-explicit to student-exploratory continuum, to help students learn to take the initiative and assume responsibility for their own learning” (Lee, 2005, p. 506). This can be difficult for teachers. Marx et al. (1997) argue that “often teachers’ ability to scaffold is related to their own mastery of the subject matter” (p. 346). Empowering ELLs to understand the language and language use of STEM classrooms “requires that teachers and curriculum developers engage students in explicit discussions of and practice in recognizing the many different and competing ‘Discourses’ at work in their learning lives” (Moje et al., 2001, pp. 473-474).

Collaboration and Groupwork

The last challenge to discuss for using STEM PBL with ELLs is that of collaboration or group learning. Marx et al. (1997) argue that “collaboration is an essential component” in STEM PBL (p. 345). However, while it can foster growth in language development, if not implemented well, it can also cause problems for students. Reid (1987) conducted a study to find out the preferred learning styles of ELLs from many different backgrounds and nationalities, to compare them with American students. She found that “most groups showed a negative preference for group learning”, choosing to work by themselves, instead (p. 7). Markham et al. (2003) suggest that we view collaboration in a different way than simply having students sit and work together, but rather we should:

Group students appropriately. Collaboration is a hallmark of STEM PBL, but collaboration takes place in different ways. Students may work in small groups or as a whole group. They may work individually on products and collaborate only on rubrics or presentations. Also, the groupings may change as the project progresses. (p. 97)

With ELLs, teachers should choose carefully what the students will collaborate on, who they will collaborate with, and how long they spend working in groups. Research done by Cheng, Lam, and Chan (2008) shows that when the quality of groupings is high, both high and low achieving students (as measured by standardized tests) improve more through working in the group than on their own (p. 216). Collaboration and group work, when planned well, can be an effective tool with ELLs, particularly with project learning.

CONCLUSION

English Language Learners have the difficult challenge of learning science or other STEM curriculum through a second language, a process that can be frustrating and discouraging if they do not receive the proper support. STEM PBL can be an effective way to teach STEM curriculum to ELL students to help them improve language proficiency, learn content knowledge, and develop academic skills. “Accomplishing these goals, however, requires time for both teachers and students to master the behaviors and strategies necessary for successful PBL” (Markham et al., 2003, p. 6). Explicitly teaching concepts and scaffolding instruction will permit students to come up to new levels of proficiency and knowledge. If teachers are patient in learning to use this curriculum approach, they will motivate their students, increase their expertise, give them the opportunity to produce greater linguistic out-put, and learn to be their own guide in discovering new STEM knowledge (Stoller, 2006).

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14. PROJECT-BASED LEARNING: AN INTERDISCIPLINARY APPROACH FOR INTEGRATING SOCIAL STUDIES WITH STEM

INTRODUCTION

A social studies perspective is academically sound, interdisciplinary, and integrative.

Robert Stahl, President (1994-1995), National Council for the Social Studies

Our society is mission oriented. Its mission is resolution of problems arising from social, technical, and psychological conflicts and pressures. Since these problems are not generated within any single intellectual discipline, their resolution is not to be found within a single discipline ... In society, the nonspecialist and synthesizer are king.

Alvin W. Weinberg, nuclear physicist, *Reflections on Big Science* (1965, p. 145)

The social studies, which includes such disciplines as history, political science, geography, economics, anthropology, and psychology in the K-12 context, has historically carried the nation's educational mission of preparing the next generation of its citizens to participate in a democratic society. Despite this core mission, social studies is often lower among the hierarchy of content areas taught in the school curriculum. In a standardized testing environment, social studies is placed below English and mathematics, courses with graduation consequences attached to them. In part, this placement is due to the challenge we face in the post-No Child Left Behind (NCLB) era in which we hope to engage students in pursuing careers in science, technology, engineering, and mathematics (STEM), as we seek to meet the employment demands of these fields. In response, the federal government has dedicated budgetary funds to be invested in STEM education. As social studies education struggles to continue its foothold in the K-12 curriculum, students receive less exposure to the importance of social-scientific connections. For example, many citizens either do not participate in civic duties, such as national elections or global interaction, or are unaware that their participation is critical to the vibrancy and continuation of a democratic state (Davis, 2003). This participatory challenge holds long-term potential impact on international relations, economics, productivity and resource development (Humphrey, Chang-Ross, Donnelly, Hersh, & Skolnik, 2005).

We believe that a collaborative effort to move from a discipline-based curriculum to an integrated, social studies-STEM-linked curriculum anchored in project-based learning (STEM PBL) is a powerful response to the resource challenges educators are facing. In support of such integration, the National Research Council (2011) notes that one of the main purposes for STEM education is to equip the next generation of citizens with the necessary knowledge and skills to engage in public discussions on science-related issues and policies and to make informed personal and civic decisions. In other words, scientific and technological knowledge is not an end but a means to interpret and improve human well-being. To further the pursuit of collaborative understandings, many US states at this time are transitioning to a common set of core standards in two areas: mathematics and English/language arts; a science core curriculum is also under construction. The common core initiatives in these fields favor in-depth treatment of core ideas and concepts cutting broadly across a wide range of disciplines. We believe therefore that the rationale and opportunities exist for social studies and STEM educators to develop an interdisciplinary PBL approach to curriculum development.

This chapter begins with a brief introduction to the key elements of STEM PBL, followed by a more detailed section on the benefits of an interdisciplinary social studies-STEM curriculum. Embedded in this section is a sample PBL project featuring the historical Abraham Lincoln as mechanic and inventor, in which social studies and STEM knowledge are integrated, followed by a table of sample projects found in the literature. The next section outlines the stages of STEM PBL for developing a social studies-STEM curriculum connection. This connection is guided here by a modification of the Wiggins and McTighe (1998) backward design model in which multiple outcomes and deeply held understandings are foundational learning goals.

CHAPTER OUTCOMES

When you complete this chapter, you should better understand:

- the benefits of a social studies-STEM linked curriculum
- essential elements and stages of STEM PBL with an interdisciplinary social studies-STEM focus
- instructional and assessment strategies to facilitate an interdisciplinary social studies-STEM focus

When you complete this chapter, you should be able to:

- use a modified backward design model as a guide to develop interdisciplinary STEM PBL curriculum
- select topics and appropriate instructional and assessment strategies

PROJECT-BASED LEARNING: KEY ELEMENTS

Project-based learning (PBL), Jonassen (1997) writes is a constructivist approach to instruction, with a specific focus on real-world but ill-structured problems. Central to a PBL orientation, he further suggests, is inquiry-based learning opportunities – that is, structured experiences based on the belief that learning occurs when the individual is prompted to inquire into and about problems. Brears, MacIntyre, and O’Sullivan (2011) explain that the process of inquiry might begin with self-reflection and evaluation. It is not surprising therefore that Brears et al. note the importance of three aspects of inquiry supportive of the learner in their quest toward problem solving: collaborative group work, emphasis on analysis and evaluation, and added reflection [on practice]. To foster the pedagogical enactment of these three aspects of the PBL process, we offer three elements supportive of them: inquiry, critical thinking and decision making.

Initiating Inquiry

Drawing on the work of Gallagher (1997), the 2011 Brears et al. report suggests that instructors [or their students] initiate learning by identifying a problem, especially an ill-defined problem so that the instructor might serve as a metacognitive coach. In the example below, *Lincoln the inventor*, it becomes clear that the problem Lincoln faced as a worker on a flatboat involved the immediate economic necessity of saving the commodities onboard his flatboat when it got stuck on a milldam. Although Lincoln was aware that this was not an unusual occurrence in the navigation of rivers during the mid-1800s, the problem remained difficult to resolve given the available resources and technological knowledge of the era.

Critical Thinking

The next step suggested in the literature about a PBL learning process is critical thinking. Saiz and Rivas (2008) offer one definition of critical thinking:

... we understand that Critical Thinking is a process involving a search for knowledge through reasoning skills, problem-solving and decision-making that will allow us to achieve the desired results more efficiently. (as cited in Saiz & Rivas, 2011, p. 35)

Critical thinking, John Dewey (1916) wrote is a process of reflective thought during which an individual suspends personal judgment, keeps an open mind and skeptically approaches the problem to be solved. Johnson (2000) writes that as we initiate critical thinking experiences, we must be aware that as learners approach a problem [even ill-defined], the reasoning, problem solving and decision making process that ensues is likely to result in a series of inferential or judgmental ideas that learners hold from prior experiences. What can learners do with their inferences as they encounter them? Johnson suggests, encountering a problem, and formulating ideas (inferences) during thinking about the problem are key processes needed to solve a problem. Others suggest extending these two steps to include a reasoning process [problem into ideas] is a necessity for learners if we want them to make decisions about their ideas – a step believed to help refine the formation of thought processes (Baron, 2005; Halpern, 2003; Mercier & Sperber, 2011).

Decision Making

Not unlike the inquiry, content knowledge, critical thinking to decision making process used by Lincoln as he encountered his flatboat stuck on a milldam, it appears that decision making might very well hold powerful promise for a typically less-resolved area in the PBL literature – *the role of action (solution) on a problem*. As

we engage our students in inquiry and critical thinking, we should also ask: What additional expectations do we have for learners? *Do we expect action?*

Burris and Garton (2007) suggest the following elements to facilitate learners' decision making as a path to PBL solution-action, beginning with the teacher-facilitation role:

- acquisition of content knowledge
- development of thinking skills and strategies
- responsibility for information learned
- presentation of solutions
- evaluation of the process used in solving the problem

The solution to a problem from a PBL model however, is not necessarily straightforward. It is often the case that several content areas intercede into and intersect with each other in the process of problem solving. For example, as a project presents a challenge, students might ask: what is the historical-contextual environment that prompted others to make particular decisions about this challenge (e.g. What resources were available in this time period? What technology or mechanical knowledge was readily known?). As anyone who has tried addressing either physical or theoretical challenges learns, decision making and problem solution can be greatly enhanced through an interdisciplinary lens.

PROJECT-BASED LEARNING: BENEFITS FOR INTERDISCIPLINARY TEACHING AND LEARNING

Historically, social studies has played a central role in the various reform efforts that advocated for an integrated, problem-focused approach to education, among those, the Progressive Education Movement founded by John Dewey and his colleagues in the 1890s and early 1900s and the Core Curriculum Movement in the 1940s and 1950s (Wraga, 1993). According to Wraga, only after the so called post-Sputnik period in the 1960s was the then popular integrated social studies curriculum separated into more rigid disciplinary areas such as history, geography, economics, anthropology, and sociology, owing largely to the era's New Social Studies Project and Bruner's (1960) work on the structure of knowledge. However, most of the curriculum configurations in the past that involved social studies emphasized integration within the social studies disciplines or between social studies and language arts or humanities. Integration of social studies and STEM areas has been very limited. Wraga (1993) states, "to limit interdisciplinary connections to the task of examining social or life issues would be to forego other opportunities for fruitful interdisciplinary connections" (p. 211). Echoing Wraga, we discuss in this section the benefits and opportunities for social studies and STEM educators to collaborate in an effort to develop interdisciplinary STEM PBL. We propose that this integrative model of STEM PBL reflects a synergetic process that benefits the mutual goals of social studies and STEM.

Social Content-Context Matters

Social studies provides a rich context for understanding the foundational ideas of an historical era and inquiring about the possibilities and potential responses to solving past or current social-scientific challenges. Sumrall and Schillinger (2004) write, "Social studies provides the obvious connections between the humanities and the natural and physical sciences," adding "the content knowledge [should be] the means through which vital information may be explored and confronted" (p. 5). For example, Zaslavsky (1994) developed the concept *ethnomathematics*, defined as an interdisciplinary curriculum uniting multicultural and mathematical perspectives. To illustrate this approach, Zaslavsky notes the study of African architecture as an example that can be incorporated into a mathematics unit on geometry and measurement. A possible interdisciplinary discussion could include topics such as why the typical shape of houses in ancient Africa tended to be round. This discussion could be extended to include concepts such as economic necessity, technological constraint, cultural beliefs, and social hierarchy. Zaslavsky argues that through ethnomathematics, students realize that mathematical ideas are often developed as a direct response to real needs and interests of human beings and therefore relevant to their lives and communities, not isolated facts and procedures to be memorized. Students from underrepresented cultures would take pride in their cultural heritage by learning their ancestors' achievements and contributions to the development of mathematical knowledge.

As suggested in other chapters in this volume, PBL holds immense possibilities for developing investigatory skills, such as rational thought, examination of primary sources and envisioning the potential of ideas and products. Etherington (2011) notes that a learner's thinking-experiential processes are enhanced when PBL is interdisciplinary. For instance, the skills to apply and synthesize content area knowledge such as

STEM are important for developing civic competence. The opportunities for practicing such skills to solve real-world social problems, however, are rare in a typical single-disciplinary curriculum. PBL, centered on an inquiry process – provides rich learning opportunities. For example, the Environmental Protection Agency's (2008) science fair project on surface water quality integrates knowledge in biology (e.g., micro-organisms, algae growth), chemistry (e.g., contents of fertilizers and cleaners), physics (e.g., gravity, velocity), and mathematics (e.g., slope). This project simultaneously can be used to examine social issues such as the consequences of human actions on the environment (e.g., use of fertilizers and cleaners) and how climate changes influences water quality (e.g., how pollutants are carried into waterways after a rainfall). Following discussion of these example topics, and using evidence they have gathered, students can then make a recommendation or suggest a solution for improving local water quality. In this case, STEM knowledge becomes a powerful means for protecting the environment and securing healthy lives.

Connection Categories

Oliva (2009) describes two categories of cross-curricular connection. The first, correlative subject matter – the content of a single subject remains, however relationships between them are explained (e.g., history and science). In the second category, curriculum integration, curriculum loses its “identity,” however the content functions to illuminate a cultural epoch (p. 427), in which content is learned through context. Nonetheless, within the continuum of these two approaches, it appears that when a cross-curricular experience is provided to students, their engagement with all content is synergistic – their interest reaches beyond single-subject foci – launching them into envisioning the socio-scientific *potentialities* for innovation.

The ethnomathematics project and the water quality project described above both represent Oliva's second category, curriculum integration. In fact, Zaslavsky (1994) argues that the ethnomathematic perspective to mathematics education requires a complete restructuring of the mathematics curriculum so that the ethnomathematical aspects are synthesized into the curriculum rather than presented as fragmented, embellished pieces. The project below, *Lincoln the inventor*, can be implemented using a correlative approach. For example, an interdisciplinary team of social studies and STEM teachers might jointly design a unit on Abraham Lincoln, to be taught in the same two week period. The project could begin with the practical problem that Lincoln faced as a flatboat worker: how to design a device that lifts vessels over river obstructions and shoals without unloading the cargo. The science teacher might teach students concepts such as buoyant force, inflation, air pressure, gravity, and density. The math teacher's focus could be on how to compute volume, surface area, density, gravity, and velocity. The history teacher could delve more deeply into the relationship between scientific and technological inventions and human life using primary documents in historical investigation. In the Lincoln example, subject content is kept intact; however, the connections between social studies and STEM are illustrated within the same inquiry project.

SOCIAL STUDIES-STEM IN PROJECT-BASED LEARNING EXAMPLES

Lincoln-the president and the inventor is one of the many topics that draw our attention across content areas. Lincoln's accomplishments as an inventor and mechanic are much less known than his political achievements as president of the United States (e.g., his leadership during the Civil War and issues of slavery, or iconic documents such as the Gettysburg Address, the Emancipation Proclamation). The fact that Lincoln is also the only president of the United States to receive a patent, we believe will capture students' immediate interest.

We envision an interdisciplinary project that can be developed based on this historical era. Thus, in addition to understanding the content area knowledge (e.g., history, science, mathematics) outlined in the previous section, students might design or build a model flatboat using the scientific, engineering, and technological aspects of the problem of river navigation. Teachers might use primary documents such as the actual patent Lincoln received in 1849 or the sketch he submitted with it to determine how to construct a flatboat, or how to improve the existing design. Along with reading social studies text or supplemental readings, students can ascertain how Lincoln's invention was a direct response to an economic problem and how his design was constrained by the lack of local resources and or modern technology. Below is an abbreviated account of the historical context for Lincoln's invention ([Figure 1](#), also see [Figure 2](#) and [3](#) for the text and sketches of the Lincoln patent).¹

[Table 1](#) portrays sample projects found in the literature in which social studies is integrated with one or more STEM fields. It should be noted that the list of projects is not exhaustive, nor are the connections identified with either social studies or STEM. The table simply shows the various possibilities for integrating social studies and STEM using PBL.

Navigation, Frontier Concern

As settlers needed to get their crops to market, and there were few roads, much less good ones, navigation of the available rivers was a constant concern on the frontier. Young Lincoln earned his first “big money” by ferrying two men out to a steamboat, on a little craft he had built in his spare time. He worked other jobs on the Ohio River and became an experienced boatman (Emerson, 2009).

In 1828 Lincoln took his first trip down the Mississippi to New Orleans, working on a flatboat with Allen Gentry, son of a local store owner. In 1830, after having helped move his parents to Illinois, he made an impromptu political speech at a campaign meeting in the tiny village of Decatur. His first public address, this speech urged the improvement of the Sangamon River for navigation.

Caught on the Milldam

In 1831, he was hired by the merchant Denton Offutt to take a flatboat full of provisions down river to New Orleans. On this trip they had to reach the Mississippi via the Sangamon River. At the village of New Salem, their flatboat, much too heavy to get over the milldam, then got stuck. Herndon and Weik (1921, p. 74) provide an account from a crew member on the boat, of Lincoln’s ingenuity in responding to the crisis. As the boat began to fill with water, Lincoln had part of its cargo unloaded to another boat. From the village he got an auger, and drilled a hole in the bow which was projecting over the dam. The water flowed out of the boat, Lincoln plugged the hole, the boat floated over the dam, and was then re-loaded.

Navigating on the Great Lakes

In 1848, Lincoln and his family were traveling home on the steamboat *Globe* over the Great Lakes, from New England where he had been making speeches for General Zachery Taylor’s presidential campaign. Emerson (2009) describes the episode that prompted Lincoln to create his invention:

As the *Globe* passed up the Detroit River during the final days of September it came upon another steamboat, the *Canada*, which had run aground on Fighting Island. From the deck of the *Globe*, Lincoln watched as the *Canada*’s captain ordered his crew to collect all the empty barrels, boxes, and loose planks on the ship and force them under the sides to buoy the boat over the shallow water. No doubt this operation reminded Lincoln of his adventure at the New Salem milldam and got the old flat-boatman thinking of this common waterway problem. For the rest of his journey home, Lincoln considered how to construct a device to free stranded boats from shallow waters. (pp. 3-4)

Lincoln’s invention comprised inflatable buoys, on each side of the boat, below the waterline. These would enable a boat to lift itself over obstructions without the necessity of unloading the boat.

Lectures on “Discoveries and Inventions”

After his loss, in the U.S. Senate race to Steven Douglas in 1858, Lincoln was “... out of office, but he had no intention of being out of the public eye” (Donald, 1995, p. 164). Given the popularity, at the time, of public lectures as a means of entertainment, Lincoln developed a lecture on a topic of interest to him, “Discoveries and Inventions,” which he gave six times in Illinois between 1858 and 1860. The words of his lecture live on, fittingly “etched in marble above the entrance to the U.S. Patent Office” (Emerson, 2009, p. 34).

Figure 1. Historical account of Lincoln the mechanic and inventor

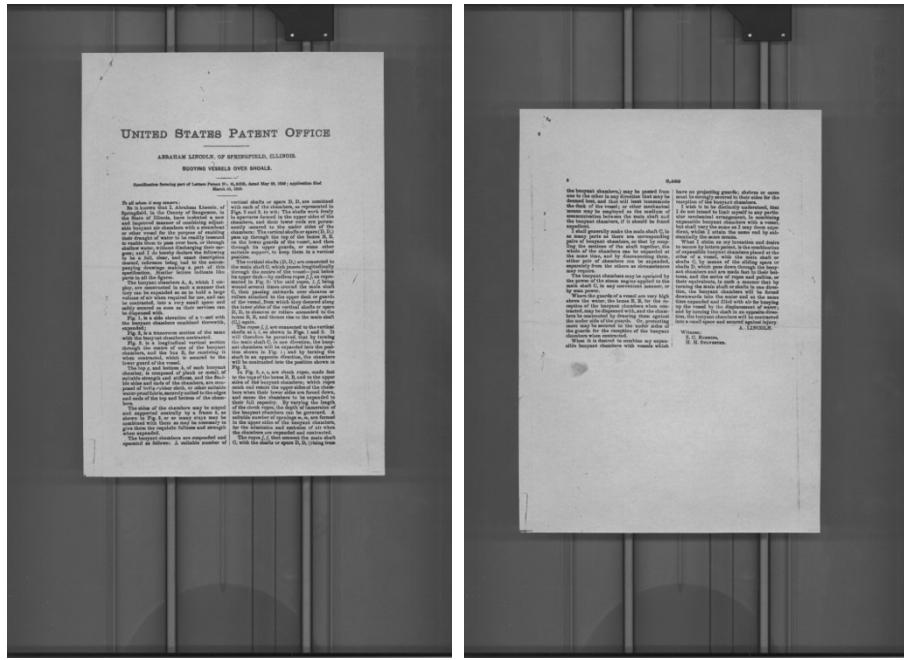


Figure 2. The text of the Lincoln patent

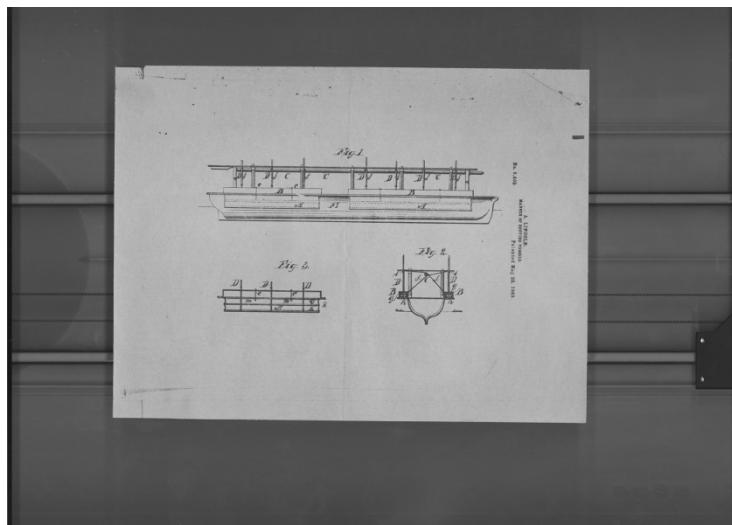


Figure 3. The sketches of the Lincoln patent

Table 1. Social studies-STEM project-based learning activities

<i>Projects & Sources</i>	<i>Connections with Social Studies Themes</i>	<i>Connections with STEM</i>
GeoMath (Hinde & Ekiss, 2005)	Science, Technology, and Society (STS) Global Connections	Statistics/Scatterplot Electronic Sources/Technology
Community Analysis (Moll, 1992)	Culture/Cultural Diversity People, Place, and Environments Production, Distribution, and Consumption Science, Technology, Society (STS)	Geometry/Measurement Statistics/Quantitative Analysis Fractions/Ratio Mechanics/Engineering
Surface Water Quality (EPA, 2008)	People, Place, and Environments Science, Technology, Society (STS) Civic Ideas and Practices	Biology/Micro-organisms Chemistry/Fertilizers/Cleaners Physics/Gravity/Velocity Mathematics/Slopes
A Tale of Two Cities (Leonard, 2004)	Culture/Cultural Diversity Time, Continuity, and Change	Geometric Shapes Measurements (area, perimeter) Congruence, Similarity Proportions/Ratios
Let Monarchs Rule (Shimkanin & Murphy, 2007)	People, Place, and Environments	Life Cycle
Ethnomathematics (Zaslavsky, 1994)	Culture/Cultural Diversity Time, Continuity, and Change People, Place, and Environment Science, Technology, and Society (STS)	Geometric Shapes Measurements (area, perimeter) Proportions/Ratios Congruence, Similarity

PROJECT-BASED LEARNING: ENHANCING A SOCIAL STUDIES-STEM CONNECTION COMMON FEATURES: PLANNING, STRATEGIES AND ASSESSMENT

In this section, we outline steps or process for developing interdisciplinary social studies-STEM PBL, using a backward design (BD) model proposed by Wiggins and McTighe (2005). There are three main benefits of using this BD model with STEM PBL. First, STEM PBL and BD share a common goal of teaching for conceptual understanding. Wiggins and McTighe state that their concept of BD is used for “the design of curriculums to engage students in exploring and deepening their understanding of important ideas and the design of assessments to reveal the extent of their understandings” (p. 3). Second, both STEM PBL and BD are not intended for meeting external standards (e.g., standardized testing) only, rather they focus on designing learning experiences that take into consideration students’ needs, interests, developmental levels, and prior knowledge. Third, both STEM PBL and BD call for evidence of multiple learning outcomes, not only summative assessment at the end of instruction but also formative assessment throughout planning and implementation.

Stage 1: Identifying Desired Results-Initiating Inquiry

The first step is to choose a topic that is worthy of enduring understanding. This requires the curriculum designer to examine and review established national, state, and local content standards. For a project linking social studies with STEM, the curriculum designer must also make connections among standards in several content areas and link specific standards in each discipline with the topic that the learning project is centered around. An interdisciplinary team might identify sustainable development of human beings, social justice, and inequalities as concepts worthy of enduring understanding. After correlating the curriculum standards in social studies and STEM areas, the team would decide to develop a unit on surface water quality to reflect these concepts. As example inquiry questions, students could be asked to compare surface water quality in

deprived and affluent communities, study the types of industries located in each neighborhood and their impact, and describe the population demographics. Students could further explore how poor water quality and flood risk may disproportionately affect the health and quality of life of people living in poverty (Damery, Walker, Petts, & Smith, 2008).

Stage 2: Determine Acceptable Evidence-Planning Assessment

When enacting a learning project, the curriculum designer is expected to begin with a detailed project assessment plan, including making decisions about what assessment evidence is considered acceptable and when each type of evidence is to be collected. Multiple sources of evidence are expected to be used to evaluate learning, including not only evidence from traditional types of assessment such as quizzes and tests but also from interviews, observations, open-ended prompts, performance tasks, and research projects.

Standardized test scores do not reflect the 21st century skills such as critical thinking, negotiating, and collaboration that students develop from participating in STEM PBL. Assessment of STEM PBL therefore needs to be authentic and related to the design of the project. Students' performance could be determined using rubrics to evaluate developed artifacts and creative materials (Bell, 2010). Students should be encouraged to engage in self-evaluation and critique and provide constructive feedback through a peer evaluation process (Colley, 2008). These processes will cultivate reflective thinking skills and enhance students' awareness of their development of meta-cognitive knowledge and strategies.

Trauth-Nare and Buck (2011) emphasize the importance of using formative assessment in order to maximize students' learning potential, especially to promote critical thinking skill during PBL. Formative assessment, according to Trauth-Nare and Buck, is a form of assessment *for* learning as opposed to assessment *of* learning. Formative assessment should be an integral part of instruction and occur multiple times during the implementation of a learning project. Assessment should be used to direct or redirect instruction and to modify or adjust learning strategies.

Stage 3: Plan Learning Experiences and Instruction-Selecting Instructional Strategies

This is the stage when the curriculum designer makes decisions about what activities to use, the sequencing of instruction, and the resource materials needed. The instructional methods that are compatible with STEM PBL typically are student-centered, hands-on, engaging, and inquiry-based. These include but are not limited to simulations, debates, group work, and research investigations. For instance, in the water quality project, students might visit a local waterway where they could collect water samples. Using collected evidence, students could then scientifically analyze their sample, discuss outcomes and finally draw conclusions.

Stage 4: Reflection and Taking Action

Colley (2008) outlined steps for Project-based Science Instruction (PBS) and included evaluating and taking action as the last step. We recommend adding this component to the original Backward Design model for PBL for the following reasons. First, this step encourages students to use the knowledge they have learned to solve practical, real-world problems. During a social studies-STEM integrated PBL, students learn concepts helpful in developing social awareness and a sense of civic responsibility and pride. Second, this step encourages students to reflect on their learning process. For instance, if the project outcomes are inconclusive, students are prompted to reflect on what additional information is needed or what steps need to be modified in order to draw more definitive conclusions. Evaluating and taking actions signify PBL as an ongoing and cyclical process rather than a limited, linear process.

Finally, it should be noted that the more integrated a social studies-STEM learning project is, the more planning, coordination, and collaboration is expected from the participating teachers. However, comprehensive integration can be associated with greater emphasis on cognitively engaging instruction (Applebee, Adler, & Flihan, 2007). Social studies and STEM educators should be aware of these challenges during the implementation of an interdisciplinary PBL.

CONCLUSION

Interdisciplinary PBL – especially STEM PBL (see also Chapter 6) that involves content areas in which a project (e.g., a science project) extends single-subject content beyond its traditional curricular boundaries to include the broad base of the social studies holds both potential and challenge. Synergistic potentialities can

include encouraging students to participate in a wide range of interests – such as engaging students interested in historical content who might be less familiar with scientific innovation. An interdisciplinary Social Studies-STEM PBL environment provides numerous learning benefits to students: personalization of learning, use of knowledge and skills developed in one field to learn in another, relating learning to real-life situations and applying knowledge in new situations, especially as knowledge might function in an environment of continuous change (Lee, 2007). Yet, there is little research based on how to construct curricular connections in less traditionally connected areas such as social studies with engineering. Moreover, although Applebee et al.'s (2007) case analysis of interdisciplinary studies indicates the benefits of interdisciplinary curricular connections, they note that most studies report the approaches teachers use in the classroom rather than the assessment of knowledge gain. Needed are strategic curricula that engage teachers at the inception of the curricular-project design. In this chapter we highlighted exemplars such as *Lincoln the mechanic-inventor* as a case that might inspire teachers as they seek to improve student content achievement. It is our hope that exemplars and topics such as those provided here might provide insights for developing powerful STEM PBL. The trend for 21st century global amalgamation (see Bell, 2010) in which social scientists collaborate within the environment of scientific innovation calls for re-thinking the separateness of teaching the content areas in STEM PBL.

NOTE

¹ In the historical account of *Lincoln as mechanic and inventor* much of the background draws on Donald (1995) except where noted. The description of Lincoln's flatboat being stuck on the New Salem milldam, and Lincoln's response draw on Emerson (2009) as well as Herndon and Weik (1921). The description of Lincoln's trip home in 1848 via the Great Lakes, and subsequent invention is drawn from Emerson (2009). The copy of Lincoln's patent application and sketch courtesy of *The National Archives and US Patent Office*. Full citations of the above sources are listed under References.

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APPENDIX A

NON-NEWTONIAN FLUID MECHANICS

Well-defined outcome: The student will be able to use measurement, measurement tools, and the scientific process to determine the effect of the percentage of water on the viscosity of a non-Newtonian fluid. Students will represent their findings using the general form of functions (including comparison of linear and quadratic) to describe the effect of % water on viscosity of silly putty and apply the general form of the quadratic parent function to explain non-linear flow of a non-Newtonian fluid (silly putty).

Objectives

Mathematics (Algebra 1)

The student understands that a function represents a dependence of one quantity on another and can be described in a variety of ways.

- a) The student describes independent and dependent quantities in functional relationships.
 - b) The student gathers and records data, or used data sets, to determine functional (systematic) relationships between quantities.
 - c) The student represents relationships among quantities using concrete models, tables, graphs, diagrams, verbal descriptions, equations, and inequalities.
 - d) The student interprets and makes inferences from functional relationships.
2. The student uses the properties and attributes of functions.
 - a) The student identifies and sketches the general forms of linear ($y=x$) and quadratic ($y=x^2$) parent functions.
 - b) For a variety of situations, the student identifies the mathematical domains and ranges and determines reasonable domain and range values for given situations.
 - c) In solving problems, the student collects and organizes data, makes and interprets scatterplots, and models, predicts, and makes decisions and critical judgments.

Science (Integrated Physics and Chemistry)

1. IPC 7A) investigate and identify properties of fluids including density, viscosity, and buoyancy;
2. IPC 8A) distinguish between physical and chemical changes in matter such as oxidation, digestion, changes in states, and stages in the rock cycle.

Materials

4% Borax solution (premixed for students but not for inservice). *If students are expected to make the solution provide balances and suitable measures to prepare the quantity of putty expected. Smaller quantities are preferred at the high school level and larger quantities at the elementary and middle levels because the precision of the measures is less important with larger quantities.*

Elmer's Glue (Not the washable kind, it does not work as well – hmmmm?) 2 Quarts of glue (one container) available at a craft store. *This is VERY important. If you provide glue bottles students will USE ALL THE GLUE and you will not get multiple attempts. By providing a specific amount of glue students will have to make decisions about partitioning and usage.*

- | | |
|---|--|
| (100) Plastic/Paper wax coated cups | Timers |
| Baggies – 1 per group | Meter Sticks or rulers – 1 per group |
| Markers | Funnels – 1 per group |
| Stirrers | Graph paper/acetates/Overhead marking pens |
| (8) Permanent sharpies (four color) ultra fine point | |
| (4) Large water containers with pouring spout | |
| (8) Graduated cylinders | |
| (8) 200 ml or similar size beakers (not too large) 50 ml will also work | |
| (100) Popsicle sticks | |
| (2) Food coloring (ALL FOUR COLORS) | |
| (8) 1/8 teaspoon measures | |

APPENDIX A

Background: The task is group based with each group having a different project. Students cannot rely on the results they see from other groups. You will need to have done some preparation with students to understand the context as described on the briefing sheets. The teacher will also have to talk about corporate espionage and the need for students to develop their own recipe and to keep track of those recipes. It also helps if students already know or have been told directly that they should only change one variable at a time in the recipe. They should all know what this means so you might want to be explicit about the borax, water, and glue, each being a variable. Conditionally, how they combine the three components is also a variable. So if they choose to dilute the glue by adding water or to dissolve the borax in water and decanting the solution from the undissolved solute would each be separate conditions so quantities of each of the three variables should be held constant so they can observe what happens as a result of these choices. If they vary the quantity of one component, they should hold the quantity of the other two variables constant. For example, if they start with 1/8 teaspoon each of borax, glue, and water and they want to alter the water in the next mixture they should keep the borax and glue at 1/8 teaspoon of each and only change the water. Groups should observe the result, write notes about the product and make a decision about what to do next. A common misconception held by students is that they change each variable in turn keeping the previously doubled variable. For example, 1/8 teaspoon of each borax, glue, and water, they double one component leaving the other two constant, note the results, double the next component adding the previously doubled component and one component constant, note results and then double the last component to the other two doubled components and note the result. The misconception is that they believe 1/4 teaspoon of each ingredient will result in a different product than did the 1/8-teaspoon of each ingredient even though the proportions are exactly the same. All they did was make twice as much but not a different product. Be sure that they have learned about proportions and ratios.

School based silly putty is typically created by mixing equal amounts of a 4% Borax solutions and Elmer's GlueTM, although some web-based resources recommend diluting the glue or altering the 1:1 mixing ratio.

Preparation: Decide if you are preparing the Borax solution or expecting students to do it. Preparation of the solution can take a bit of time because you may find you did not make enough. For a class of 25 consider making about 2000ml of solution and giving each group 400ml. Expect spillage and waste so you may want to distribute 200ml and allow one refill or make careful use of the solution a criteria on the grading rubric. **IF** you are having students create the solution provide only small amounts of the Borax, consider standard supplies of about 1/4 teaspoon and you can also prevent waste by including its careful use valued on the rubric.

Question: *What role do different mixing conditions and proportions of ingredients have on the product each group is charged with making?*

Explanation:

You are going to be put into groups and each group will be an engineering team with a separate project (see Corporate Briefing). Assign each group a different Corporate Briefing. While the tasks may appear different they all require the set of skills. Each project will be related to silly putty. You must keep your task a secret and you will have to prepare a PowerPoint or a video for the purpose of showing how well your product meets the expectations of the firm that hired you. This is a sales pitch. Remember address ALL the requirements in the briefing. (Refer to the Appendix for the storyboarding guide, and rubrics on presentations, and team work or design your own guidelines.) The additional explanation is for the teacher and may or may not be read in part or whole to the class.

The glue contains a polymer called polyvinyl acetate resin. We changed the polymers behaviors twice in this activity; once when we added water to the Elmer's glue and the second time when we added borax. What did the borax actually do? The borax is called a cross-linker. It chemically 'ties together' the long strands of the polyvinyl acetate. This tying together changed the viscosity of the glue. It increased the viscosity because the new cross-linked chains interfere with the ability of the solution to flow. As a result the silly putty is 'stiffer.' It is not a solid though. How do we know this? If we leave the silly putty alone on a table it will flatten out. It is also not a liquid because we can form it into a shape. So what is it?

Many fluids exhibit a non-linear response to stress, and are called non-Newtonian fluids. Such fluids fall halfway between being a solid (where the stress depends on the instantaneous deformation). For such 'soft

solids' or 'elastic liquids', the stress depends nonlinearly on the history of the deformation (Institute for Non-Newtonian Fluid Mechanics – http://innfm.swan.ac.uk/innfm_updated/content/about/glossary.asp?index=4).

Read more about Non-Newtonian fluids on the Internet. We recommend <http://antoine.frostburg.edu/shem/senese/101/liquids/frag/non-newtonian.shtml> at General Chemistry Online for a good conceptual answer or a more detailed, but understandable explanation at Wikipedia – http://en.wikipedia.org/wiki/Non-Newtonian_fluid.

Safety Notes: Use safety glasses and gloves when mixing the Borax solution and do not allow students FREE to access to the dry powder. A little goes a long way. The Borax solution is a mild bleaching agent and is thus a basic, so students should wash their hands after the lab. The silly putty product is nontoxic and can be taken home by students.

Engagement (As close as we get to stating the ill-defined task)

Guiding Questions – 1) What effect does % water have on the viscosity of the product? 2) How can the general form of a function help us interpret the relationship? 3) What other factors can I alter besides water? 4) What effect do you dissolving the solute in water before adding the glue would have on the product? 5) 6) How many variables can I change during any one trial? 7) What notes should I take to help me decide which variable to alter next if not the same one I already altered? These questions are not intended to be used in rapid succession, but as the inquiry and interest pique. They are designed to help the teacher assess student preparedness for the project and to teach or reteach as needed before allowing students to work with the materials.

Day 1 (5-15 minutes)

Play with a large “ball” of silly putty as the students walk into class.

Answer questions about what you are playing with. Be ready to ask if it is a solid or a liquid if that is not asked.

Guiding Question – What effect does % water have on the viscosity of silly putty ... and how can the general forms of functions help us interpret this relationship?

Exploration

Day 1 (30-60 minutes – the rest of the period!)

The students will explore the Internet or other resources to find suitable recipes for silly putty (teachers may substitute similar products such as GAK or slime, but be aware that slime requires the purchase of poly vinyl alcohol in advance from a chemical supplier such as Flynn Scientific ... it is also harder and more expensive to make). The students will then write up a procedure to make and test the viscosity of the chosen material. School based silly putty is typically created by mixing equal amounts of a 4% Borax solution and Elmer's GlueTM, although some web-based resources recommend diluting the glue or altering the 1:1 mixing ratio – hence the inquiry!

HINT: Alter the amount of water while holding the other components constant. Their original design might not work – that is a good thing! Don't “prefect” their designs for them – that is the purpose of doing the PBL!

Day 2 (45-90 minutes)

Make some silly putty and test it. Students need to be prompted to keep good notes on different trials for their write-up and they may eventually need some hints to get data which answers the question(s).

Explanation

Day 3

The Math – In the activity, students will construct a scatterplot that shows a definite nonlinear relationship that – when the domain and range are properly controlled – appears to be quadratic in nature. Vocabulary that needs to be reviewed and/or discussed include: dependent / independent / control variables, linear / nonlinear / quadratic, domain and range, functions / parent functions. HINT: Use REAL student data in the explanations/discussion.

The Science – The glue contains a polymer called polyvinyl acetate resin. We changed the polymers behaviors twice in this activity; once when we added water to the Elmer's glue and the second time when we added

APPENDIX A

borax. What did the borax actually do? The borax is called a cross-linker. It chemically ‘ties together’ the long strands of the polyvinyl acetate. This tying together changed the viscosity of the glue. It increased the viscosity because the new cross-linked chains interfere with the ability of the solution to flow. As a result the silly putty is ‘stiffer’! It is not a solid though. How do we know this? If we leave the silly putty alone on a table it will flatten out. It is also not a liquid because we can form it into a shape. So what is it?

Many fluids exhibit a *non-linear* response to stress, and are called non-Newtonian fluids. Such fluids fall halfway between being a solid (where the stress depends on the instantaneous deformation) and Newtonian fluids (where the stress depends on the instantaneous rate of change in time of the deformation). For such ‘soft solids’ or ‘elastic liquids’, the stress depends nonlinearly on the history of the deformation (Institute for Non-Newtonian Fluid Mechanics – http://innfm.swan.ac.uk/innfm_updated/content/about/glossary.asp?index=4).

Read more about Non-Newtonian fluids on the Internet. We recommend <http://antoine.frostburg.edu/shem/senese/101/liquids/frag/non-newtonian.shtml> at General Chemistry Online for a good conceptual answer or a more detailed, but understandable explanation at Wikipedia – http://en.wikipedia.org/wiki/Non-Newtonian_fluid.

Extension

Day 3 or 4 (depending upon available time)

What would the data for a Newtonian fluid look like?

Do all viscous materials flow nonlinearly?

Are there other common nonlinear fluids?

Could this test be used to identify Non-Newtonian fluids?

How do engineers take advantage of nonlinear flow?

What kinds of problems does nonlinear flow create for engineers?

Evaluation

Day 4 (or homework depending upon available time)

Formative assessment I will focus on questioning individuals and small groups relative to dependent / independent / control variables, linear / nonlinear / quadratic, domain and range, functions / parent functions while they are working on the PBL.

Formative assessment II will be whole group discussion of vocabulary and science concepts PRIOR to students finishing their write-ups.

Formative assessment III will be a formal write-up answering the initial question(s). Require the students to answer at least one extension question in the write-up.

Summative assessment will be a traditional paper and pencil exam with a combination of open-ended questions that are similar to the design activities and multiple-choice questions that are similar to the state exam that the students will take. One example from a previously administered TAKS test (The Texas accountability exam) is provided below. The correct answer for the sample question is F, which represents a linear function instead of a nonlinear function like the example in the item to test for learning transfer. Identify the graph that best represents the relationship between the number of gallons of gasoline Mr. Johnson purchased at \$1.49 a gallon and the total cost of his gasoline.

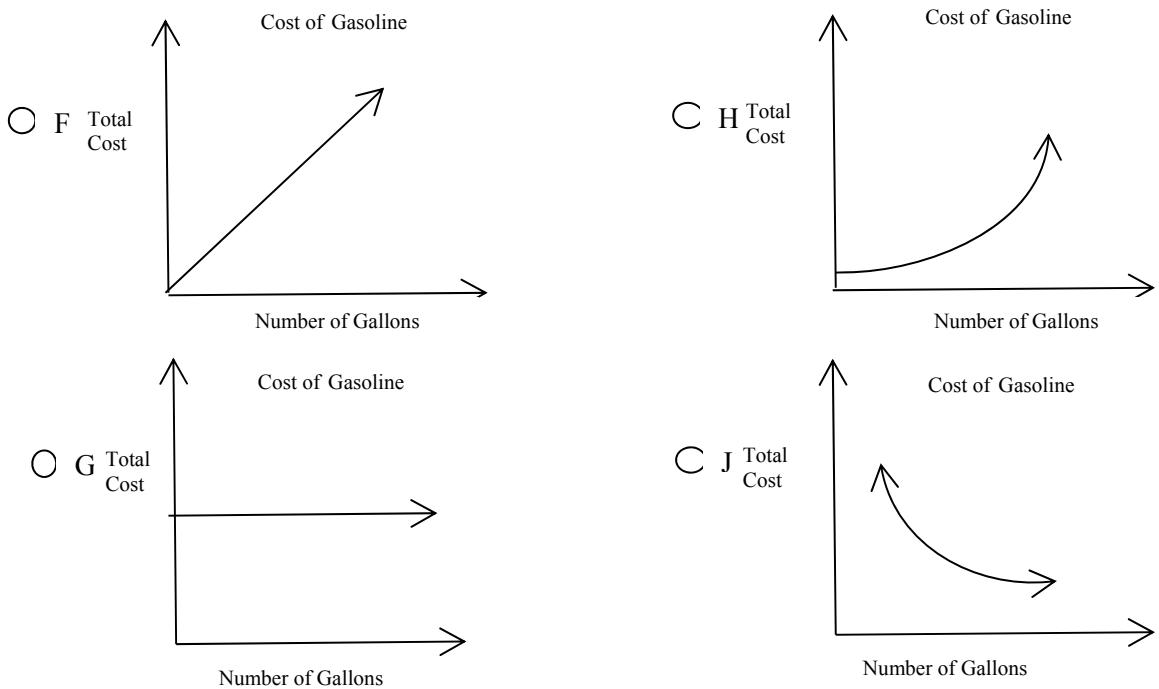


Figure 1. Multiple-choice question.

Previously administered TAKS exams are available at
<http://www.tea.state.tx.us/student.assessment/resources/release/>).

APPENDIX A

CORPORATE BRIEFING

Our client, *Super Rubber Inc.*, a subsidiary of *You Play Too Much*, and a wholly owned partnership by the Sistas Sledge, has determined that the market is ripe for a new toy – A super bouncy ball. They commissioned us to develop the toy and provide them with the exact recipe so they can manufacture it. Your code name for the project is “Supa Ruba Blubba Balla.” The design specifications are detailed below. The base recipe was acquired by our corporate spies from the now defunct company Pitiful Engineering® before their bankruptcy. If anyone should discover your task, your mission, or your product you will lose to your competitors. Do not discuss this task with anyone who is not on your team.

Design Specifications:

1. Your Research and Design Budget is exactly \$300,000. You have the following costs:
 - a. You must design an account sheet to keep track of all your costs.
 - b. Before you can start you must present a budget that accounts for as close to \$300,000 as possible.
 - i. Your budget categories are as follows:
 1. Salary per day, per person and total
 2. Research facilities per hour
 3. Equipment rental
 4. Materials costs
 5. Total spent
 6. Total remaining
 7. Research
 - c. Use of the research facilities is \$525 per hour. You must pay for every hour you are in the research facility.
 - d. The rental of the equipment is a fixed cost per day \$27,845 regardless which equipment is used or how long you use it.
 - e. Each member of the team earns at least \$800 per day, you need to set your daily salary in advance and budget for the task. You may pay yourselves more than \$800 per day but you may not pay anyone on the team less than \$800 per day.
 - f. You may purchase research from experts at negotiated costs, or you may do your own research at no cost.
 2. The ball must bounce back $\frac{3}{4}$ or more of the distance from which it was dropped.
 - a. You must design the test and set the parameters
 - b. You must have a drawing/diagram of the test you plan to use, a list of materials, and specify the height at which you will test the material.
 - c. You may not throw the ball to get it to bounce back the required height.
 3. You must determine the exact recipe to make exactly $\frac{1}{4}$ cup of the material.
 4. Sistas Sledge will only pay you in full if the material is “mint green.” Dark green or pale green will not be acceptable.
 5. You must develop a PowerPoint Presentation selling your recipe and process for making “Supa Ruba Blubba Balla.”
 - a. You must have all forms completed
 - b. An attractive PowerPoint presentation
 - c. A justification for having delivered exactly what the customer was wanting to purchase.
 6. Your presentation must include:
 - a. A marketing pitch.
 - b. The exact recipe and how you discovered it.
 - c. An explanation of the test you designed and pictures of your trials.
 - d. The cost to make 1 batch of the “Supa Ruba Blubba Balla.”
 - e. The exact size of the material necessary to make the ball bounce back $\frac{3}{4}$ the distance.
 - f. How much you think the product can sell for.
 - g. An estimate of the profit from one batch of “Supa Ruba Blubba Balla.”
 7. Each 1/8-teaspoon of Elastic Resin costs \$185 in R&D but only 3 cents in production.
 8. Each 1/8-teaspoon of Powder Elastic Resin Activator cost \$1,734 but only 22 cents in production.
 9. Each $\frac{1}{2}$ teaspoon of universal solvent costs \$345 but only .35 per gallon in production.

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10. Containers and mixers are included in the cost of the lab as long as you wash and retain them each day. If you lose, destroy, or fall prey to corporate theft each replacement will cost \$1,756 and lab-cleaning fees for failing to clean your equipment will cost \$10,000. So be sure to keep up with your materials, keep them clean, and keep your supplies so you do not have fees.

APPENDIX A

CORPORATE BRIEFING

Our client, *Ooey Gooey Inc.*, a subsidiary of *Junk in the Trunk Enterprises*, and a wholly owned partnership by Men to Bois, has determined that the market is ready for a new extreme toy-- A super slick product that easily flows and reminds adults of "SNOT". They commissioned us to develop the product and provide them with the exact recipe so they can manufacture it. Your code name for the project is "Bugger Burger Bustin Out." The design specifications are detailed below. The base recipe was acquired by our corporate spies from the now defunct company Snot Us Engineering and Products® before their CEO embezzled all the money. If anyone should discover your task, your mission, or your product you will lose to your competitors. Do not discuss this task with anyone who is not on your team.

Design Specifications:

1. Your Research and Design Budget is exactly \$245,000. You have the following costs.
 - a. You must design an account sheet to keep track of all your costs.
 - b. Before you can start you must present a budget that accounts for as close to \$245,000 as possible.
 - i. Your budget categories are as follows:
 1. Salary per day, per person and total
 2. Research facilities per hour
 3. Equipment rental
 4. Materials costs
 5. Total spent
 6. Total remaining
 7. Research
 - c. Use of the research facilities is \$395 per hour. You must pay for every hour you are in the research facility.
 - d. The rental of the equipment is a fixed cost per day \$22,545 regardless of which equipment is used or how long you use it.
 - e. Each member of the team earns at least \$800 per day, you need to set your daily salary in advance and budget for the task. You may pay yourselves more than \$800 per day but you may not pay anyone on the team less than \$800 per day.
 - f. You may purchase research from experts at negotiated costs, or you may do your own research at no cost.
 2. The "Bugger Burger Bustin Out" must flow to a relatively flat form about the thickness of 2 millimeters in 5 seconds.
 - a. You must design the test and set the parameters
 - b. You must have a drawing/diagram of the test you plan to use, a list of materials, and specify the height at which you will test the material.
 - c. You may not throw or squeeze it to get it to flatten out.
 3. You must determine the exact recipe to make exactly $\frac{1}{4}$ cup of the material.
 4. Men to Bois will only pay you in full if the material is "snot yellow". Dark yellow or pale yellow will not be acceptable.
 5. You must develop a PowerPoint Presentation selling your recipe and process for making "Bugger Burger Bustin Out."
 - a. You must have all forms completed
 - b. An attractive PowerPoint presentation
 - c. A justification for having delivered exactly what the customer was wanting to purchase.
 6. Your presentation must include:
 - a. A marketing pitch.
 - b. The exact recipe and how you discovered it.
 - c. An explanation of the test you designed and pictures of your trials.
 - d. The cost to make 1 batch of the "Bugger Burger Bustin Out."
 - e. The exact size of the material necessary to make it spread out to 2mm in 5 seconds to an area of no more than 10 square centimeters.
 - f. How much you think the product can sell for.
 - g. An estimate of the profit from one batch of "Supa Ruba Blubba Balla"
 7. Each 1/8-teaspoon of Elastic Resin costs \$185 in R&D but only 3 cents in production.

8. Each 1/8-teaspoon of Powder Elastic Resin Activator cost \$1,734 but only 22 cents in production
9. Each $\frac{1}{2}$ teaspoon of universal solvent costs \$345 but only .35 per gallon in production.
10. Containers and mixers are included in the cost of the lab as long as you wash and retain them each day. If you loose, destroy, or fall prey to corporate theft each replacement will cost \$1,756 and lab-cleaning fees for failing to clean your equipment will cost \$10,000. So be sure to keep up with your materials, keep them clean, and keep your supplies so you do not have fees.

Top Secret

APPENDIX A

CORPORATE BRIEFING

Our client, *Recovery Associates*, a subsidiary of *We Know it All*, and a wholly owned partnership by Baby Einsteins, has determined that they need a product to measure the volume of irregular solids-- A product should be easily molded and should easily take the shape of the container it is in. Because the containers are used for food products they have to be able to recover 100% of the material after measuring the container. They commissioned us to develop the product and provide them with the exact recipe so they can manufacture it. Your code name for the project is "Phorm Phitting Phunk." The design specifications are detailed below. The base recipe was acquired by our corporate spies from the now defunct company Shapes Ain't Us Enterprises ® before their workers all left to work at Burger King. If anyone should discover your task, your mission, or your product you will lose to your competitors. Do not discuss this task with anyone who is not on your team.

Design Specifications:

1. Your Research and Design Budget is exactly \$355,000. You have the following costs:
 - a. You must design an account sheet to keep track of all your costs.
 - b. Before you can start you must present a budget that accounts for as close to \$355,000 as possible.
 - i. Your budget categories are as follows:
 1. Salary per day, per person and total
 2. Research facilities per hour
 3. Equipment rental
 4. Materials costs
 5. Total spent
 6. Total remaining
 7. Research
 - c. Use of the research facilities is \$795 per hour. You must pay for every hour you are in the research facility.
 - d. The rental of the equipment is a fixed cost per day \$26,845 regardless which equipment is used or how long you use it.
 - e. Each member of the team earns at least \$800 per day, you need to set your daily salary in advance and budget for the task. You may pay yourselves more than \$800 per day but you may not pay anyone on the team less than \$800 per day.
 - f. You may purchase research from experts at negotiated costs, or you may do your own research at no cost.
 2. The "Phorm Phitting Phunk" must flow to fit the container and be completely recoverable without tools or other materials. Within 15 seconds.
 - a. You must design the test and set the parameters
 - b. You must have a drawing/diagram of the test you plan to use, a list of materials, and specify the quantity you will test.
 - c. You may not push or squeeze it to get it into the container.
 3. You must determine the exact recipe to make exactly $\frac{1}{4}$ cup of the material.
 4. Baby Einstein will only pay you in full if the material is "light blue." Dark blue or will not be acceptable.
 5. You must develop a PowerPoint Presentation selling your recipe and process for making "Phorm Phitting Phunk."
 - a. You must have all forms completed
 - b. An attractive PowerPoint presentation
 - c. A justification for having delivered exactly what the customer was wanting to purchase.
 6. Your presentation must include:
 - a. A marketing pitch.
 - b. The exact recipe and how you discovered it.
 - c. An explanation of the test you designed and pictures of your trials.
 - d. The cost to make 1 batch of the "Phorm Phitting Phunk."
 - e. The exact size of the material necessary to make fill a container with a volume of 8 square centimeters.
 - f. How much you think the product can sell for.

- g. An estimate of the profit from one batch of “Phorm Phitting Phunk.”
7. Each 1/8-teaspoon of Elastic Resin costs \$185 in R&D but only 3cents in production.
 8. Each 1/8-teaspoon of Powder Elastic Resin Activator cost \$1,734 but only 22 cents in production.
 9. Each $\frac{1}{2}$ teaspoon of universal solvent costs \$345 but only .35 per gallon in production.
 10. Containers and mixers are included in the cost of the lab as long as you wash and retain them each day. If you loose, destroy, or fall prey to corporate theft each replacement will cost \$1,756 and lab-cleaning fees for failing to clean your equipment will cost \$10,000. So be sure to keep up with your materials, keep them clean, and keep your supplies so you do not have fees.

Top Secret

APPENDIX A

CORPORATE BRIEFING

Our client, *Too Round for your Ride* a subsidiary of *Junk Food is Us*, and a wholly owned partnership by Kalorie Kids, has determined that they need a product they can place on top of a newspaper to lift off the print. They plan to use the product to steal negatives of prints from their competitors. The product should be easily molded, easily concealed and should be easily squished down onto newspaper and removed taking the print with it but not the paper. They commissioned us to develop the product and provide them with the exact recipe so they can manufacture it. Your code name for the project is “Copy Kating from the Phat Kats.” The design specifications are detailed below. The base recipe was acquired by our corporate spies from the now defunct company Edukated Engeneers ® before they were closed down for blowing up the block where they business was located. If anyone should discover your task, your mission, or your product you will lose to your competitors. Do not discuss this task with anyone who is not on your team.

Design Specifications:

1. Your Research and Design Budget is exactly \$333,000. You have the following costs.
 - a. You must design an account sheet to keep track of all your costs.
 - b. Before you can start you must present a budget that accounts for as close to \$333,000 as possible.
 - i. Your budget categories are as follows:
 1. Salary per day, per person and total
 2. Research facilities per hour
 3. Equipment rental
 4. Materials costs
 5. Total spent
 6. Total remaining
 7. Research
 - c. Use of the research facilities is \$735 per hour. You must pay for every hour you are in the research facility.
 - d. The rental of the equipment is a fixed cost per day \$25,445 regardless of which equipment is used or how long you use it.
 - e. Each member of the team earns at least \$800 per day, you need to set your daily salary in advance and budget for the task. You may pay yourselves more than \$800 per day but you may not pay anyone on the team less than \$800 per day.
 - f. You may purchase research from experts at negotiated costs, or you may do your own research at no cost.
 2. The “Copy Kating from the Phat Kats” material must retain the print for 1 minute.
 - a. You must design the test and set the parameters
 - b. You must have a drawing/diagram of the test you plan to use, a list of materials, and specify the quantity you will test.
 - c. You may not rip the paper that you copy the image from.
 3. You must determine the exact recipe to make exactly $\frac{1}{4}$ cup of the material.
 4. Kalorie Kids will only pay you in full if the material is white.
 5. You must develop a PowerPoint Presentation selling your recipe and process for making “Copy Kating from the Phat Kats”.
 - a. You must have all forms completed
 - b. An attractive PowerPoint presentation
 - c. A justification for having delivered exactly what the customer was wanting to purchase.
 6. Your presentation must include:
 - a. A marketing pitch.
 - b. The exact recipe and how you discovered it.
 - c. An explanation of the test you designed and pictures of your trials.
 - d. The cost to make 1 batch of the “Copy Kating from the Phat Kats.”
 - e. The exact size of the material necessary to make it spread out to 2mm in 5 seconds to an area of no more than 10 square centimeters.
 - f. How much you think the product can sell for.
 - g. An estimate of the profit from one batch of “Copy Kating from the Phat Kats.”
 7. Each 1/8-teaspoon of Elastic Resin costs \$185 in R&D but only 3 cents in production.

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8. Each 1/8-teaspoon of Powder Elastic Resin Activator cost \$1,734 but only 22 cents in production.
9. Each $\frac{1}{2}$ teaspoon of universal solvent costs \$345 but only .35 per gallon in production.
10. Containers and mixers are included in the cost of the lab as long as you wash and retain them each day. If you lose, destroy, or fall prey to corporate theft, each replacement will cost \$1,756 and lab-cleaning fees for failing to clean your equipment will cost \$10,000. So be sure to keep up with your materials, keep them clean, and keep your supplies so you do not have fees.

IDEATION RUBRIC

		ACCEPTABLE		UNACCEPTABLE		EXEMPLARY (<i>In addition to ACCEPTABLE</i>)	
PROJECT TITLE:	Evaluator:						
Authenticity	Rigor	<ul style="list-style-type: none"> <input type="checkbox"/> Project has little or no connection with the outside world or other curricular areas <input type="checkbox"/> Questions have little or no meaning to the students <input type="checkbox"/> Task has a single correct answer 	<ul style="list-style-type: none"> <input type="checkbox"/> Project simulates the “real world”. Working world adults are likely to tackle the task <input type="checkbox"/> Question has meaning to the students and provides a clear “need to know” <input type="checkbox"/> Project has several possible correct solution 	<ul style="list-style-type: none"> <input type="checkbox"/> Entities or persons outside of the school will or could use the product of student work <input type="checkbox"/> Students will present and defend their solution to a real and appropriate audience 	<ul style="list-style-type: none"> <input type="checkbox"/> There is a well defined, clear driving question that is derived from national, state or district content standards <input type="checkbox"/> Project demands breadth and depth of central concepts. <input type="checkbox"/> There is an expectation for supporting evidence, viewpoints, cause and effect, precise language, and persistence) 		
Academic Application	Learning Rigor	<ul style="list-style-type: none"> <input type="checkbox"/> Project is not based on content standards <input type="checkbox"/> Project demands little specific knowledge of central concepts 	<ul style="list-style-type: none"> <input type="checkbox"/> Project is derived from specific learning goals in content area standards <input type="checkbox"/> Project demands specific knowledge of central concepts <input type="checkbox"/> Student develop & demonstrate life skills (e.g., collaboration; presentation; writing) 	<ul style="list-style-type: none"> <input type="checkbox"/> New knowledge applied in solution <input type="checkbox"/> Students work in groups where content is discussed and debated in project context <input type="checkbox"/> Students use self-management skills informally 	<ul style="list-style-type: none"> <input type="checkbox"/> Knowledge applied to a realistic and complex problem <input type="checkbox"/> High-performance work organization skills (e.g., teamwork, communicate ideas, collect, organize and analyze information) <input type="checkbox"/> Formally use self-management skills (e.g., develop a work plan, prioritize work, meet deadlines, allocate resources) 	<ul style="list-style-type: none"> <input type="checkbox"/> Includes field-based or experimental research (e.g., interview experts, survey groups of people, work site exploration) <input type="checkbox"/> Students gather information from a variety of sources through a variety of methods (interviewing and observing, gathering and reviewing information, collecting data, model-building) 	
Adult Connections	Active Exploration	<ul style="list-style-type: none"> <input type="checkbox"/> Little independent research is required <input type="checkbox"/> Majority of information gathered from textbooks or encyclopedia-like materials provided by the teacher 	<ul style="list-style-type: none"> <input type="checkbox"/> Students conduct own, independent research <input type="checkbox"/> Students gather information from authentic sources <input type="checkbox"/> Students use raw data provided by the teacher 	<ul style="list-style-type: none"> <input type="checkbox"/> Students have limited contacts with outside adults (e.g., guest speakers, parents) <input type="checkbox"/> Teacher uses role playing or other staff members to simulate “expert” contact 	<ul style="list-style-type: none"> <input type="checkbox"/> Students have multiple contacts with outside adults who have expertise and experience that can ask questions, provide feedback, and offer advise <input type="checkbox"/> Outside adults provide students with a sense of the real-world standards for this type of work 	<ul style="list-style-type: none"> <input type="checkbox"/> Students help in establishing assessment criteria <input type="checkbox"/> Students have many opportunities for feedback on their progress from teachers, mentors, and peers 	
Use of Tech.	Assessment Practices	<ul style="list-style-type: none"> <input type="checkbox"/> Students are not provided with clear explanation of the assessment process or and expectations <input type="checkbox"/> Assessment of project is summarized into a single final grade <input type="checkbox"/> Students are not required to use technology or technology use is superficial 	<ul style="list-style-type: none"> <input type="checkbox"/> Clear explanation of assessment and expectations <input type="checkbox"/> Structured journals or logs used to track progress <input type="checkbox"/> Assessments are varied; include content & life skills <input type="checkbox"/> Final product is an exhibition or presentation demonstrating student knowledge <input type="checkbox"/> Technology is used to conduct research, report information, or to calculate results where appropriate 	<ul style="list-style-type: none"> <input type="checkbox"/> Create interactive media, conduct experiments, manipulate data, or communicate with adult experts 			

ORAL PRESENTATION RUBRIC

Category	4 (Exemplary)	3 (Proficient)	2 (Novice)	1 (Emerging)
Content	<input type="checkbox"/> Presentation is flawless or nearly flawless <input type="checkbox"/> relevant components are well represented	<input type="checkbox"/> Presentation is acceptable, relevant components are well represented <input type="checkbox"/> Information is complete <input type="checkbox"/> Well supported by detail <input type="checkbox"/> Increased audience's knowledge to some degree	<input type="checkbox"/> Quality is sporadic, aspects of components are missing or weak. <input type="checkbox"/> Important information may be missing <input type="checkbox"/> Few supporting details	<input type="checkbox"/> Components are emerging, poor demonstration of new knowledge <input type="checkbox"/> Presentation needs to be reworked to include more information on the major points
Thinking and Communication	<input type="checkbox"/> Presentation conveys deep and thorough understanding of the topic <input type="checkbox"/> Speaker's main points are logical and persuasive	<input type="checkbox"/> Presentation conveys good understanding of the topic, with some lapses <input type="checkbox"/> Speaker's main points may be clear, but may not be persuasive	<input type="checkbox"/> Presentation seems to convey only limited understanding of the topic <input type="checkbox"/> Main points may not be clearly stated or may not be persuasive	<input type="checkbox"/> Presentation needs to be reworked, to make major points – clearly, – thoroughly, and – persuasively
Organization, Mechanics, and Vocabulary	<input type="checkbox"/> Introduction captures audience attention and gives a clear statement of purpose. <input type="checkbox"/> Presentation is well organized, sequential, and supported by detail <input type="checkbox"/> Closing is a thorough summary of all major points <input type="checkbox"/> Speaker demonstrates a rich topic vocabulary	<input type="checkbox"/> Introduction includes purpose but does not capture attention <input type="checkbox"/> Presentation is organized and sequential with some supporting details <input type="checkbox"/> Closing is a summary of most of the major points <input type="checkbox"/> Vocabulary is appropriate to the topic, with minor issues	<input type="checkbox"/> Introduction unclear or missing supporting details <input type="checkbox"/> Fails to capture audience attention <input type="checkbox"/> Body of the presentation somewhat confusing with limited supporting details <input type="checkbox"/> Closing may be unclear, or does not include all of the major points <input type="checkbox"/> Topic-related vocabulary is somewhat limited	<input type="checkbox"/> Something is needed to capture audience attention <input type="checkbox"/> Body of the presentation needs organization and supporting details <input type="checkbox"/> A suitable closing is needed <input type="checkbox"/> Lacks ownership of key terms, words, and phrases relevant to the topic
Illustration	<input type="checkbox"/> Aids are clearly linked to material <input type="checkbox"/> Aids are well executed, and informative	<input type="checkbox"/> Aids are appropriate to topic <input type="checkbox"/> Aids not well integrated into the overall presentation	<input type="checkbox"/> Aids did not enhance audience understanding <input type="checkbox"/> Aids created confusion	<input type="checkbox"/> Lack of presentation aids <input type="checkbox"/> Missed opportunity to ensure audience understanding
Presentation	<input type="checkbox"/> Strong, clear speaking voice easily understood by audience <input type="checkbox"/> Makes and maintains eye contact <input type="checkbox"/> Creativity keeps audience engaged <input type="checkbox"/> Conveys confidence about the topic <input type="checkbox"/> Effective use of body language, physical gestures, and facial expressions <input type="checkbox"/> Conveys energy and enthusiasm	<input type="checkbox"/> Recovers easily from speaking errors <input type="checkbox"/> Creativity apparent, but not well integrated <input type="checkbox"/> Confident, but appears slightly nervous in delivery <input type="checkbox"/> Good eye contact with audience throughout most of presentation <input type="checkbox"/> Body language, physical gestures and facial expressions appear forced or artificial at times	<input type="checkbox"/> Clarity of speech is uneven; delivery may be halting <input type="checkbox"/> Limited evidence of creativity <input type="checkbox"/> Not completely confident about topic; nervous or disengaged <input type="checkbox"/> Limited or sporadic eye contact with audience <input type="checkbox"/> Limited or inappropriate use of body language, physical gestures and facial expressions	<input type="checkbox"/> Needs to control speaking tone, clarity, and volume <input type="checkbox"/> No evidence of creativity <input type="checkbox"/> Visibly nervous <input type="checkbox"/> Conveyed a lack of interest in the topic <input type="checkbox"/> Eye contact was minimal or non-existent <input type="checkbox"/> Body language, physical gestures and facial expressions were lacking or inappropriate

Notes _____

PRESENTATION RUBRIC PT1 INDIVIDUAL

	1. _____	2. _____	3. _____	4. _____	
Category	Ind. Score _____	Ind. Score _____	Ind. Score _____	Ind. Score _____	Ind. Score _____
Content	Exemplary (15) Information is complete & well supported by detail, significantly conveying knowledge of the topic.	Proficient (10) Information is complete with basic supporting details, conveying knowledge at least some degree.	Novice (5) Important information missing, or there are too few supporting details.	Beginning (0) The presentation does not include information on the major points.	
Thinking and Communication	The presentation conveys deep & thorough understanding of the topic. The speaker's main points are logical.	The presentation conveys good understanding of the topic, with some lapses. The speaker's main points are clear.	The presentation seems to convey only limited understanding of the concepts. The main points are not stated.	The presentation does not express the concepts or issues clearly. Concepts were omitted.	
Illustration	Presentation aids are clearly linked to the material, well executed, & informative.	Presentation aids are appropriate but are not well integrated into the overall presentation.	Presentation aids do not enhance understanding, are not well constructed, or confusing.	No presentation aids.	
Presentation	Strong, clear speaking voice easily understood. Use of creativity keeps audience engaged. Speaker conveys confidence in talking about the concepts and issues. Excellent eye contact. Use of physical gesture & facial expression conveys energy & enthusiasm.	Good speaking voice; recovers easily from speaking errors. Creativity apparent, but it is not well integrated into presentation. Speaker is in command of the topic, but appears slightly nervous in delivery. Good eye contact. Use of physical gesture & facial expression good, but forced at times.	Clarity of speech is uneven; delivery is halting. Limited evidence of creativity. Speaker is not completely sure of topics; appears nervous or disengaged. Limited or sporadic eye contact with audience. Limited or inappropriate use of physical gesture & facial expression.	Control of speaking tone, clarity, & volume is not evident. No evidence of creativity. Speaker is visibly nervous & does not convey interest in the topic. Speaker does not make eye contact with audience. Physical gesture & awareness of facial expression are absent.	

Notes _____

APPENDIX E

PRESENTATION RUBRIC PT2

GROUP

	Exemplary (20)	Proficient (15)	Novice (10)	Beginning (5)
Organization and Mechanics	<p>The introduction captures attention & gives a clear statement of purpose.</p> <p>The group organizes the presentation so that it is sequential & provided good transitions between members.</p> <p>The closing provides a thorough summary of all the major points.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> </div>	<p>The introduction states the purpose but does not capture attention.</p> <p>The group is organized and sequential. Transitions between group members are fair.</p> <p>The closing provides a basic summary of most of the major points.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> </div>	<p>The introduction is unclear or fails to capture attention.</p> <p>The group is not well organized. Transitions between group members are poor.</p> <p>The closing is unclear or does not include many of the major points.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> </div>	<p>No introduction is used to capture attention.</p> <p>The group needs organizational help. There are no transitions between group members.</p> <p>A suitable closing is missing.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> </div>
Cohesion	<p>The team worked well together with shared responsibility.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> </div>	<p>The team worked well but not all members presented equally.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> </div>	<p>The presentation was somewhat disorganized with members not sure when or what to say or not knowing whose turn it was.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> </div>	<p>The team was clearly disorganized; the presentation was disjoint because it was clear they had not attempted the presentation earlier. OR Only one member or a couple members did the entire presentation.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> <div style="text-align: center;"><input type="checkbox"/></div> </div>

Place team member initials in the boxes provided under each descriptor.

Overall Grades (100 pts. Possible) Sum Parts 1 & 2

$$\begin{array}{l}
 \text{Member 1: } \underline{\hspace{1cm}} + \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \\
 \text{Member 2: } \underline{\hspace{1cm}} + \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \\
 \text{Member 3: } \underline{\hspace{1cm}} + \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \\
 \text{Member 4: } \underline{\hspace{1cm}} + \underline{\hspace{1cm}} = \underline{\hspace{1cm}}
 \end{array}$$

STEM PROJECT-BASED LEARNING STORYBOARDING GUIDELINES

Preproduction Items

- 1. Type of project** (marketing, financial report, request support, solicit an action, literary work, audio, video, etc.)
- 2. Characters**
 - Who are the people responsible for completing each part of the project?
 - Who are the characters in this project?
 - What will the characters do?
 - What is each character like?
- 3. Target audience**
 - Who will read the story, see the presentation, listen to the podcast, or watch the video?
- 4. Purpose of the project**
 - What is the goal of the project?
 - What are we trying accomplish through the project?
- 5. Setting**
 - Where does the story take place?
 - Is it in one location or more than one?
 - How will you communicate the setting to the audience?
- 6. Plot**
 - What will happen in the story?
- 7. Deadlines**
 - What is the completion date for the project?
 - List the subparts you will have to complete and the dates.

- i. _____
- ii. _____
- iii. _____
- iv. _____
- v. _____
- vi. _____
- vii. _____
- viii. _____

8. Dialogue

- What do the characters say to the audience?
- What will the characters say to each?

9. Production (see form STEM PBL Story Boarding)

1. Set up the first slide for your introduction.
 - Names of the people involved in the project, the title of the project, a brief description of the purpose.
 - Include slide numbers.
2. Set up your second slide with your logo, graphic, catch phrase, text box, title text box, etc. as your template for the rest of the slides. Copy as many times as you need.
3. Write the exact script for each of the characters
 - Place only the necessary text on the actual PowerPoint slide.
 - Everyone should memorize their scripts.
 - NO ONE should read from the screen.

10. Improving your Work

1. Present your storyboard to others for comments.
2. Ask them to respond to each of these questions
 - a. What is the main message you understood from the storyboard?
 - b. Did we communicate it clearly?
 - c. Was anything spelled wrong?
 - d. Were there any missing words?
 - e. What can we do to improve the storyboard?
 - f. Were the graphics useful to convey the message?
 - g. Should we use some other graphic or picture?
 - h. Was the language appropriate to the audience?

CROSSING THE ABYSS: POPSICLE STICK BRIDGE: WDO/IDT

There is a huge chasm and the only way around it takes 19 days and there is no way through it. The best situation would be to erect a bridge across it to join the two rights of ways into a single traversable right of way. Build a bridge to cross the abyss safely. Falling into the abyss means certain and immediate death. Don't fall into the abyss. The design specifications indicate that the lightest bridge that supports the greatest load (lowest weight ratio of bridge to load) is the best design. Given two bridges that carry the same weight, the lightest bridge will be the best designed. When you begin to plan the design of your bridge, keep in mind that you have a limited number of supplies, your car must be able to get across, and that the bridge must be long enough to span the distance of the abyss. The bridge must be constructed using the following materials.

Materials

- Popsicle sticks
- Hot glue sticks – two hot glue sticks per group. Groups are allowed to buy extra hot glue sticks for \$1 per stick with a maximum of 5, if you need more
- Hot glue gun
- 36 inches of string
- White glue

Judging materials (provided at the time of judging)

- Bowl
- Hook
- Sand
- Glass
- Rope
- Assembled Hanger plate provided (3" square plate)

Objective

You will design (show all 6 sides), build, and test a Popsicle stick bridge that meets all design constraints. The best bridge will be the one that supported the greatest weight and looked the most professional. You will learn the following during your bridge construction:

Vocabulary

www.pbs.org/wgbh/nova/bridge/meetarch.html

www.pbs.org/wgbh/nova/bridge/meetbeam.html

www.howstuffworks.com/bridge1.htm

Students will be able to distinguish three major types of trusses Howe, Pratt and Warren.

1. **Abutments:** supports at the end of an arch bridge that carry the load and keep the ends from spreading out.
2. **Spandrels:** vertical supports of an arch bridge used to distribute the weight of the roadway to the arch below.
3. **Anchorage:** securing devices that are embedded in the solid rock or massive concrete blocks that spread cables over a large area to evenly distribute the load and prevent the cables from breaking free.
4. **Span:** the distance between two bridge supports
5. **Compression:** a force that acts to compress or shorten the thing it is acting on.
6. **Tension:** a force that acts to expand or lengthen the thing it is acting on.

APPENDIX G

7. **Buckling:** what happens when the force of compression overcomes an object's ability to handle compression.
8. **Snapping:** what happens when tension overcomes an object's ability to handle tension.
9. **Dissipate:** to spread force over a greater area so that no one spot has to bear the brunt of the concentrated force.
10. **Transfer:** to move force from an area of weakness to an area of strength.
11. **Truss:** supporting latticework added to create very tall beams that add rigidity to an existing beam greatly increasing its ability to dissipate the compression and tension.
12. **Torsion:** a rotational or twisting force.
13. **Deck-stiffening trusses:** a supporting truss system beneath the bridge deck.
14. **Resonance:** a fatal force to a bridge that is a vibration caused by an extended force that is in harmony with the natural vibration of the original thing. Resonance vibrations travel through a bridge in waves.
15. **Dampeners:** a technique used to interrupt the resonant waves.

Day 1 – 180 minutes

Students will learn the design process of a project. They will first develop a design, then test their design, and finally, create their final prototype at the end of the project.

They will identify the problem and constraints according to WDO/IDT. Students will watch the Youtube video of a Popsicle stick bridge for 10 minutes (http://www.youtube.com/watch?v=LZR_izGo6Lc).

After the description of the WDO-IDT, students will be placed into groups of two. Then they will be provided with rubric and explained the weight for each item. Students will be explained that there will be three different categories in awarding: (1) highest load / weight ratio, (2) most realistic looking bridge, and (3) best design.

Students will be tasked with researching and then deciding what bridge they will be designing. Students will draw in a rough sketch or a picture of their bridge design. Students will experience how the materials work before they build the bridge.

Design

Students will:

1. Draw their bridge design before using any materials. The complete drawings will include their design specifications.
2. Each team will develop their design specifications for their bridge.
 - a. How wide will your bridge be?
 - b. How long will your bridge be?
 - c. What shapes will your bridge be comprised of?
 - d. How will your bridge be assembled?
 - e. What materials will you use to attach your Popsicle sticks? Road base, uprights, top etc.?
 - f. How high will your bridge be?
 - g. What shape will you use for building your foundation?

Day 2 – 180 minutes

Students will be provided with the knowledge of physics and geometry behind the bridge building. The instructor will review the sketches that students drew of their bridge design on the first day. Students will learn the weakness and strengths of their bridge design from instructor. Students will explain the mathematical and physical arguments behind their bridge design. Constraints will be explained to students before they begin to build their design.

Students will start to build their bridges. Materials will be given to students, including; Popsicle sticks, hot glue gun, hot glue sticks, Elmer's glue, and string to start building process.

Constraints of the project

Dimensions

1. The abyss measures 16". So your bridge's span should be greater than the abyss. Your bridge's foundation must rest on solid ground and abut the edge of the abyss.
2. The maximum width of the bridge (roadway) is 4.5".
3. The minimum height of the bridge will be 3 inches above the ground. There must be at least 3" between the table surface (ground) and the lowest point on the bridge.
4. The maximum length of each bridge support is 3".
5. [Figure 1](#) is presented for clarification:

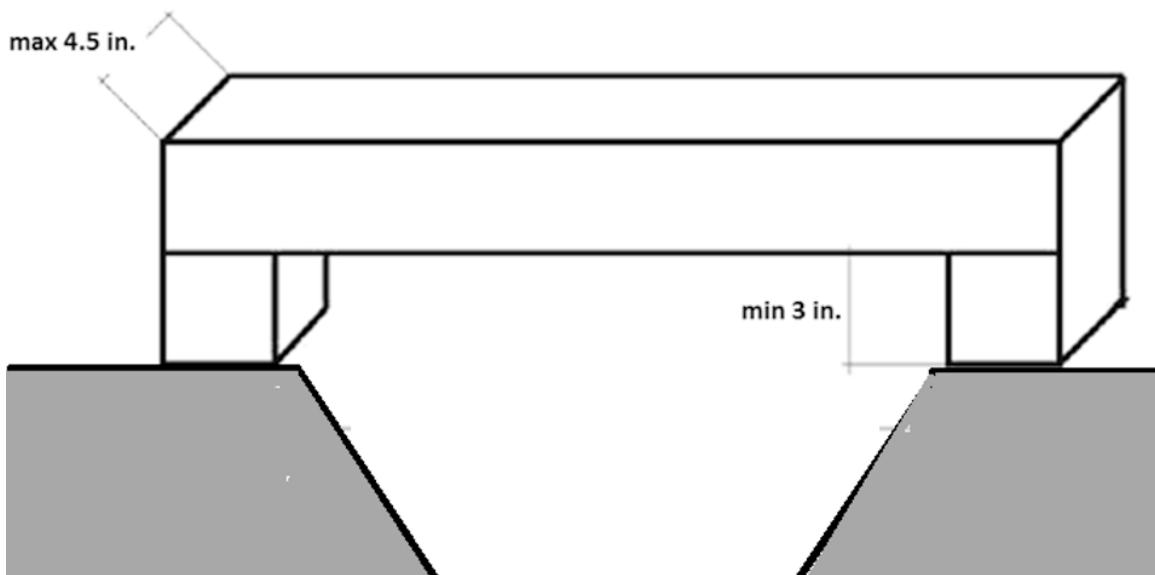


Figure 1.

5. The bridge must be able to stand on its own.
6. The bridge must be able to support the load at the loading point (indicated by the arrow). The loading point will be the midpoint of the abyss between cliffs which is 8 inches from each side.

Roadway

- The roadway must be constructed as if wheeled traffic were to cross over its span.
- The roadway must be continuous along its width over the entire distance between the supports.
- No gaps shall exist in the roadway except where natural warping has occurred after construction of the bridge.
- The roadway is the portion of the bridge to be loaded. If you have bridge structure over the roadway, at least a 3-inch square opening must be maintained above the loading area on the roadway to allow the bridge to be loaded.
- The roadway must be constructed to accommodate a 3-inch high, 3-inch wide vehicle.
- The roadway must not exceed a horizontal: vertical slope of 2:1 (approx. 26.5 degrees from the horizontal).

APPENDIX G

Construction: 50% Rule

No more than 50% of any plan surface of any member may be laminated. Each member consists of two plane surfaces (the two larger sides unless all sides are equal then all sides must comply with the 50% rule).

Let's look at [Figure 2](#) as an example, when using a full-length stick, the sum of glued lengths (1) and (2) must be less than or equal to half of the stick's total length (2-1/4 inch).



Figure 2

[Figure 3](#) shows that the length labeled (A) must be equal to or greater than half of the stick's total length.

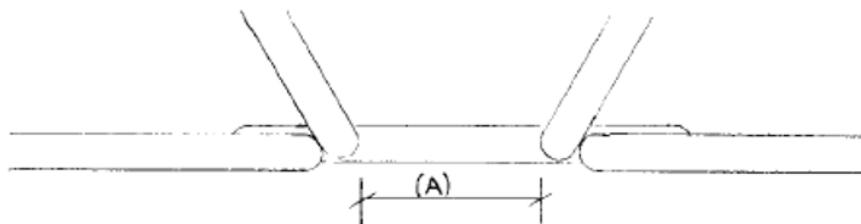


Figure 3

Stacks & Gaps

A maximum of 6 parallel sticks may be stacked at any joint. There must be at least a 1-inch clear gap between any two stacks. Stacks and gaps are illustrated in [Figure 4](#).

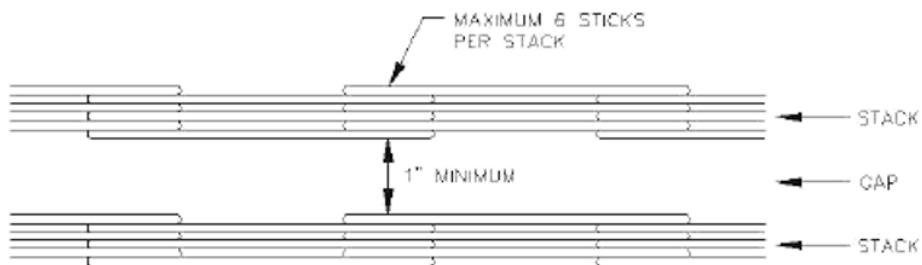


Figure 4

Loading

The bridge will be loaded in the midpoint of abyss, which is 8 inches from one side of the table.

The load will be applied on a 3-inch square plate placed above the loading point on the roadway.

Miscellaneous

The bridge must be self-supporting over its entire span.

The bridge must not exert any horizontal force on the supports other than friction. Therefore the bridge may only come into contact with the top surface of the end supports.

Day 3-4-5 – 180 minutes (per day)

Students will continue to build their bridges.

Day 6 – 30 to 50 minutes

Students will finalize their Popsicle stick bridge project. They should end up with a bridge, which can stand by itself. Students will also prepare a presentation that will explain the reason why they designed their bridge in that particular form.

The Competition Day

1. Inspection will test that the construction rules were followed and will record the mass of the bridge.
2. Certified bridges will be placed over “Crusher Canyon” by the team members, who may make final adjustments in its position. The canyon will consist of a 16 in space between two flat desktops.
3. Once the bridge is in position, the loading tray will be attached in the position indicated above. The load will hang below the bridge.
4. Bridges will then be subjected to loading. Bridge failure will be considered the point at which the bridge breaks or the point at which the loading tray drops more than 4 in from the unloaded position.

Judging and Scoring

1. The greatest load prior to failure will be a bridge’s capacity.
2. The capacity divided by the bridge mass will be the bridge's score (highest load/weight ratio).

$$\text{Efficiency Rating} = \frac{\text{Load (lbs.) X 454 (g/lbs)}}{\text{Mass of Structure (g)}}$$

3. There will be three different award categories:
 - Efficiency Rating (Highest load / weight ratio)
 - Most realistic looking bridge (best workmanship)
 - Best design (Best Design and documentation) The design notebook for both members. For consideration both partners must have the best quality design notebook.

APPENDIX G

Engineering and Design

Bridge Rubric Final Efficiency Rating

Name _____ Group _____
 First _____ Last _____

70% of Grade	10	9	8	7	6	5	4	3	2	1
	EXCELLENT			AVERAGE				BELOW AVERAGE		

- _____ Trusses include all basic members of commonly used trusses, i.e. Howe, Pratt, and Warren
- _____ Trusses are constructed in a way that shows good workmanship
- _____ Gluing is done in a neat way so that extra glue does not show
- _____ The deck is attached to the trusses in the strongest possible way
- _____ The top structure is designed to give the bridge maximum stability
- _____ The roadway is traversable by the automobile provided
- _____ The piers are stable and support the weight of the bridge evenly across each base
- _____ The barrier rail or top structure is firmly affixed to the roadway.
- _____ The piers are permanently affixed to the bridge and not to the table or any other structure
- _____ The bridge is symmetrical with respect to the main span and placement of the piers.

30% of Grade

- _____ Grams Weight of Structure
- _____ Lbs. Weight Held by the Structure
- _____ Efficiency Rating of the Structure (calculated)

Engineering and Design
Bridge Rubric Final Design Notebook

Name _____	First _____	Last _____	Group _____		
70% of Grade	10 9 8 7 6 5 4 3 2 1	EXCELLENT	AVERAGE	BELOW AVERAGE	POOR

- _____ Notes are provided about the three main types of trusses
- _____ Notes are provided documenting research on types of bridges
- _____ Notes of provided of sample bridge designs
- _____ Clear and concise drawing of the front of the bridge is presented and labeled
- _____ Clear and concise drawing of the back of the bridge is presented and labeled
- _____ Clear and concise drawing of the left side of the bridge is presented and labeled
- _____ Clear and concise drawing of the right side of the bridge is presented and labeled
- _____ Clear and concise drawing of the piers of the bridge is presented and labeled
- _____ Construction methods are detailed. For example, if sections are to be created (segmental box girder) and then assembled the directions are clearly written in steps or if piers are to be created first that is clearly described.
- _____ The assembly methods are specified for example where cold glue and hot glue will be used.

30% of Grade Drawings

- _____ All pictures are carefully drawn
- _____ All drawings are proportional
- _____ All drawings are neat and exhibit high quality workmanship

ESTABLISHING COOPERATIVE GROUP BEHAVIORS AND NORMS FOR STEM PBL

The best way to change class norms and behaviors is by engaging students in a group task, and then critically discussing the experience after having students respond in writing about their own personal reflections. Attempts to omit the experience and substitute teacher lectures or class discussion will be of little value for either the teacher or the students.

It is important to think carefully about behaviors you as the teacher want to propagate and those behaviors you may want to extinguish. Therefore, you will need to consider these:

1. New behaviors you want to establish must be labeled and discussed.
 - a. Why they are necessary?
 - b. How are they useful?
 - c. Why they will benefit from developing them?
2. Regardless of whether you are trying to start a new behavior or reduce the incidence of a negative behavior **students must learn to recognize the behavior when they or a classmate exhibit it.**
 - a. Discuss praise words for the new behavior being fostered.
 - b. Discuss gentle reminders when negative behaviors crop up.
3. Students must learn to use labels and discuss behaviors in an *objective* way.
 - a. Provide examples of how to label a behavior and not the person.
 - i. When you say “Whatever” it makes me feel useless.
 - ii. When you do not do your job, I feel like you do not care about the rest of us.
 - b. Avoid value-laden words like lazy, dumb, and argumentative.
4. Students must have a chance to practice new behaviors.
 - a. Using low-stakes group activities can be more effective to foster or extinguish behaviors in which you have an interest.
 - b. Low stakes activities remove performance anxiety for both high and low achievers while providing a low-risk, high-value experience when students receive praise for how they handle group conflict and exhibit the behaviors.
5. Rubrics should be used to reinforce enactments of behaviors you want to propagate and value the absence of behaviors you want to extinguish. Often naming the behaviors you want to extinguish is sufficient for improving group culture in your classroom activities.
 - a. Use both teacher rubrics and peer evaluation rubrics. This will familiarize students with rubrics as well as provide a clear picture of what the expectations are.

Examples of Group Behaviors you would like to encourage for high performance:

1. Equal participation – No one dominates, no one is silent.
2. Respect – Using civil language and avoiding physical intimidation
3. Active listening – body language shows interest, brief words of encouragement.
4. Helping – Everyone has the right to ask for help, everyone has duty to help.
5. Giving – Responsive to other’s needs. I give, I do not just take.
6. Explaining – Explanations are complete, not just the right answer.
7. Politeness – Ask for help in a kind way and thank those who give it.
8. Brainstorming – Talk about each idea without ignoring any; identifying the positives and negatives of EVERY idea and then selecting the one with most positives and least negatives.

If behaviors become problematic use peer observers not part of the team and have them use the rubric for 10 minutes and have the observer talk with the group about where they did well, and where they could improve.

BUILDING HIGH QUALITY TEAMS

Rules for High Performance Collaboration

1. Each person on the team is responsible for his or her own behavior and learning.
2. Each member of the team should be willing to help every other team member who asks for help.
3. Each team member is responsible for everyone else's ability to talk about and explain the task and the team's solution.
4. You can only ask the teacher for help when all members of the team have the same question.
5. It is critical to work, think about, and engage in the task you are asked to do.
6. Any time that you think your team is done with the task you were asked to do:
 - a. Look around if everyone else is also doing the same thing you might be finished, if not you may be missing something.
 - b. Review the task sheet.
 - c. Reread the constraints using "Round Robin" or read-aloud. Then verify you met all the constraints. All members must agree you exactly followed the constraints.
 - d. Review all the rubrics and each team member should review the project submission using the rubric. Make necessary changes.
7. Share your praises and your concerns with your teammates
 - a. Never use put downs
 - b. Always start with a positive
 - c. Never do anything to anyone else you would not like done to you

Positive Words and Phrases for Encouragement

- Excellent!
- Thanks!
- Can I help?
- Can we make a plan so everybody has something to do?
- _____ has a good idea. Let's all listen for a minute.
- What do you think, _____?
- Does everybody agree with the plan?
- Any other ideas?
- _____, we need your help.
- I don't think we heard _____'s idea.

General Hint: Say it with a SMILE ☺ Frowns are always interpreted as negative and tone can ruin the meaning of the words.

PERSONAL RESPONSIBILITY AND TIME MANAGEMENT REPORT

You may receive an additional ___ points. **DO NOT GUESS.** Please use your *Personal Responsibility and Time Management Log* to complete this form. You must submit both to receive credit.

Questions	My Response	Teacher's Response
How many times were you tardy?		
How many times did you check or send e-mail?		
How many Instant Messenger messages did you send?		
How many times did you play on-line games?		
How many times did you visit websites that weren't project related?		
How many times did you leave the classroom on school-related business?		
How many times did you leave the classroom on non-school-related business?		
How many times did you socialize with friends in class?		
How many times were you asked by a teacher to get back on task?		
If you were to grade yourself for your personal responsibility and time management, what would it be?		
Did you show improvement from the previous report? Explain		

APPENDIX K

ACCOUNTABILITY RECORD

Group _____ Date _____

Point changes. These points are deducted from or added to (Specify rubric)									
Name	Date								Total

Name	Assignments not turned in/incomplete	Total point loss

Name	Extra Credit Assignments/Tasks/ Social Conduct	Bonus

APPENDIX L

PEER EVALUATION HANDOUT

The following is a list of statements to be answered about yourself and each of your group members. Think carefully about assigning rating values for each of the statements. Your individual answers will not be shared with your team members. However, an overall rating based on the combined teammate scores will be given for each member.

Group: _____

1-Strongly Agree 2-Agree 3-Neutral 4-Disagree 5-Strongly Disagree

Names	Self:	Teammate	Teammate	Teammate	Teammate
Was dependable in attending group meetings.					
Willingly accepted assigned tasks.					
Contributed positively to group discussions.					
Completed work on time or made alternative arrangements.					
Helped others with their work when needed.					
Did work accurately and completely.					
Contributed a fair share to assignments.					
Worked well with other group members.					
Overall was a valuable member of the team					

Additional Comments:

APPENDIX M

LEADERSHIP/EFFORT BONUS WORKSHEET

At the end of the project your group must meet to assign the leadership/effort bonuses. Leadership is not being bossy, or giving orders, it is helping other, being thoughtful, and being an example of appropriate behavior.

Leadership bonus: **One** member of your group may receive the 25 bonus points for leadership.

I recommend _____ for the leadership bonus. My reasons for the nomination are

Work ethic/effort bonus of 20 points: Up to **three** members may earn a bonus for working especially hard. You can divide these points in any way between **three** people.

Nomination	Rationale	Bonus
1)		
2)		
3)		
Total		Must sum to 20 points. No fractional points

Options when your group cannot reach consensus

Option 1: No one gets any bonus.
or

Option 2: Each member gets a piece of paper containing all group members' names. Then rank order the members using the number 1-j, where j is the total number of team members with 1 being the highest rank. Each member does this secretly. Work individually and the person earning the leadership bonus will tally. Add the total number of points and one with the lowest score gets the points.

Example of one person's vote:

Rayya	4
Shayla	3
Berta	2
Davion	1

APPENDIX N

SIMPLE GROUP CONTRACT

OUR CONTRACT

- 1) We all promise to listen to each other's ideas with respect.
- 2) We all promise to do our assigned work to the best of our ability.
- 3) We all promise to turn in our work on or before due dates.
- 4) We all promise to ask for help if we need it.
- 5) We all promise to share responsibility for our success and for our mistakes.
- 6) We all promise to turn in work that is our own.

If someone in our group breaks one or more of our rules, the group has the right to call a meeting and ask the person to follow the rules. If the person still breaks one or more of our rules, we have the right to vote to fire that person.

Group member signatures:

Date:

APPENDIX O

SAMPLE GROUP CONTRACT

Members

List all members

Task List

List everyone's tasks

Group Constitution

Forward: This contract is a binding legal document and governs the group until the assigned project deadline. If the group separates, or a member is fired, the basic contract laws remain intact for both parties. However, being fired may cause work responsibilities to shift.

- | Article | I: | Absence | Policy |
|---------|--|---------|--------|
| a. | If a group member will be absent on a day in which work is due, they must tell another group member a day in advance and have all work that they are responsible for turned in. All group members must stick to the provided agenda to have the assignments completed on time. If there will be an unexpected absence, the group member is to complete the work from home and email another group member to let them know they are gone for the day. | | |
| b. | Group members will contact one another if they are absent for any amount of period during the time allotted for working on the projects. | | |

Article II: Work Policy

- a. Any member that is mentally or physically disabled and can prove that they cannot complete the work assigned to them alone they may acquire assistance from other group members to help complete it. This will only apply for work that is group work and not individual work, and work will only be finished by that group member, and the assisting group member will not write it.
- b. Each group member will work to the best of their ability, making sure to complete the work is up to standards, and that they completed it with punctuality.
- c. If a group member commits plagiarism, they are solely responsible and incur the punishment on their own.

Article III: Leadership

- a. At the beginning of the project, a leader will be voted upon democratically. If a group member is absent at the time of voting, they waive their right to participate in voting. The person who wins the most votes becomes the leader. If there is an unclear outcome (same number of votes for different people), the group will have no leader until one can be chosen by a revote.
- b. By being elected leader, the person must perform the following duties:
 1. Organize group meetings.
 2. Create and enforce a group agenda to govern group progress.
 3. Organize any out of school project efforts.
 4. Provide communication between group members in order to help individuals work towards the project goal.

If they fail to perform these duties, or another person is also carrying them out, a revote may be taken to determine whether to obtain a new leader.

APPENDIX O

- c. If a leader fulfills his or her duties, they will receive the 20 extra credit leadership points at the end of the project. The current group leader will receive these points, regardless of how long they lead the group for. If no leader has been assigned, a majority vote will decide who receives the leadership points.

Article IV: Work Ethics

- a. If a group member does not complete work they were assigned, the punishment for the infringement will be of detriment solely to the group member at fault. No negative grading shall be given to any other group members.

- b. At the end of the project, 'hard workers' will be designated by means of a democratic vote. The people voted as the top two will each receive the ten bonus points. If one candidate is voted as hard worker by a margin of 75%, they will receive 20 points. If there is a tie, the group will discuss and come to resolution or else no points will be granted to the disputed individuals.

Article V: Member Dismissal

- a. The following conducts will result in a group member being able to be dismissed;

- i. Incomplete or missing group work.
- ii. Plagiarism or any form of cheating.
- iii. If group member decides to leave under his or her own will.

- b. Any group member leaving under their own will be able to submit all their own work, while the other group members may not. Any group member fired for breaking any of the conducts under Article V-a (i-iii). will have their work taken from their possession to be used at the discretion of the original group, but not for the individual being fired. In addition, any fired member may not use any work completed by other group members, subject to punishment under Article 2-c.

- c. If a group member leaves under the stipulation of Article V-a (iv), they retain all the work they have already provided for the group. The original group cannot use this work or it is subject to punishment under Article 2-c.

Article VI: Signature

By signing this contract the following group members abide to the articles above. If any member fails to abide by the articles of this contract, they may be fired from the group given at least a 50% vote in favor of firing the individual.

Signatures:

TEAM CONTRACT

Team Members:

Our Purpose:

Code of Conduct

We will:

1. Provide the opportunity for all members to participate.
- 2.
- 3.
- 4.
- 5.

Decision Making

We will make project decisions by:

- 1.
- 2.
- 3.

Timeline

TASK	DUe	Person Responsible	Status Report Date

Use the back if necessary.

Conflict Resolution

When we encounter conflict or someone does not fulfill his/her responsibilities we will:

- 1.
- 2.
- 3.

Sign, date and make a copy for each member:

Date _____

SELF REFLECTIONS

Reflection Requirements

Self-Reflections are to be completed each week by the end of class Friday.

Each week select 2 prompts to guide your reflection. Prompts are posted on the board each day.

Please date each week's reflection and separate the entries by skipping a line between each reflection.

Be sure your work is legible and complete.

If you are absent, you are still responsible for completing each week's reflections.

Content & Length Requirements

Each reflection must be at least 5 sentences long and meet the criteria.

5 Points

Clear main idea; In-depth explanation; Meets all assignment requirements

4 Points

Identifiable main idea; Support is attempted but limited; Meets all assignment requirements

3 Points

Identifiable main idea; Support is attempted but limited; Only 3-4 sentences

Revise

Identifiable main idea; Support is not attempted; Less than 3 sentences

(See Sample Generic Prompts (not sufficient to full self-reflection requirements))

APPENDIX R

REFLECTION ON TEAM COLLABORATION

Directions: The following statements can promote or impede group progress and decision-making. Please rate each item as it applies to your group's situation on the following scale: These ratings will not affect your grade.

		Accurately describes our group meetings	Does not describe our group meetings at all		
	5	4	3	2	1
All members participate					
Members offer solutions to problems	5	4	3	2	1
Members ask questions that promote decision-making	5	4	3	2	1
Members provide positive and constructive feedback	5	4	3	2	1
Members actively listen to all members' ideas	5	4	3	2	1
Member(s) interrupt(s) others	5	4	3	2	1
Member(s) put others down	5	4	3	2	1
Members do not make compromises	5	4	3	2	1
Members engage in off-topic conversations	5	4	3	2	1
Members are unclear as to what needs to be done	5	4	3	2	1
As a team, I am most proud of our ability to ...					

We would work more effectively as a team if we ...

APPENDIX S

TEACHER PEER EVALUATION OF STEM PBL PROJECT

PROJECT CRITERIA	EVIDENCE Check all that Apply
The project is focused on questions that engage students in the central concepts and principles of a discipline.	<input type="checkbox"/> Project is centered on curriculum and aligned with national, state, or district standards. <input type="checkbox"/> Project demands depth and breadth of understanding of central concepts and “Big Ideas”. <input type="checkbox"/> Project is organized around an open-ended driving question, problem, or question that inspires higher-level thinking. Comments:
The project involves students in investigation of authentic issues.	<input type="checkbox"/> The driving question or problem has meaning to students and may be generated by them. <input type="checkbox"/> The questions or problems are like those faced by people in the world outside of school. <input type="checkbox"/> Students are required to do extensive exploration and research, including field-based activities. <input type="checkbox"/> Students are required to have contact with adults outside of the classroom teacher or have the opportunity to work with adults in the community or online. <input type="checkbox"/> Students are encouraged to direct their own inquiry process and investigate their own questions. Comments:

<p>The project incorporates the use of authentic tools, including technology.</p>	<ul style="list-style-type: none"> <input type="checkbox"/> Students develop and use habits of mind (e.g. concern for evidence, viewpoint, cause and effect; precision; persistence). <input type="checkbox"/> Project work provides opportunities to develop workplace competencies (e.g. work in teams, use technology appropriately, communicate ideas, collect, organize and analyze information). <input type="checkbox"/> Students work in groups and use formal self-management skills (e.g. develop a work plan, prioritize pieces of work, set deadlines). <input type="checkbox"/> Students and teachers are involved in a wide range of communication patterns, roles, and activities. <input type="checkbox"/> Technology is used to extend and enrich learning. Students have opportunities to use computers and other technologies as tools for creating, analyzing, and presenting new knowledge. <p>Comments:</p>
<p>The project requires products that solve problems, explain dilemmas, or present information</p>	<ul style="list-style-type: none"> <input type="checkbox"/> Knowledge and skills are applied to solving a complex problem. <input type="checkbox"/> Information comes from a variety of sources, many of which are discovered by the student (e.g. readings, interviews, observations, libraries, websites, etc.). <input type="checkbox"/> Final product(s) and performances show that all students have the opportunity to understand the subject matter in depth, acquire new skills, and demonstrate their knowledge. <p>Comments:</p>
<p>The project uses performance-based assessments that describe high expectations and rigorous challenges</p>	<ul style="list-style-type: none"> <input type="checkbox"/> Criteria and standards by which student work will be judged are clearly explained to students, who may also help establish the criteria. <input type="checkbox"/> Students are taught how to self-assess and are required to use structured methods such as journals, conferences, rubrics, reviews of progress, etc. <input type="checkbox"/> Students receive timely feedback on their work in progress. <input type="checkbox"/> Products and performances are closely aligned to standards and are rich and varied enough to make credible judgments about their learning. <input type="checkbox"/> Students complete a culminating exhibition, presentation, or product that demonstrates their knowledge and skills. <input type="checkbox"/> Student work is reviewed by a “real” audience. <input type="checkbox"/> Students understand what is required of them, and are given exemplars (models of high quality work) and tools (rubrics, checklists) for monitoring their own performance. <input type="checkbox"/> The project helps all students develop and apply skills in writing, reading, or mathematics. <p>Comments:</p>

PROJECT-BASED LEARNING OBSERVATION RECORD

Teacher _____

Date/Time _____

Subject area _____

School _____

PBL Title _____

PBL Description _____

To what extent was the following present? Please mark the box that best displays your response on a scale of 5 to 1. **5= to a great extent, 1 = no evidence.**

(5) (4) (3) (2) (1)

Justification* _____

I. PBL Structure

1. The PBL has a well-defined outcome.

(5) (4) (3) (2) (1)

Justification* _____

2. The PBL contains rigorous subject area content, which as a consequence leads to higher-order thinking.

(5) (4) (3) (2) (1)

Justification* _____

3. The PBL lends itself to multiple, creative and unique tasks in which students can demonstrate a continuum of knowledge and understanding.

(5) (4) (3) (2) (1)

Justification* _____

4. The PBL covers subject/grade level TEKS.

(5) (4) (3) (2) (1)

Justification* _____

5. The PBL is not a stand-alone lesson.

(5) (4) (3) (2) (1)

Justification* _____

6. The PBL is interdisciplinary.

(5) (4) (3) (2) (1)

Justification* _____

7. The PBL contains high functioning activities that require students work in organize groups.

(5) (4) (3) (2) (1)

Justification* _____

APPENDIX T

II. PBL Facilitation

8. The teacher clearly stated goals and tasks.

- (5) (4) (3) (2) (1)

Justification* _____

9. The teacher facilitated the students to remain on-task.

- (5) (4) (3) (2) (1)

Justification* _____

10. The teacher asked effective open-ended questions.

- (5) (4) (3) (2) (1)

Justification* _____

11. The teacher worked with members of all small groups.

- (5) (4) (3) (2) (1)

Justification* _____

12. The teacher achieved objectives he/she identified.

- (5) (4) (3) (2) (1)

Justification* _____

III. Student Participation

13. The students were actively engaged.

- (5) (4) (3) (2) (1)

Justification* _____

14. The students could explain tasks and solution strategies.

- (5) (4) (3) (2) (1)

Justification* _____

15. The students could explain the goal(s).

- (5) (4) (3) (2) (1)

Justification* _____

IV. Resources

16. The appropriate resources are ready and available for student use.

- (5) (4) (3) (2) (1)

Justification* _____

17. The students were proficient in using the resources (i.e. calculators, test books, computers).

- (5) (4) (3) (2) (1)

Justification* _____

V. Assessment

18. The assessment(s) was/were continuous and varied.

- (5) (4) (3) (2) (1)

Justification* _____

19. The evidence of holistic assessments existed (e.g. rubrics for participation/engagement, early stages of the PBL, or group work).

- (5) (4) (3) (2) (1)

Justification* _____

20. The students understood how the rubric would be used as an assessment.

- (5) (4) (3) (2) (1)

Justification* _____

VI. Classroom Learning Environment.

21. The teacher identified and engaged students around their prior knowledge.

- (5) (4) (3) (2) (1)

Justification* _____

22. The teacher identified and engaged the students around their cultural diverse contexts.

- (5) (4) (3) (2) (1)

Justification* _____

Other comments or observations

Observer _____

Date _____

PROJECT DEVELOPMENT RUBRIC

CRITERIA	PROFICIENT		ADVANCED in Addition to Proficient
	UNSATISFACTORY	GOALS	
Goals	<input type="checkbox"/> Goals of the project do not seem to be tied to any specific content area standards or are not rigorous enough to challenge the students <input type="checkbox"/> Goals of the project seem to address only the lowest levels of critical thinking skills.	<input type="checkbox"/> The goals of the project are tied to specific content area standards and 21 st Century Skills <input type="checkbox"/> Goals are rigorous enough to challenge all students. <input type="checkbox"/> Goals of the project require the students to use high-order critical thinking skills.	<input type="checkbox"/> Goals of the project are clearly defined and successfully integrate content standards from multiple subject areas
Engagement	<input type="checkbox"/> Engagement seems unlikely to engage the student's curiosity. <input type="checkbox"/> Precipitating event fails to create a realistic role or project for the students <input type="checkbox"/> Task seems unclear but leads to a content-based "need to knows" or next steps. <input type="checkbox"/> Engagement fails to establish a timeline	<input type="checkbox"/> Engagement seems likely to engage the student's curiosity in a realistic scenario <input type="checkbox"/> Engagement establishes a clear role and tasks. <input type="checkbox"/> Engagement leads to a list of content-based "need to knows" and next steps <input type="checkbox"/> Engagement establishes a clear timeline and assessment criteria	<input type="checkbox"/> Engagement engages the students in a real world problem that they can help solve <input type="checkbox"/> Entry document creates a thorough list of relevant, content specific "need to knows" <input type="checkbox"/> Project is launched with the help of outside person or entity
Planning	<input type="checkbox"/> The project plan may be a good idea, but little thought has been put into how to implement the idea in the classroom <input type="checkbox"/> No thought has been put into the resources and materials required for this project	<input type="checkbox"/> The project plan has a general outline including the various phases and student activities <input type="checkbox"/> Some thought has been put into resources and materials that are required for this project <input type="checkbox"/> The project has a list of student products	<input type="checkbox"/> The plan includes a ... <input type="checkbox"/> Detailed description of various phases with progress checks and benchmarks <input type="checkbox"/> Complete list of resources and materials <input type="checkbox"/> Well thought out plan for implementation <input type="checkbox"/> Description of student products and how they will be evaluated against the project goals
Scaffolding	<input type="checkbox"/> The project lacks activities to help students work as an effective team on a long term project <input type="checkbox"/> Reflect on their "need to knows" and to develop next steps <input type="checkbox"/> Understand the content and make use of the resources available (including any necessary remediation that might be needed)	<input type="checkbox"/> The project has appropriate activities to help students work as an effective team on a long term project (time management, collaboration, etc) <input type="checkbox"/> Reflect on their "need to knows" and to develop next steps <input type="checkbox"/> Understand the content and make use of the resources available (including any necessary remediation that might be needed)	<input type="checkbox"/> The project has differentiated activities for individual students and groups <input type="checkbox"/> Work as an effective team on a long term project <input type="checkbox"/> Reflect on their "need to knows" and to develop next steps <input type="checkbox"/> Understand the content and use resources available (including any remediation necessary)
Assessment	<input type="checkbox"/> Rubrics are not developed, do not seem tied to the goals of the project, or are unusable by students <input type="checkbox"/> Evaluation does not include use of school-wide rubrics	<input type="checkbox"/> Rubric are designed to clearly lay out final product expectations as defined by project goals <input type="checkbox"/> Evaluation includes the use of school-wide rubrics <input type="checkbox"/> Rubrics are easy for students to use in self- and peer-assessment activities.	<input type="checkbox"/> Several rubrics are used to evaluate multiple individual and group products based on the stated content and goals of the project. <input type="checkbox"/> Assessment includes input from outside sources
End Product	<input type="checkbox"/> End product does not demonstrate understanding and application of content standards <input type="checkbox"/> End product is not authentic <input type="checkbox"/> End product is not age level appropriate	<input type="checkbox"/> End product clearly demonstrates understanding and application of content standards <input type="checkbox"/> End product is authentic and reflects real world work <input type="checkbox"/> End product is tailored to student skill level	<input type="checkbox"/> End product contains multiple opportunities to demonstrate learning (multiple products) <input type="checkbox"/> End product could be used externally <input type="checkbox"/> End product incorporates a variety of media

COMMENTS:

WHO KILLED BOB KRUSTY? A DYNAMIC PROBLEM-SOLVING EVENT

Contributed by Christopher Romero, Mathematics Teacher, Houston, Texas

At 3:15 a.m. on a night in 2006. Ms. Fine, a maid who worked in the home of multimillionaire Bob Krusty was awoken by the sound of a loud thud outside her window. She got out of bed to discover that her employer had apparently “fallen” from one of his mansion’s three balconies; Bob Krusty was dead. There were balconies located on the 2nd, 3rd, and 4th floors of his mansion. Police arrived at 3:25 a.m. and immediately noticed that Mr. Krusty was more than 10 feet horizontally away from the end of the balconies. He had obviously been pushed and murdered.

Immediately, the police sequestered those who were in the house that night; all were suspects in the murder. Police contacted Mr. Krusty’s secretary, who was not at the house that evening, and obtained his schedule from the day before. Mr. Krusty had had a dinner party the evening before. He had invited his former business partner and his wife, Mr. and Ms. Smith. The smiths arrived at 2 p.m. and spent the hour between 3:30 and 4:30 alone with Mr. Krusty in a closed meeting over tea. Mr. and Mrs. Jefferson, Mr. Krusty’s old friends, had arrived late to the dinner and for about an hour met with him privately over coffee when dinner ended at 7:45.

As the CSI team arrived, the police began to interview the maid, Ms. Fine. She told them that indeed Mr. Krusty hosted a dinner party that night. She had even prepared Mr. Krusty’s favorite dessert, rhubarb pie. In addition to the Smiths and the Jeffersons, Ms. Fine indicated that Mr. Krusty’s son John had attended the dinner. John had arrived that morning. Mr. Krusty had brandy with his son from 10:30 to 11:30 p.m. and had read alone in his study between the meetings with his son and the Jeffersons.

According to Ms. Fine, Mr. Krusty’s evening had not been very eventful. She had last seen him alive at 11:45 p.m. when she brought him his medication with a glass of water. At that time he was alone and going to sleep. She also noted that Mr. Krusty had elected to sleep with the doors to his 4th floor balcony open despite the cool evening temperature of 62° Fahrenheit. Additionally, she indicated that the two couples slept that evening in the guest bedrooms on the 2nd floor. John slept on a cot in his father’s 3rd floor office and she slept in the maid’s quarters on the 1st floor.

Following Ms. Fine’s interview, the CSI team told the detectives that it was definitely a murder; there were no bloodstains on the sidewalk where Mr. Krusty had landed. Given his injuries, they determined that he had hit the ground with a velocity of between 45 and 50 feet per second. (Assume that Mr. Krusty’s fall can be modeled with the function: $d = -16t^2$ where d represents vertical distance and t represents time.) After sealing off the house and sending Mr. Krusty to the morgue for further tests, the CSI crew left the mansion around 6:30 a.m. but left uniformed officers to monitor the guests until the detectives could return at 11:00 a.m. to question the suspects.

At 10:00 a.m. the investigators returned and told the suspects that toxicology results had left them puzzled. The medical examiner had estimated the victim’s core body temperature at 83.3° Fahrenheit at 4:00 a.m. and 45.2° Fahrenheit when they loaded him into the hearse at 6:15 a.m. Body temperature at death can be modeled with the following integral equation

$$\int_a^b \frac{dT}{(T-62)} = \int_0^t -k_B dt$$

where T is the cooled body temperature after t hours and k_B is a constant dependent on the victim’s body weight and surface area. You may assume that the victim’s body temperature at the time of death was 98.6°.

The toxicology report indicated that 705 milligrams of some poison were present in Mr. Krusty’s system and had been ingested sometime in the past 24 hours. (Hint: A person dies after absorbing the fatal dose of a poison and the amount of poison present at the time of death remains constant.) The rate at which a poison is absorbed by the body may be modeled with the equation

$$\frac{dy(t)}{dt} = k_p y(t)$$

APPENDIX V

where $y(t)$ is the amount of poison remaining in the body t hours after the poison was administered. You should assume that $y(0) = 705$. $K_{\text{sub-}p}$ is the constant that is characteristic for a given poison, which may be any of the following:

3. Poison	4. $K_{\text{sub-}p}$	5. Fatal Dose (mg)
Acrylamide	-0.29500	1275
Aniline	-0.95200	2025
Arsenic	-0.09200	215
Cyanide	-2.42300	50
Methanol	-1.16700	790
Phenol	-0.00004	15
Strychnine	-0.07400	105

PBL REFRESHER

Quick Quiz – PROJECT-BASED LEARNING

In general, PBL is the creation of complex settings and environments where students develop important skill sets and apply prior knowledge in the creation of new flexible knowledge. The problem-solving approach is incredibly important to the PBL environment where mathematics, science, and engineering are key components.

1. Data collection is important.
True False
2. Numerical accuracy is an essential skill for a successful final product.
True False
3. Statistics is not important for making use of PBL.
True False
4. Ethics and education in ethics are NOT key components of Project-Based Learning.
True False
5. Peer assessment is an important and essential aspect of PBL.
True False

ASPECTS OF PBL

Please check all that apply to the key aspects of a well-developed PBL. If you do not place a check in the box, cross out or write in the word or phrase that would allow you to place a check in the box.

Structure of PBL

- Problem solving is stressed.
- Projects should be irrelevant to students but closely address learning objectives
- Teaching should be innovative with active learning.
- Learning objectives have no place in the design of PBL.
- Rigorous mathematics and science are integrated.
- Students work in groups.
- Team building is a secondary skill that should be addressed if everything else is working well.
- Exclusion from participation is a first line of behavior management.
- One group member selected at random presents the group's project.

Planning PBL

- ONLY one project per semester will result in the learning outcomes I expect, and the district will be satisfied.
- All the interpersonal, behavioral, and metacognitive skills students will need should be present before I try a PBL, or they should have them all when they finish the first PBL.
- Projects are set well in advance, and all the teachers and administrators are stakeholders in making this a success.
- Training is not important to planning and conducting meaningful PBL.
- Administrators have a very important role in successful PBL, but they only need to give permission and provide supplies and have no other role.
- Teachers should develop a set of common resources used for the PBL.
- On-going collaborative meetings across and among all teachers involved are necessary for a PBL success.

Assessment in PBL

- Group work but individual accountability.
- Individual accountability for all summative assessments.
- On-going peer review only works when the teacher is completely in charge.
- Peer assessment.

APPENDIX W

- The use of culminating events like developing a marketing plan, conducting a trial, or developing a persuasive exposé can be used to explain, justify, or sell the PBL to investors, argue evidence, or prepare a news article are important to integration of writing and expressing ideas logically.
- Summative PBL reporting should be **only** in writing or **only** orally but **NEVER** both.

Student/Group Responsibility

- Students should develop a design notebook that details what they did and how their work crosses curriculum boundaries.
- Group members need to learn to engage in conflict.
- Conflict resolution is idiosyncratic and does not need to be taught or modeled.
- Individuals are responsible for their behaviors.

Benefits of Teams and Team Building for PBL

- Improved attendance
- More confusion for parents
- Improved engagement for teachers
- More community concerns

TEACHER PROJECT-BASED LEARNING CHECKLIST

Yes	No	PBL Headings			
<input type="checkbox"/>	<input type="checkbox"/>	1) Project Title:			
<input type="checkbox"/>	<input type="checkbox"/>	2) Teacher Names:			
<input type="checkbox"/>	<input type="checkbox"/>	3) Grade Level:			
<input type="checkbox"/>	<input type="checkbox"/>	4) PBL Dates:			
<input type="checkbox"/>	<input type="checkbox"/>	5) Teacher Introduction:			
<input type="checkbox"/>	<input type="checkbox"/>	6) Objectives: <i>Selected from TEKS</i>	<i>Does this section include...</i>	Yes	No
			Rigor	<input type="checkbox"/>	<input type="checkbox"/>
		7) Connections: <i>How does this PBL connect to other units in your subject?</i>	<i>Does this section include...</i>	Yes	No
<input type="checkbox"/>	<input type="checkbox"/>	8) Introduction: <i>An introductory paragraph to the PBL written for the students</i>	<i>Does this section include...</i>	Yes	No
<input type="checkbox"/>	<input type="checkbox"/>	9) Well-defined Outcome: <i>Students will investigate a situation modeled by a square root function, write an equation for the situation, and find solutions for problems in the situation</i>	Rigor	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	10) Materials used: Name tags for job responsibilities, meter sticks, books, transparent tape, graphing calculators, marbles, stopwatch, highlighters, graph paper, markers.			
		11) Engagement: http://www.youtube.com/watch?NR=1&feature=endscreen&v=Xlaovi1JWY	<i>Does your plan address...</i>	Yes	No
		<i>Grouping</i> <input type="checkbox"/> Large <input type="checkbox"/> Small	<i>Questioning (Indicate the number)</i> <input type="checkbox"/> Open-ended... <input type="checkbox"/> Probing... <input type="checkbox"/> Guiding...		
		12) Exploration: <i>Explain the conditions of the free exploration and the real PBL experience; talk about the constraints, limitations (budget, time), and introduce the formative assessment rubric.</i>	<i>Does your plan address</i>	Yes	No

APPENDIX X

		6. Communication and Metacognition	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/> <input checked="" type="checkbox"/>	13) Explanation: <i>Explain the subject matter knowledge (theory behind), and the other issues you'd like to make them clear.</i>	Does your plan address	Yes	No
		1. Problem Identification	<input type="checkbox"/>	<input checked="" type="checkbox"/>
		2. Research	<input type="checkbox"/>	<input checked="" type="checkbox"/>
		3. Ideation	<input type="checkbox"/>	<input checked="" type="checkbox"/>
		4. Analysis of Ideas	<input type="checkbox"/>	<input checked="" type="checkbox"/>
		5. Testing and Refinement	<input type="checkbox"/>	<input checked="" type="checkbox"/>
		6. Communication and Metacognition	<input type="checkbox"/>	<input checked="" type="checkbox"/>
14) Extension: <i>How can you extend this PBL for the students who are more able and/or for those who have finished before the others?</i>				
15) Evaluation: <i>Includes the formative and summative rubric, as well as Good Questions (Multiple Choice).</i>				
16) References (websites); Guest Speaker information; Ordering information:				

STANDARDS BASED PROJECTS

PROJECT CRITERIA	EVIDENCE
The project is focused on questions that engage students in the central concepts and principles of a discipline.	<ul style="list-style-type: none"> <input type="checkbox"/> Project is centered on curriculum and aligned with national, state, or district standards. <input type="checkbox"/> Project demands depth and breadth of understanding of central concepts and “Big Ideas”. <input type="checkbox"/> Project is organized around an open-ended driving question, problem, or question that inspires higher-level thinking.
The project involves students in investigation of authentic issues.	<ul style="list-style-type: none"> <input type="checkbox"/> The driving question or problem has meaning to students and may be generated by them. <input type="checkbox"/> The questions or problems are like those faced by people in the world outside of school. <input type="checkbox"/> Students are required to do extensive exploration and research, including field-based activities. <input type="checkbox"/> Students are required to have contact with adults outside of the classroom teacher or have the opportunity to work with adults in the community or online. <input type="checkbox"/> Students are encouraged to direct their own inquiry process and investigate their own questions.
The project incorporates the use of authentic tools, including technology.	<ul style="list-style-type: none"> <input type="checkbox"/> Students develop and use habits of mind (e.g. concern for evidence, viewpoint, cause and effect; precision of thought and language; persistence). <input type="checkbox"/> Project work provides opportunities to develop workplace competencies (e.g. work in teams, use technology appropriately, communicate ideas, collect, organize and analyze information). <input type="checkbox"/> Students work in groups and use formal self-management skills (e.g. develop a workplan, prioritize pieces of work, set deadlines). <input type="checkbox"/> Students and teachers are involved in a wide range of communication patterns, roles, and activities. <input type="checkbox"/> Technology is used to extend and enrich learning. Students have opportunities to use computers and other technologies as tools for creating, analyzing, and presenting new knowledge.

APPENDIX Y

<p>The project requires products that solve problems, explain dilemmas, or present information</p>	<ul style="list-style-type: none"> <input type="checkbox"/> Knowledge and skills are applied to solving a complex problem <input type="checkbox"/> Information comes from a variety of sources, many of which are discovered by the student (e.g. readings, interviews, observations, libraries, websites, etc.). <input type="checkbox"/> Final product(s) and performances show that all students have the opportunity to understand the subject matter in depth, acquire new skills, and demonstrate their knowledge.
<p>The project uses performance-based assessments that describe high expectations and rigorous challenges</p>	<ul style="list-style-type: none"> <input type="checkbox"/> Criteria and standards by which student work will be judged are clearly explained to students, who may also help establish the criteria. <input type="checkbox"/> Students are taught how to self-assess and are required to use structured methods such as journals, conferences, rubrics, reviews of progress, etc. <input type="checkbox"/> Students receive timely feedback on their work in progress. <input type="checkbox"/> Products and performances are closely aligned to standards and are rich and varied enough to make credible judgments about their learning. <input type="checkbox"/> Students complete a culminating exhibition, presentation, or product that demonstrates their knowledge and skill, and their ability to apply it. <input type="checkbox"/> Student work is reviewed by a “real” audience. <input type="checkbox"/> Students understand what is required of them, and are given exemplars (models of high quality work) and tools (rubrics, checklists) for monitoring their own performance. <input type="checkbox"/> The project helps all students develop and apply skills in writing, reading, or mathematics.

RUBRIC FOR WELL-DEFINED OUTCOME AND ILL-DEFINED TASK (WDO-IDT)

1. Describe the ***learning*** students will own when they are finished (focus on the verb).
 - a. Write the verb here _____
2. List the ***constraints***-or limitations that keep the project within boundaries. Remember to consider costs, allocated time, safety, availability, and student readiness. Add more space if necessary but feel free to use less as long as the constraints are clear and complete for the target population.
 - a.
 - b.
 - c.
 - d.
 - e.
 - f.
 - g.
 - h.
3. Describe the ***deliverable*** – what you want students to build or create at the end. It is important to recognize the requisite knowledge necessary to complete the task being sure that it has already been taught. For example, asking kids to make a spreadsheet if they have not already learned to use a spreadsheet application would not be productive or a wise use of time. Add more space if necessary but feel free to use less as long as the deliverables are clear and complete for the target population.
 - a.
 - b.
 - c.
 - d.
 - e.
 - f.
 - g.

The ill-defined task <i>IS</i> or is <i>NOT</i>		
Indicator	YES	NO
4 There is sufficient content that requires teaching	<input type="checkbox"/>	<input type="checkbox"/>
5 Students who read it understand exactly what they have to create	<input type="checkbox"/>	<input type="checkbox"/>
6 There is ample information for in depth planning and lesson preparation	<input type="checkbox"/>	<input type="checkbox"/>
7 The teaching role is clear	<input type="checkbox"/>	<input type="checkbox"/>
8 The well WDO-IDT is much longer than an objective	<input type="checkbox"/>	<input type="checkbox"/>
9 The structure is clear and transparent	<input type="checkbox"/>	<input type="checkbox"/>
10 The teaching materials to meet all the goals are evident	<input type="checkbox"/>	<input type="checkbox"/>
11 There is enough information to develop the rest of the plan	<input type="checkbox"/>	<input type="checkbox"/>
12 Is integrally linked to both summative and formative assessment.	<input type="checkbox"/>	<input type="checkbox"/>

APPENDIX Z

13	There is a story that builds interest and sets the stage	<input type="checkbox"/>	<input checked="" type="checkbox"/>
14	State level objectives are explicitly stated	<input type="checkbox"/>	<input checked="" type="checkbox"/>
15	The verb is not important	<input type="checkbox"/>	<input checked="" type="checkbox"/>
16	The final product is clearly described	<input type="checkbox"/>	<input checked="" type="checkbox"/>
17	The vocabulary is in teacher or expert language	<input type="checkbox"/>	<input checked="" type="checkbox"/>
18	Content specific vocabulary is appropriate for student learning	<input type="checkbox"/>	<input checked="" type="checkbox"/>
19	<u>The final product is clearly described in student language</u>	<input type="checkbox"/>	<input checked="" type="checkbox"/>