EFFECTS OF PROBLEM BASED LEARNING ON DEVELOPMENT OF CRITICAL THINKING SKILLS AND DISPOSITIONS IN ENGINEERING

By

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To my family

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LIST OF ABBREVIATIONS

ABET	Accreditation Board of Engineering and Technology
AGCEER	Advancing the Global Capacity for Engineering Education Research
ASCE BOK	American Society of Civil Engineers Body of Knowledge
ASCE	American Society of Civil Engineers
ASEE	American Society for Engineering Education
CAEE	Center for the Advancement for Engineering Education
CCTDI	California Critical Thinking Disposition Inventory
CCTST	California Critical Thinking Skills Test
ECPD	Engineering Council of Professional Development
EEC	Engineering Education Coalition
EECP	Engineering Education Coalition Program
EJEE	European Journal of Engineering Education
JEE	Journal of Engineering Education
NRC	National Research Council
NSB	National Science Board
NSF	National Science Foundation
PBL	Problem Based Learning
SPEE	Society for the Promotion of Engineering Education

Abstract of Dissertation Presented to the Graduate School
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Researchers have promoted the importance of education institutes providing learning environments in which critical thinking skills and dispositions can be fostered. Active learning environments are known to support the production of graduates who are better at critical and creative thinking. This empirical study examined the effect of Problem Based Learning (PBL), one of highly praised active learning methods, on development of critical thinking skills, disposition, and content knowledge acquisition in a civil engineering undergraduate class. The pre-test post-test control group experimental design implemented for four weeks. The correlation between learning styles and critical thinking dispositions, and student perception of own critical thinking and actual critical thinking ability were determined, as well as effects of demographic differences. Statistical analysis of data illustrated no significant difference between the means of control group and treatment group in terms of critical thinking skills, critical thinking dispositions, and knowledge acquisition; however in class observations indicated increased student motivation in treatment group.

CHAPTER 1
INTRODUCTION

Statement of Research Problem

As Heraclitus stated, “nothing endures but change”. In the recent past, our world has been changing at an incredible rate. To stay competitive and survive in this environment, corporations and educational institutions have to accommodate to the changes. Unfortunately, engineering education has not adapted to these changes such as changes in technology, changes with globalization for the last 30 years (Galloway, 2007a). Although the 1,740 undergraduate engineering programs in the United States vary in their emphases, they are remarkably consistent with their goal: acquisition of technical knowledge (Sheppard, Macatangay, Colby, & Sullivan, 2008). According to Sheppard et al. (2008) undergraduate engineering education programs also share a remarkably homogenous curriculum and pedagogy. It is discovered from readings of Accreditation Board for Engineering and Technology (ABET) reports, interviews with faculty, administrators, and students, classroom observations; and readings of the history of engineering and engineering education that teaching is generally linear.

In the Preparation for Professional Series reports, (Sheppard et al., 2008) explored three important questions: 1) Is academic understanding of what engineers must know and be able to do in parallel to the requirements of professional practice? 2) Does the design and delivery engineering curriculum meet the requirements of new world? 3) If not, what changes are necessary to meet needs of contemporary engineering? Through their observations Sheppard et al. found that undergraduate engineering education in the U.S. emphasizes the acquisition of technical knowledge followed distantly by the preparation for professional practice. Laboratory portions of courses are understood as applications that follow the learning theory instead of vehicles for creative discovery. Teaching only technical knowledge is not enough to meet the needs of the new world market place. Students should be also taught professional skills and critical thinking. In the past, the skills that engineers acquired would often serve them well for decades. However, in the 21st century the success of an individual or a company is measured against how well they can adapt to changing situations which demands different kind of skill sets (Splitt, 2003). The traditional engineering education offered at most U.S. universities provides a good foundation in the technical aspects of engineering; yet, it is unsatisfactory in promoting competence, ethics, and professionalism. Galloway (2007) identified the following areas as receiving little or no attention in many engineering curricula: Sustainable development and the environment, working in teams, critical and creative thinking, approach to quality, customer needs are some of the critical emergent areas that seem to receive little or no attention in many engineering curricula. Unsurprisingly, by early 1990s, numerous reports emerged emphasizing the deficiencies in engineering education and calling for major reforms (Shuman, Besterfield-sacre, & Mcgourty, 2005) and these reports resulted in questioning the efficacy of the accepted teaching practices (Johri & Olds, 2011).

Research Motivation

The role of the construction industry in socioeconomic development, quality of life, and environment is well-known. Thus, it is imperative that successful completion of construction projects is a priority to multiple parties. The increased complexity of construction projects leads to innovations in technology, sophistication in construction equipment and software, and higher demand for well-educated and well trained construction managers (Arditi & Polat, 2010). The engineering profession faces the challenge of preparing practitioners as facilitators of sustainable development, appropriate technology, and social and economic changes. Being able to meet this challenge may provide a chance for U.S. to regain its leadership role in 21st century which seems to be diminishing (Amadei & Sandekian, 2010).

In Educating the Engineer of 2020, the National Academy of Engineering (NAE) reported that today there is a need for further change in engineering education because of the change in required knowledge and change in professional environment (NAE, 2005). This change must be encouraged and facilitated by change in engineering education(Atman et al., 2010; Duderstadt, 2007). Engineering education should be shaped in a way that promotes critical thinking to develop higher level thinking skills and deep understanding; and using active learning methods are found to be best at fostering critical thinking (Felder, Brent, & Prince, 2011; Smith, Sheppard, Johnson, & Johnson, 2005; Şendağ & Odabaşı, 2009).

Research Objectives

The objectives of the proposed research are:

1. Through extensive literature review:
    - Formulate 21st century expectations of engineers.
    - Identify the importance of critical thinking and problem based learning (PBL) in higher education.
2. Develop an ill-structured problem to implement in a PBL classroom environment with the intention of promoting critical thinking skills and dispositions in a civil engineering undergraduate class in University of Florida.
3. Use the California Critical Thinking Skills Test (CCTST) to assess changes in students' skills and use the California Critical Thinking Disposition Inventory (CCTDI) to assess changes in students' dispositions after being exposed to the course through pre-and post-test experimental control group design.

4. Design a survey to determine students' self belief of own critical thinking.

5. Use course test results to measure the change in students' content knowledge acquisition.

6. Determine students' learning styles; and relationship between critical thinking dispositions and active learners and passive learners.

Purpose of the Study

The main purpose of this study is to examine the effects of problem based learning (PBL) active teaching method on development of critical thinking skills and dispositions. Also correlation of variables that are stated under research objectives will be determined.

Research Questions and Hypotheses

The following questions directed the study:

Research question 1: What is the effect of PBL on critical thinking skills and dispositions in undergraduate civil engineering majors?

- Null hypothesis 1: There is no difference between the pre and post testing scores on the CCTST.
- Null hypothesis 2: There is no difference between the pre and post testing scores on the CCTDI.
- Null hypothesis 3: Critical thinking skills will increase regardless of teaching method.
- Null hypothesis 4: Critical thinking disposition will increase regardless of teaching method.

Research question 2: Does learning styles play a role in critical thinking skills and disposition?

- Null hypothesis 1: There will not be any relationship between learning methods and CCTDI.

Research question 3: Is there any difference in content knowledge acquisition between traditional teaching method and PBL?

- Null hypothesis 1: Content knowledge acquisition will be equal both methods.

Research question 4: Is there any difference between students' perception of their critical thinking and their actual critical thinking?

- Null hypothesis 1: There will not be any difference between students' perception of own critical thinking skills and their actual ability.

Significance of the Study

Although the importance of active learning methods and critical thinking skills and dispositions has been recognized in the general education community; in the engineering community empirical data related to these subjects are limited. Lack of creative and critical thinking of engineering graduates has been emphasized many times on numerous reports and scholarly articles (Atman et al., 2010; Duderstadt, 2007; Phase, 2005; Prevatt, 2011; Sheppard et al., 2008). The goal of this study is to demonstrate methods to improve critical thinking process and create situations for students to apply these methods. To reach this goal, the researcher challenges students with ill-defined, "out of the ordinary" problems followed by constructive questions with the intention of leading the students toward being more engaged in the learning process.

The results of this study will contribute to the field of engineering education by demonstrating an empirical study and by providing quantitative data analysis as a result of implementation of PBL. The potential implication of this study is to help civil engineering educators to better nurture students' critical thinking skills and provide a simple in class implementation of PBL.

Summary of the Study

In this study, the researcher discusses the motivation for the proposed research, describes previous experiments contributing to the current state-of-knowledge of engineering education, reviews the research objectives, reviews literature thoroughly for chosen concepts, explains the research methodologies and approaches to analyses methods. Finally she discusses the result of the study along with limitations and assumptions.

CHAPTER 2
LITERATURE REVIEW

In the early century, education system focused on equipping students with "literacy skills: reading, writing, and arithmetic calculating". The higher education system was not responsible of educating students to read and write critically, solve complex and challenging problems, or express themselves articulately, clearly and persuasively. On the other hand, aforementioned qualities are necessities for graduates to adapt to and be successful in business environments full of challenges (Brasnford, Brown, & Cocking, 2000; Cheah, Chen, & Ting, 2005; Duderstadt, 2007; Lang, Cruse, McVey, & McMasters, 1999).

This chapter review of engineering education history from 1747 to 2006 to underline the major historical events that brought to engineering education to its current stage. A discussion on how the position of engineering education changes throughout history is preceded by a list of skill sets that are demanded by modern society. This chapter also includes a review of the effectiveness of active teaching methods in engineering-specifically problem based learning. Definition of critical thinking, its brief history and relevance to Bloom's Taxonomy is discussed as well as valid ways to measure it.

History of Engineering Education

The Ecole Nationale de Ponts et Chaussées is considered to be the first formal engineering school in the world opened its doors in 1747 found by Jean Rodolphe Perronet, chief engineer of bridges and highways, referred as a father of engineering education. This school later became the Ecole Polytnecnique which served as a model for several early engineering education schools in the U.S. (Grayson, 1980). The U.S.

engineering curricula originally was derived from French model (Grayson, 1980),and consisted of a curriculum of basic sciences, technical subjects and humanities, with theory taught before application (Sheppard et al., 2008). Almost from the beginning engineering education was taught by educators rather than practitioners (Grayson, 1980).

After the declaration of independence, and The No Importation agreement of 1774 (Grayson, 1980), the need for trained engineers to meet with the demands of development was clear. In 1802, U.S. Congress established the United States Military Academy at West Point in New York (West Point, n.d.). Although academic degrees were not granted until 1933, West Point is considered to be the first engineering school in U.S. The program developed for the institution was largely influenced by the Ecole Polytechnique. The civil engineering curriculum consisted of the design and construction of bridges, roads, canals, and railroads (Grayson, 1980).

By 1862, there were a dozen engineering schools in the U.S. At that point, education growth was steady with clear lines of its development. When the need emerged to construct a transcontinental railroad from Nebraska to California, many engineering obstacles had to be overcome such as desert wastes, wooded plateaus, and steep mountains. The need of such a construction changed the course of engineering education. The self-taught on the job engineers were not adequate for the job, and the need for engineering education schools emerged (Grayson, 1980). In 1862, the Morrill Land Grant Act passed, which provided federal money for states to establish institutions of higher education (Schexnayder & Anderson, 2011).

In 1870, engineers rather than scientists were involved in education. The U.S. curricula began to diversify to meet the needs of engineering talent; however, lecturing in engineering became widespread. This was accomplished through textbooks and articles in the journals of newly forming technical societies (Lang et al., 1999).

By 1885, practical shop work attained its maximum position in engineering curricula. American engineering education turned away from the European models and started to search for materials in its own country. At this time engineering began to diversify into its main branches, and universities started to grant degrees in branches such as civil engineering and mechanical engineering. National engineering societies were established shortly after their respective curricula. The growing relationship between the profession and the school of engineering showed that profession has not assumed a leadership and responsibility for professional education which consequently widened the gap between education and profession (Grayson, 1980). The American Society of Civil Engineers (ASCE) was the first professional organization established in 1852 (“ASCE in Brief,” n.d.). In the late 19th century, U.S. education achieved a major step in its evolution. The number of colleges and the students increased; thus, the purpose of education was on the change. There was a huge emphasis on practical use of engineering and many new fields of engineering became worthy enough to be included in the curricula. Engineering education was accepted as a distinct field of higher education in 1893 in Chicago World’s Fair, known as the World’s Columbian Exposition. This was the first notable meeting of engineering in which engineering education was recognized as legitimate branch of engineering. The conference promoted the creation of the Society for the Promotion of Engineering Education

(SPEE) ("ASEE", n.d.). Hence, engineering became a first profession where a society devoted solely to education for the profession. Number of members, however, was considerably lower than other engineering societies and included people from higher education more than from profession.

One of the important developments of the late 19th century is the beginning of engineering education in the West Coast: The introduction of part time education and cooperative education, and the passage of the first law to license engineers for practice (Grayson, 1980). States began to license engineers to practice their profession especially in disciplines with direct effect to the safety and health of public.

The pressure to produce graduates who would enter the industry immediately, a condition of the Morrill Act, left no time for engineering education to examine its structure or ensure its relevance to needs of the profession (Schexnayder & Anderson, 2011). With the support of Carnegie Foundation, the first comprehensive study report of engineering education was issued in 1918. Authors suggested returning to fundamentals and moving towards the unification of engineering curricula. The need for the development of students' intellectual capabilities and discipline in habits of work and study was emphasized.

America's involvement in the second world war changed the direction of engineering education by revealing weaknesses (Seely, 1999). Engineers took administrative roles in the war causing engineering education to skew toward the administrative and economic sides of engineering. To address the immediate need during the war, short, intensive college level courses were created with the intention of training students for specific industrial jobs. For the purpose of preparing engineers with technical, administrative, and executive responsibilities, schools developed curricula that could be used in a wide range of occupations. As a result, most of the schools did not prepare engineers for professional practice unlike medicine and law (Grayson, 1980). By June 1945, 227 colleges participated in Engineering, Science and Management War Program (Grayson, 1980). This program made people realize the need for education for economic betterment. Therefore, the increase in the number of college students during war times never went down to its previous state. The war demand for advancement in science and technology, also, caused schools to involve in graduate education and research more seriously. Undergraduate curriculum was revised to prepare some of its students for immediate need, and others for graduate studies (Grayson, 1980).

The second major evaluation of engineering education was conducted by the professionals from 1923 to 1929. Under the sponsorship of Society for the Promotion of Engineering Education (SPEE), the most comprehensive study on engineering education conducted to date was produced. The committee headed by W.E. Wickenden examined every aspect of engineering education in the U.S., including its historical development, its comparison to engineering education in Europe, curricula, faculty preparation, relationships with industry, opinions of past graduates, and other aspects. The report had a tremendous effect on engineering education. One of these effects was giving an authority to the engineers’ joint council to accredit engineering curricula for professional development. Seven engineering societies found the Accreditation Board for Engineering and Technology (ABET) in 1932 as the Engineers’ Council of

Professional Development (ECPD) which was renamed as ABET in 1980 ("ABET - History," n.d.).

After 1932, the evaluation of engineering continued and the SPEE Committee issued another report named 'Aims and Scope of Engineering Curricula' (1940) and found that the curricula were surprisingly similar in different universities. The committee pointed out that to furnish students with the wide variation of technical, administrative, and executive responsibilities, curricula variation was necessary. In 1946, the SPEE changed its name to the American Society for Engineering Education (ASEE) (Grayson, 1980).

As Jeseik (2009) stated, "In the 1980s, worries about global competitiveness and the decline of Cold War stimulated new discussions about the state of engineering education in the U.S." In the 1980s Engineering Education in the U.S. began with an intention to 'promote the application of science to the common purposes of life' (Grayson, 1980).

By 1986, the National Science Foundation (NSF) issued a report called "Neal Report" which expressed concerns about economic and technological competitiveness (Jeseik, 2009). The authors also proposed increasing the quantity of the graduates as well as improving the quality of their education (Jesiek, 2009). They asked the academic community to use scholarship to improve the science and engineering education and put the NSF in charge to lead the reform. This move helped to stimulate support for NSF's division of undergraduate education. In 1990 NSF also launched an Engineering Education Coalition (EEC) program to promote comprehensive reports on undergraduate education. In the early 1990s, the quality of engineering education drew more attention as the demand for engineers (Jesiek, 2009). In 2000s two National Research council (NRC) reports called for rigorous education research across disciplines as well as adopting research based knowledge to guide educational reforms. They also established principles to guide scientific inquiry. As interest in teaching and learning issues among engineering education emerged, the ASEE's Journal of Engineering Education (JEE) suggested changing the engineering education system (Jesiek, 2009).

Many reports and articles called for transformation within and beyond the engineering education (ASCE, 2008; Duderstadt, 2007; Felder et al., 2011; Kirschenman, 2011; Redish & Smith, 2008; Rugarcia, Felder, Woods, & Stice, 2000). Among these reports, ABET's Engineering Criteria 2000 is especially notable ("ABET - History," n.d.). ABET document promoted the connection between search for a quality education and scholarly research on teaching and learning. The report called for systematic assessment in engineering education by emphasizing outcomes, competencies, and continued improvements in the accreditation process. Below are some other establishments related to engineering education.

Continued NSF for EEC program from 1990-2005 also enabled the formation of eight such coalitions involving more than 40 colleges and universities. Most of them serve as training sites for graduate students and faculty to conduct engineering education research. Another multi-institutional, NSF supported initiative, the Center for the Advancement for Engineering Education (CAEE) was launched in 2003 (Jesiek, 2009). The center consists of five schools, and its goal is to advance the scholarship of engineering teaching and learning.

Another indicator of engineering education becoming a new discipline coincides with the formations of Purdue and Virginia Tech engineering education departments and graduate degree programs in 2004 and 2006 respectively. In years 2005 and 2006, three NSF supported engineering education colloquies, more than 70 U.S. participants helped to determine the main research areas in this new discipline.

Other prominent organizations now advocate for a global scale-up of engineering education as a research field. The Advancing the Global Capacity for Engineering Education Research (AGCEER) a project initiated by the JEE and the European Journal of Engineering Education (EJEE), is also promoting engineering education research through a series of conference panels.

Sheppard (2008) states the miscommunication between academia and profession "Although engineering schools aim to prepare students for the profession, they are heavily influenced by academic traditions that do not always support the profession's needs" (Sheppard et al., 2008). According to them, the solution to this dilemma has always been to add more courses rather than to consider the overall design of the curriculum. Thus, a jam-packed curriculum focused on technical knowledge has been used to prepare students for the profession.

In 1990s, engineering education went through a substantial change driven by ABET which is created by engineering societies, indicative of societies desire to improve engineering curriculum. The importance and influence of ABET on the design of engineering curricula and engineering institutions is undeniable. Therefore, there is a need to explain the importance and sanction of ABET in details.

American Board of Engineering and Technology (ABET). There are numerous papers, reports, and proceedings in the literature that embody the ineffectiveness of engineering education in terms of preparing students for their profession endeavors. The United States Accreditation Board for Engineering and Technology (ABET) has been involved in addressing these inefficiencies. ABET is an outcome based model, where the outcome of the process is emphasized more than the process itself. A small core and basic requirements along with the parameters are defined to help stakeholders to identify the goals and objectives of the program (Kam, 2011; Lang et al., 1999). ABET provides proof that when a collegiate program has met certain standards to produce graduates who are ready to enter their professions ("ABET - Why Accreditation Matters," n.d.). It holds engineering schools accountable for knowledge, skills, professional values engineering students acquire (or fail to acquire) in the course of their education. All U.S. engineering department have to demonstrate that their graduates possess communication, multidisciplinary teamwork, lifelong learning skills; and awareness of social and ethical issues as well as knowledge of science, mathematics and engineering fundamentals (Woods, Felder, Rugarcia, & Stice, 2000).

ABET has several criteria under 'general' and 'program specific' areas. It provides a guide on what and how the outcome should be, however, it does not give any guidance on how the process should be. Figure 2 shows the list of technical and professional skills that all engineering baccalaureate graduates are required to demonstrate that they possess under ABET accreditation.

Acquisition of hard skills (technical knowledge) has been given more attention by higher education institutions in the recent history while the expected outcome is the balance between these two skill sets.

Meeting ABET requirement is taken seriously by institutions because it is the leading program among accreditation of engineering boards in the U.S. Currently it has an leading instate in this area (Kam, 2011).

Changing Engineering Education Paradigms

There has been a substantial change in engineering education throughout the history. In the early parts of 19th century, the focus of education was the acquisition of literacy skills which were simple reading, writing, and calculating. Nowadays, educational systems are expected to produce graduates who are able to think and read critically, express themselves clearly and persuasively, solve complex problems in science and mathematics. Educational focus has shifted from local to global. Before, most of the engineering was done locally; however now most engineering is taken oversees. Another change is the speed of information and knowledge. “The meaning of knowing has shifted from being able to remember and repeat information to being able to find and use it” since it is virtually impossible to keep up with change at a substantial rate (Brasnford et al., 2000).

In today’s competitive world, employers have fewer resources to invest in training. As a result, they call for graduate students to be equipped with the necessary skills and knowledge to ensure that a new employee is a productive employee (Williams & Pender, 2002). Students with skills such as communication, teamwork, innovative thinking, critical thinking, creativity design capabilities are desired. These skills are also referred as ‘soft skills’ (Riley, Horman, & Messner, 2008) (Figure 2-2), which are not developed within the traditional education system(Aparicio & Ruiz-Teran, 2007). Today's engineers simply do not possess many of the proficiencies needed to compete globally (Galloway, 2007a).

Implementing engineering education reform goes to the core of making the U.S. more competitive in the global world. In the 21st century, an increasing need will emerge for an engineer who can work across borders (Cheah et al., 2005), cultural boundaries, and social contexts (Sherif & Mekkawi, 2010). After intensive review of peer reviewed papers and reports the following concepts are found to be the most influential factors in changing the content of engineering education of 21st century.

Technology

Changes in the technology tend to modify the set of skills and knowledge requirements for engineers. The instruction of civil engineering students must constantly reconstructed with the aim of ensuring that future graduates have the skills and knowledge required to satisfy the demands of industry in terms of technology (Aparicio & Ruiz-Teran, 2007), and of equipping them with higher-order skills (Zheng, Shih, Lozano, & Mo, 2011). Education must enable them to adopt emerging technologies, create innovative solutions and share of acquired knowledge within the framework of cooperative work (Reyes & Gálvez, 2011).

Because change happens so rapidly, by the time the need is identified, the courses are developed, and the students are trained for one technology, it is likely that more and significant technological advancements would be made. Therefore, rather than teaching certain technological discoveries; education should focus on teaching problem solving skills (Chau, 2007) promoting lifelong learning and equipping students with skills they will use to change themselves parallel to technological change (Rugarcia et al., 2000).

According to Galloway (2008), the level of technological developments defines the parameters within which the 21st century engineer will be working; thus, it is crucial that engineers understand both technological limitations and potential for future developments.

Globalization

Another fundamental concept engineers must fully understand is globalization (Galloway, 2007b). Galloway defines globalization as “changes in societies and in the world economy that are the result of dramatically increased trade and cultural exchange”. It refers to increasing integration of nations through tariffs, investments, transfer of technology, and the exchange of ideas and cultures.

Succeeding internationally requires greater cultural and economic understanding in addition to technological expertise. 21st century engineers need to think and act globally (Rugarcia et al., 2000; Adeli, 2009). Academic institutions, professionals, and corporations compete to benefit from the commercial advantages, creative ideas, and competitive advantages of multicultural teams. Members of multicultural teams need to be cooperative, well-structured, and educated with curricula with international content. Communication, collaboration, coordination, and conflict resolution systems are crucial to be successful globally and survival in the global market. Also the volume of business depends on competitive advantages of cooperation in coping with challenges (Galloway, 2007a).

Unfortunately, traditional skills and education style of engineers and construction managers do not equip them to successfully deal with the globalization issues

(Soibelman et al., 2011). Engineering graduates have difficulty recognizing differences and lack the required cross-cultural social, technical, and managerial skills. They are unfamiliar with the standards, materials, and methods of other countries. Student techniques, communication, collaboration, management, and teaming skills are essentially domestic and inadequate for cross-national practice.

Communication

It is a common notion that engineers are poor communicators, and part of this can be attributable to education (Kirschenman, 2011). Those who entered the engineering profession often are perceived to be analytical introverts, and thus are not exposed to the art of effective communication. Communicating effectively with public is as important as communicating with other professions. Because the world of engineering intersects with the world of business, law, economics, finance, politics and many other fields within today's marketplace, it is important for engineers to develop their communication skills to strengthen their performance (Galloway, 2007b). Zitomer et al (2003) state the importance of communication, by documenting employers rank communication, teamwork, and professional ethics among the top five subjects that emerging engineers need to know.

Ethics and Professionalism

Despite some variances with the respect to the word "moral" may mean, a number of universal values upheld by engineers encompass what one would call to mind when speaking or ethics, and they are truth, honest, and trustworthiness, respect for human life and human welfare, including the life and welfare of future generations; a sense of fair play; and transparency and competence (Harris, Pritchard, & Rabins, 2008). Ethical standards are similar worldwide. While it might be hard to find two nations defining morals and values precisely the same, some universal or nearly universal morals are applied in the global workplace: avoiding exploitation, paternalism, bribery, accepting and offering expensive gifts, refraining from violating human rights, promoting the welfare of host country, respecting the cultural norms and the laws of the host country, protecting the health and safety of people in the host country, protecting the environment of the host country, and protecting a society's institutions(Harris et al., 2008).

Leadership

While engineering practice today requires formal training and experience, it also requires acquiring skills that will reestablish them as leaders in public's eye. According to Galloway (2007b), if today's engineers are not prepared to assume leadership positions, they will not be able to succeed in the 21st century global marketplace.

Environmental Issues and Sustainability

Environmental issues cannot be overlooked in engineering, as a matter of fact in any education field, anymore. Modern engineering work requires a sophisticated understanding and consideration of the interplay between the nature and artificial structures (Sheppard et al., 2008). The importance of making students fully aware of environmental issues should be underlined, as this is basic foundation on which future engineers can implement sustainable development (Reyes & Gálvez, 2011). The paradigm of producing more in order to gain more has changed. To ensure sustainability and ecosystem well-being, the main concern should be acquiring more output while using less resource, and reducing damage to environment. Increasing threats to the quality of life due to extensive use of non-renewable resources are sources of growing concern. Because engineers' work directly effects the world, engineers must know and think about the consequences of their intervention on the environment (Sheppard et al., 2008). “Now, in addition to quality and productivity, industry will require that profitability be achieved within a context of not harming people or their habitat” (Rugarcia et al., 2000).

Splitt (2003) describes the importance of sustainability for ABET as “It was evident to the ABET that sustainable development was becoming a dominant economic, environmental, and social issue of the 21st century; and that a fundamental change in engineering education was required to help the next generation of engineers learn to design for sustainable development and long-range competitiveness”. Courses on sustainable development found their ways into some of the engineering disciplines. The emphases of these courses vary from general principles to specific subjects, such as green buildings, sustainable infrastructure, alternative-fueled transportation, waste management, and pollution prevention. Many of these courses do not create teaching environments where students can put sustainable principles into practice. This points out the general problem with learning environments that focus on the what information students should be told rather than effective ways for students to learn and apply information (Steinemann, 2003). The understanding of the importance of the integrating sustainability into the curriculum resulted in integration of sustainability in different engineering disciplines such as mining engineering, design ecological engineering, and environmental engineering (Chau, 2007).Because there is an increase in awareness in the community and because the environmental figures are becoming significant in the global community, the new direction in engineering education suggest that all engineers should be aware of the effect of their product to the environment beginning from the design stage (Ciocci, 2000).

There is a need to inspire and equip students with the means of design and implement the required solutions incorporating sustainability concepts. Education system has to ensure that students have the ability to understand, analyze, and comprehend the multidimensional aspect of sustainable development problems and have a desire to find a solution to these problems. Three aspects of sustainability should be emphasized: environmental, social, and economic.

ASCE became one of the first organizations that explicitly address sustainable development in its code of ethics (Steinemann, 2003), which are the guidelines to practice under, is declared on ASCE website (ASCE 1996):

> Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.

All of the ASCE's Code of Ethics acknowledges that:

> The overall mission of the profession is to contribute to human welfare. In line with this mission they describe the overriding importance of public safety, health, and welfare and the protection of environment.

Effective Teaching Methods

The fundamental role of teaching staff is to teach students how to learn. In a learning environment where students are taught the ways of thinking and learning should be also assess for their attitudes towards learning besides for their training (Reyes & Gálvez, 2011). Unfortunately, students graduate primarily with textbook knowledge rather than problem solving abilities. Traditional methods of academic institutions, such as traditionally constructed lectures, may contribute to the weak transition from classroom to professional life. The problem with the traditional methods is that they focus on what students should learn, instead of how students can learn skills to acquire and apply knowledge to solve practical problems (Shepherd & Cosgrif, 1998). Problem solving requires more than an analytic exercise on the paper; it requires working with people towards the solution (Steinemann, 2003).Group activities and oral presentations are helpful for the development of aforementioned professional skills; however, these activities are usually graded based on the final product with a little emphasis on the process (Riley et al., 2008) such as how the team worked together and what is the contribution of the team members towards solution, and what was their reaction when they faced with conflict.

Constructivist learning theory has been a source for the development of student centered approaches. There are several teaching methods that indeed emphasized student's behavioral activity during learning such as being responsible of own learning and active in learning rather than consuming knowledge and content provided by instructor (Baeten, Kyndt, Struyven, & Dochy, 2010). Characteristics of these teaching methods are: 1) student is active and independent, 2) teacher is the coach; and 3) knowledge is a tool rather than an aim. Many empirical and theoretical studies are conducted to identify the teaching methods that comply with the nature of civil engineering. As a result, several teaching methods proven to be effectively implemented in engineering classrooms, such as computer aided teaching (Chau, 2007; Sherif & Mekkawi, 2010), multimedia presentations (Duderstadt, 2007), and internet based instructions(Marks & Sibley, 2011).

Many student who struggled in their education could have been succeeded if effective instruction practices were available, for those who were able to be successful in the traditional system could have developed skills, attitudes and knowledge that could have significantly affected their achievements (Brasnford et al., 2000). Several active teaching methods are available and have been used in engineering education to some extent. Project based learning, service learning, case study and inquiry learning are just some of them. In this paper the researcher focuses on one of the active teaching methods, problem based learning which found to be effective in not only improving problem solving skills of students, but also equipping them with professional skills. It motivates students to take a better approach to studying and learning.

Problem Based Learning

Problem based learning (PBL) is the learning that results from the process of working on the understanding or resolution of a problem (Walker & Leary, 2009). It has emerged and grown across the world around 1960s to improve the methods of professional instruction as a result of research conducted by Barrows on reasoning abilities of medical students (Barrows, 1996). The author’s concern was to produce medical students with an ability to relate knowledge they gained in college to problems presented by the patients. He was aware of the inadequacy of leading students to develop predetermined competencies; “With a curricula that focuses on such narrow skills students are consequently offered little scope or latitude in the terms of long term usefulness of skills to the professional life”. Socrates is one of philosophers who promoted learning through questioning. He provided students with questions which required them to interrogate their assumptions in their answers, and values and inadequacies of their preferred solutions. PBL origins can be traced to progressive development especially John Dewey since he believed teachers should teach in a way that triggers the students’ creative and investigative instincts (Ribeiro & Mizukami, 2005). John Dewey supported the idea of knowledge being bound up with activity, therefore he opposed to the theories of knowledge that considered knowledge to be independent of its role in problem solving enquiry. PBL can offer students learning with real meaning to the life. According to Savin-Baden, the bulk of literature in the late 1970's and 1980's argued for the use of PBL for four key reasons: i) to develop student's reasoning skills; ii) to enable learning to take place within a context that is relevant to student; iii) to assure that learning is in tune with the demands of real world; and iv) to promote s independent inquiry (Savin-Baden, 2000).

Perhaps the most ambitious option for promoting the development of skills in most of the tasks is PBL. Problem solving context allows students to develop useful knowledge and skills. When it is used, students face the problem in learning environment for the first time before obtaining necessary knowledge to solve it, however, they are not expected to learn a predetermined series of right answers, but they are expected to engage with the complex situation presented to them and figure out what information and skills needed to successfully solve the problem (Savin-Baden, 2000). This inductive ordering triggers research environment: students begin the process of problem solving with a problem, and then proceed to figure out what they need to know to solve it, create hypotheses, read the literature and/or search in the internet, talk to experts with related knowledge (if possible), acquire critical information through modeling, experimenting and discovering, and finally solve the problem (Figure 2-3) (Woods, Felder, Rugarcia, & Stice, 2000; Hmelo-Silver & Eberbach, 2012).

From the first time of meeting the problem students must engage in questioning to obtain additional information and to reach their goal. Contrary to conventional instruction which uses problems after theoretical content is introduced, PBL uses problem as a tool to challenge, motivate, focus, and initiate learning (Ribeiro & Mizukami, 2005). The purpose of initial discussion is to trigger one's prior knowledge about the topic and discover gaps in one's knowledge. The awareness of one's knowledge gaps is believed to trigger interest in the subject matter and motivate the students (Mayer & Alexander, 2010, p. 366). After this trigger, group brainstorms to identify the gaps and clues, hypothesis are critically explored through reasoning and then organized by priority or likelihood. The need for additional information is identified and tasks are determined either to be followed either by group or individuals, a conclusion is reached after considering evidence and information, and lastly learning process is review for improvements.

According to researchers, to promote flexible thinking, problems should be complex, ill structured, and open ended (Gijbels, Dochy, Van den Bossche, & Segers, 2005; Schmidt, Van der Molen, Te Winkel, & Wijnen, 2009; Yadav, Subedi, Lundeberg, & Bunting, 2011). To support intrinsic motivation, they must also be realistic and connect with learners' experience. *Good problems* trigger curiosity from the beginning and allow students to get started with their initial knowledge.

PBL creates a classroom environment in which students are actively participating in learning and have responsibility for their learning, which is an important component of critical thinking. With this method, classroom turns into a learning environment where there is increased motivation for students to acquire knowledge. Students work in groups collaboratively and learn from each other.

According to Barrows (1996), the characteristics of PBL are as following:

- Learning is student centered (students must take responsibility for their own learning).
- Learning occurs in small student groups.
- Teachers are facilitators or guides.
- Problems form the organizing focus and stimulus for learning.
- Problems are vehicle for the development of problem solving skills.
- New information is acquired through self-directed learning.

The role of the teacher in PBL is a facilitator, guide, tutor, co-learner, and professional consultant (Ribeiro & Mizukami, 2005). In PBL, facilitator is an expert learner developing strategies for thinking and learning rather than transferring the knowledge. Facilitators reduce their supports as students start to gain experience. Facilitators are responsible for moving the students through the various stages and monitoring group process. The facilitator guides the development of higher order thinking by encouraging students to explain their thinking and promotes self-reflection by directing appropriate questions to students. The facilitator often uses open ended and metacognitive questions (Hmelo-Silver & Eberbach, 2012) to create an interactive environment, such as what do you know; what do you need to know; what concepts/ approaches could be applied to this problem; which ones will work best; what comes next; what options do we have; what assumptions are we making; how do you know if your answer is reasonable (Barroso & Morgan, 2012). The major component in teaching using a PBL method is the development of appropriate projects. Developing a project will depend on the desired outcome; and based on the length of the project, several problems can be prepared. An appropriate problem should i) be relevant to student's life to keep students' interest, ii) guide student to find the needed information, and iii) be complex so there is no single answer. Some form of PBL is adopted by capstone instructors (often unknowingly) by having students solve semester long projects.

Where the traditionally taught classes permit the efficient delivery of basic knowledge, problem based learning classes provide an opportunity for the synthesis of the knowledge, development of skills, and possibility of finding innovative solutions to engineering problems (Williams & Pender, 2002). The first goal of PBL is to construct flexible knowledge which integrates information across multiple domains on long term memory (Hmelo-Silver & Eberbach, 2012). Additionally knowledge needs to be conditionalized, that is, people need to understand when and why knowledge is useful and should be applied. PBL supports knowledge construction of knowledge since students are required to activate their knowledge in initial discussion. It also allows social construction of knowledge since it requires students to work in small groups (Hmelo-Silver & Eberbach, 2012). Construction classes of University of Glasgow in United Kingdom are examples of successful implementation of combination of traditional learning and PBL. Formal student feedback suggests that this implementation resulted in effective use of resources and created an effective and motivating learning environment. Informal feedback from local employers suggests that the use of PBL in the final year produces graduates with knowledge, skills, confidence, and self-reliance necessary to make a successful transition from university to industry. These courses provide opportunities for the improvement of communication skills as well as written and graphical skills (Williams & Pender, 2002). PBL is a useful tool to address some of the ABET criteria (Felder & Brent, 2003).

According to (Halpern, 2003), ill-defined problems are problems with many possible answers. The difficulty with these problems lies in evaluating possible solutions to choose the best one. Often the goal in these problems is vague or incomplete. There are the features of ill structured problems. They require more information for understanding the problem than is initially available, have multiple solution paths, change as new information is acquired, prevent students from knowing that they made the right decision, create interest and controversy, cause the learner to ask questions, are open-ended, are complex enough to require collaboration and thinking beyond recall, and contain content that is authentic to the discipline.

Professional problem solving skills in engineering requires the ability to reach a solution with an incomplete data while trying to satisfy the demands of clients, government and general public, minimizing the impacts of any solution on the social and physical environment and doing this with the lowest cost possible. PBL might be a partial answer to resolve engineering education issues; however it cannot be the only answer; other active learning methods should be incorporated to implement on appropriate context (Mills & Treagust, 2003).

Some of the shortcomings of PBL from faculty perspective are following (Williams & Pender, 2002): i) identification of suitable real-life projects to develop PBL is time consuming, ii) the open-ended nature of PBL courses may require stakeholders to be constantly available.

Critical Thinking

As Pitcher and Sodden (2000) state, national government policies as well as employers are demanding education to prepare students, no matter in which discipline, to think smarter than was the case in the past. Gaining ability to solve problems through critical thinking is one of the four areas that identified for instruction improvement by University of Louisville’s Education Quality Enhancement Plan (Hagerty & Rockaway, 2012). Being a lifelong learner is another expected skill from engineering graduates by faculty and industry. Although an engineer must be able to use science and mathematics in their thinking, this thought process is not oriented toward theory, but design and discovery (Sheppard et al., 2008).

According to Bonney and Sternberg (2011) one of the important jobs for teachers in the classroom is to teach students how to learn and become critical thinkers not solely transferring the knowledge. Critical thinking is purposeful and reasoned where cognitive skills and strategies are used to increase the likelihood of desired student outcome. Although there are different approaches to critical thinking, all of them have the same assumption: critical thinking skills are identifiable and teachable; and when students learn and are able to apply these skills to different situations suitably, they turn into better thinkers. Critical thinking is being able to identify and create questions that are worth pursuing and pursue answers with self directed research, to transfer knowledge and to support one’s argument. This kind of thinking requires more than only technical knowledge on a specific subject matter. Higher Education Quality Council acknowledged this by stating that graduates are expected to learn not only the technical content but also develop skills which can be transferrable to wide range of disciplines (Pithers & Soden, 2000). When thinking skills are especially taught for transfer, using multiple examples from different disciplines, students can learn to transfer their thinking across academic domains (Halpern, 1999). When subject is taught context based, its transfer to the other contexts is hard; however if subject is taught in multiple context people are more likely to develop a pattern and transfer it to new contexts.

Thanks to Internet and technology, having access to information is made relatively easy; however, the reliability of information is questionable (there is no evaluation process of information to be posted on the internet), and some information is intentionally deceptive for marketing purposes. Being able to judge the creditability of an information source has become an indispensable critical thinking skill that needs to be deliberately and repeatedly taught in college and earlier (Halpern, 1999). Schafersman (1991) adds another purpose of teaching critical thinking in sciences or in any other discipline is to prepare students to succeed in the world. Halpern shares the same ideas with him:

> Changes in technology and the workplace have made the ability to think critically more important than ever before. Instruction designed to help college students think critically focuses on skills that are widely applicable across domains of knowledge and disposition to use these skills" (Halpern, 1999, p. 69)

Because most of the current engineering curricula revolves around teaching students what to think rather than how to think (Schafersman, 1991), through transmission of knowledge, students are likely to get the correct answer without fully understanding the subject matter but only memorizing. Papadopoulos et al. (2004) empirical research on assessment of critical thinking in Mechanics in Engineering Education resulted in favor of this assumption by showing students tend to miss at least one critical element of a problem even when they have the right answer; student should be able to get the right answer with the correct reasoning to be to become good problem solvers, and be able to identify their knowledge boundaries and go beyond it. When students think to learn, they learn to think as well. Also, for learners to be able to apply in a practical manner, they need to have knowledge to apply (Sternberg, Grigorenko, & Zhang, 2008).

For critical thinking to occur, students should be active and should engage in the classroom material. They should be asked to actively choose their strategies to tackle the problems, consider resources that are in use, and receive feedback on their process. If students are not intrinsically interested in the topic at the first place, critical thinking and inquiry is not likely to occur(Mayer & Alexander, 2010, p. 177;Brasnford et al., 2000). Linsey et al. (2009) framed Active Learning Products (ALPs) to help students create a better connection between theoretical and practical experiences; facilitate students' engineering skills; develop students' skills and dispositions in engaging collaborative project based inquiry and critical thinking skills (Linsey, Talley, Jensen, & Wood, 2009). The importance of critical thinking in a technology and information age has been made clear. It is undeniable that there is an urgency to provide students with learning environments where they can foster their critical thinking. Contrary to belief not all of the engineering students are critical thinkers; in fact; most of the students never turn into critical thinkers.

Students' motivation can be assessed by examining how engaged they are in the learning process. Students who can make connections with pre-existing knowledge are able to monitor their learning of the content presented by using critical thinking skills (Amelink, Scales, & Tront, 2012). It is apparent that since the information content is increasing, what is important is being able to find, understand, and evaluate the information rather than trying to learn the more.

Definition of Critical Thinking

There are several definitions of critical thinking in the literature but most of them emphasize the same underlying principles. Following are some of the definitions of critical thinking created by influential people in critical thinking literature:

> It is the deliberate use of skills and strategies that increase the probability of desired outcome by Halpern who wrote extensively on learning and teaching of critical learning (Halpern, 1998).
>
> It is an active, purposeful, organized cognitive process we use to carefully examine our thinking and the thinking of others, in order to clarify and improve our understanding (Chaffee, 2004).
>
> It is skillful, responsible thinking that facilitates good judgment because it relies upon criteria, is self-corrective, and is sensitive to context (Lipman, 1988).
>
> It is correct thinking in the pursuit of relevant and reliable knowledge about the world (Schafersman, 1991).
>
> It is the kind of thinking that consists in turning a subject over in the mind and giving it serious consecutive consideration (John Dewey, date).
>
> It is thinking that has a purpose (solving a problem, interpreting what something means, proving something), and it can be collaborative and noncompetitive (Facione, 1990).
>
> Critical thinking is a purposeful, self-regulatory judgment which results in interpretation, analysis evaluation and inference, as well as explanation of the evidential, conceptual, methodological, criteriological or contextual considerations on which the judgment is based (APA 1990, p.3).

Definition of critical thinking is broad enough to encompass a variety of viewpoints, such as it can be taught as argument analysis, problem solving, decision making, or cognitive process (Halpern, 1999). Surely, knowing only the definition of critical thinking will not be enough to implement critical thinking. In order for teachers to teach and for students to learn to think critically, the steps and attributes of critical thinking should be defined.

Acquiring critical skills and being able to determine the right conditions to use them is not enough by itself; students also should have the attitude and disposition to use it and be willing to use the mental effort to apply it. As Halpern (1999) states “no one can develop an expertise in an area unless engaging the effortful process of thinking”. Understanding where, when, and why to use knowledge can be enhanced through contrasting cases. When students are exposed to numerous different cases, distinguishing between relevant and irrelevant information becomes easier. Learners of all ages are more motivated when they see the use of acquired knowledge and when they actually apply it to make a difference in other people’s lives. Increasing motivation is one of the most important factors when it comes to fostering the disposition in favor of critical thinking. Case studies, projects, problems conducted around sustainability create a great environment for motivation.

Brief History of Critical Thinking

At the beginning of 20th century John Dewey (1933), who is a major figure in American education and supporter of pragmatism, defended that reflective thinking is a basic principle for organizing the curriculum (Idol, Jones, & U.S., 1991). According to Dewey, instruction process is unified in the production of good thinking habits. Similar to Dewey, in General Education in a Free Society, one of the three educational abilities proposed to override others was to think effectively. In 1961, the Educational Policies Commission of the National Education Association promoted teaching for rational thinking: “The purpose which runs through and strengthens all other educational purposes- the common thread of education- is the development of the ability to think”.

During period of 1960 to 1980, the importance of critical thinking was acknowledged. A burst in critical thinking was in 1980s because it was believed thinking voters were the basis of democracy. Some of modern world concerns related to education were similar even three decades ago: complexity and rapid change that is characterized with the modern world. Fostering critical thinking skills are considered to be essential to protect democracy and to ensure competent workforce for an increasingly complex world (Tsui, 1999). The Commission on the Humanities, the College Board, the Panel on the General Professional Education of the Physician (Case, 2005) by the College Board (1983) , and Action for Excellence (1983) by the Task Force on Education for Economic Growth of the Education Commission of the States, Integrity in the College Curriculum by Association of American Colleges (1985), and Involvement in Learning by National Institute of Education (1984) are some of the reports that emphasized the importance of critical thinking in the education curriculum. By the end of 1980s, the curricula began to infuse with thinking.

In 1984, Diane Halpern published the book of "Thought and Knowledge: An Introduction to Critical Thinking" which became one of the definitive books in critical thinking; Preseisen (1984) developed the first taxonomy of critical thinking curriculum namely; cognition, metacognition, and epistemic cognition in 1984; Ennis (1985) proposed a basis to measure critical thinking skills. These are just some of the examples of critical thinking initiatives. Even though there was emphasis on the importance of critical thinking, critics began to point out that developed curricula was not successful in transferring the critical thinking skills and suggested that educational authorities needed to be more proactive (Marzano, 1988).

In the period of 1989-1999, there were more than 1,000 articles, papers, reports, and government documents published on critical thinking (Case, 2005). In 1990, as interest in critical thinking increased along with the criticisms of the curricula and assessments; 46 experts from different disciplines convened to determine the skills and dispositions that characterize critical thinking, effective ways to teach and assess it. This panel developed recommendations by using Delphi Method (Facione, 1990). Table 2-1 shows the cognitive skills and affective dispositions determined by the research committee in the panel.

Core critical thinking skills and sub-skills categorize skills that an individual should possess in order to be a critical thinker. Dispositions skills show to what degree an individual is prone to using critical thinking skills.

Here are the knowledge, abilities, attitudes, and habitual ways of behaving of a critical thinker characterized by Raymond Nickerson in 1987 (Schafersman, 1991). A good critical thinker:

- Uses evidence skillfully and impartially
- Organizes thoughts and articulates them concisely and coherently
- Distinguishes between logically valid and invalid inferences
- Suspends judgment in the absence of sufficient evident to support a decision
- Understands the difference between the reasoning and rationalizing
- Attempts to anticipate the probable consequences of alternative actions
- Understands the idea of degrees of belief
- Sees similarities and analogies that are not superficially apparent
- Can learn independently and has an abiding interest in doing so
- Applies problem solving techniques in domains other than those in which learned

- Can structure informally represented problems in such a way that formal techniques such as mathematics, can be used to solve them

- Can strip a verbal argument or irrelevancies and phrase it in its essential terms

- Habitually questions own views and attempts to understand both the assumptions that are critical to those views and the implications of the views

- Is sensitive to the difference between the validity of a belied and the intensity with which it is held

- Is aware of the fact that one's understanding is always limited, often much more than would be apparent to one with a noninquiring attitude

- Recognizes the fallibility of one's own opinions, the probability of bias in those opinions, and the danger of weighting evidence according to personal preferences

According to Schafersman (1991), this is not a definite and complete list by any means; however, it serves a good base for how a critical thinker supposed to be.

Metacognition is one of the indispensable components of critical thinking. Halpern (2002) defines metacognition as "what we know about what we know". Research show that when students are aware of themselves as active learners and knowing when knowledge they acquired is enough to take the next step, transferring the knowledge is more efficient. While incorporating critical thinking into their learning process, students also need to monitor their learning and check whether the intended goal was reached or not, time and mental effort used at the decision making process (Halpern, 1999). Metacognitive monitoring defined as ways to use this knowledge and improve the thinking process. Transfer of the knowledge can be improved by students becoming more aware of themselves and assess their readiness for a particular test or assessment (Brasnford et al., 2000).

Bloom’s Taxonomy of Learning Domains, a classification of learning domains, has a big influence in design process of engineering education curriculum. Higher order critical skills and higher levels of cognitive domain of Bloom’s taxonomy overlaps in many ways.

Bloom’s Taxonomy and Critical Thinking

Bloom (1956) developed classification of levels of intellectual behavior learning. The intent of the taxonomy was to create a platform where educators can talk about educational objectives (Aviles, 2000). This taxonomy contained three domains: cognitive, psychomotor, and affective. Cognitive domain of Bloom’s Taxonomy, in which objectives related with the recall or recognition of knowledge and development intellectual abilities and skills, is adapted by ASCE because it found appropriate for the levels of achievement in the American Society of Civil Engineering Body of Knowledge ASCE-BOK (ASCE, 2008). BOK committee believes that Bloom’s taxonomy is widely known by the education community and the use of measurable, action oriented verbs provides more consistent and effective assessment (ASCE, 2008).

Bloom’s cognitive skills taxonomy (especially higher thinking levels as it can be seen in Table 2-2) serves as a guide for development of active learning activities such as problem based learning.

For many subject matters, higher levels of the taxonomy (analyze, evaluate, and create) are the goal. Critical thinking is an essential part of these levels; therefore, Bloom’s domains are useful for developing critical thinking skills, and critical thinking is an essential part of Bloom’s taxonomy.

Measuring Critical Thinking Skills

Several researchers criticized critical thinking in terms of its "teachability" (Bloom & Weisberg, 2007; Willingham, 2008). However they all agree that, if proper metacognitive strategies are employed; it is, indeed, possible to teach critical thinking. When a group of experts gathered with a purpose of defining critical thinking concepts, they reached a consensus on a set of cognitive skills and sub-skills, which are published in Delphi Expert Consensus report. The panel, also, concluded there were four ways in which people can be judged for acquisition of critical skills (Facione, 1990, p. 15)

> One way is to observe a person over time performing those activities, process, or procedures generally regarded as presupposing that skill for proper execution. The second way is to compare the outcomes (if any) from executing a given skill against some set of criteria. A third way is to query persons and receive their descriptions of the procedures and judgments that they are using as they exercise that skill. A fourth way is to compare the outcomes (if any) that result from performing another task against some set of criteria, where the performance of that task has been shown to correlate strongly with exercising the skill or interest.

In this study a comparison of outcomes of PBL process is observed and tested through California Critical Thinking Skills Test (CCTST) and California Critical Thinking Disposition Inventory (CCTDI).

CCTST is one of the several outcomes of this panel. It is used to measure skills components previously identified by the very same panel. CCTST has been called the "gold standard" of college level critical thinking tests which has been used in widely in the U.S. and around the world ("Insight Assessment", n.d).

Forms of the CCTST are designed to provide both an overall score for critical thinking and a selection of scale scores to assist the instructor to focus on curricula and course design to address particular weaknesses as a group or as an individual. The instrument development team includes experts in critical thinking, assessment, psychometrics and measurement, statistics, and decision science.

CCTST is an objective measure of the core reasoning skills needed for reflective decision making concerning what to believe or what to do. CCTST results are given in the categories listed below.

California critical thinking skills test (CCTST)

As mentioned earlier, CCTST is a product of research aims to measure reasoning and decision making process. It is designed to capture the reasoning process and expose common mistakes result from weak critical thinking. The test provides overall score as well as selection of scale scores. Below are the definitions of each scale scores stated in CCTST manual published by Insight Assessment.

> **Overall**. Overall score describes the overall strength in using reasoning to form reflective judgments about what to believe or what to do. It predicts the capacity for success in educational or workplace settings which demand reasoned decision making and thoughtful problem solving.
>
> **Analysis.** Analytical reasoning skills enable people to identify assumptions, reasons, and claims, and to examine how they interact in the formation of arguments. We use analysis to gather information from charts, graphs, diagrams, spoken language, and documents. People with good analytical skills tend to notice the details and patterns.
>
> **Interpretation**. Interpretative skills are used to understand the meaning of a message or signal, whether it is a gesture, set of data, diagram, and chart, written or spoken word. Correct interpretation relies on understanding the message in its context and in terms of who sent it and for what purpose. Interpretation means clarifying what someone means, determining the significance of a message, grouping and categorizing information.
>
> **Inference**. Inference skills enable us to draw conclusions from reasons and evidence. Inference is used when making thoughtful suggestions and hypotheses. Inference skills indicate the necessary or very probable consequences of a given set of facts and conditions.
>
> **Evaluation**. Evaluative reasoning skills enable to assess the credibility of sources of information and the claims they make. These skills are used to

determine the strength or weaknesses of an argument. Through applying these skills, the quality of analyses, interpretation, explanation, conclusion, inference, options, opinions, belief, ideas, proposals and decisions can be judged.

Explanation. Explanatory reasoning skills, when exercise prior to making a final decision about what to believe or what to do, allows to describe the evidence, reasons, methods, assumptions, standard, or rationale for those decisions, opinions, conclusions, and beliefs. These skills enable one to discover, to test, and to articulate the reasons for beliefs, events, actions, and decisions.

Induction. Decision making in context of uncertainty relies on inductive reasoning. inductive skills are used to draw inferences about what to think must be true based on analogies, case studies, prior experience, statistical analyses, simulations, hypothetical, and familiar circumstances and patterns of behavior. Even though it does not provide certainty, inductive reasoning can provide a solid basis for confidence in conclusions.

Deduction. Decision making in precisely defined contexts where rules, operating conditions, core beliefs, values, policies, principles, procedures, and terminology completely determine the outcome depends on strong deductive reasoning skills. Deductive validity is rigorously logical and clear-cut. Deductive validity leaves no room for uncertainty, unless meaning of the words or grammar of the sentence is altered.

Each test taken provides four types of information about test takers: an overall score of critical thinking ability, a recommended performance assessment of the strength of this overall score, the percentile ranking of this score when compared to a group of similar test takers, and a set of scale score that helps to understand which of the skills areas are particularly strong and which are weaker and require training attention.

California critical thinking disposition inventory (CCTDI)

Excellence in thinking skills and dependability in taking a reasoned approach to thinking and problem solving requires being both willing (habits/attributes) and able (skills/abilities) to think well in critical situations. Critical thinking is habit of mind as well as skill. CCTDI is the premier critical thinking disposition instrument in the world today

(Insight Assessment, 2013). The CCTDI is specifically designed to measure the disposition to engage problems and make decisions using critical thinking. It measures the values and attitudes that affect the test taker's capacity to learn and apply critical thinking skills; disposition toward open mindedness or intolerance, toward anticipating possible consequences of being heedless of them, toward proceeding in a systematic or unsystematic way, toward being confident in the powers of reasoning o mistrustful of thinking, thinking, toward mature and nuanced judgment or toward rigid simplistic thinking. An overall critical thinking disposition score is also calculated.

Test score are given in following categories (Insight Assessment, 2013):

CCTDI total score. It is a measure that estimates one's overall disposition towards critical thinking. One can be strongly positive or hostile toward it.

Truth-seeking. It is a habit of always desiring the best possible understanding of nay given situation. Truth seekers ask hard, even sometimes frightening questions, they do not ignore relevant detail; they try not to let bias or preconception to affect their search for truth.

Open-mindedness. It is the tendency to allow others voice their opinions which one may not agree. Open-minded people act with tolerance knowing that people have beliefs which makes sense only from their perspectives. Open mindedness is crucial for the harmony in the society.

Analyticity/foresightfulness. It is the ability to be alert to what happens next. This is a habit of striving to anticipate both the good and the bad potential consequences or outcomes of situations, choices, proposals, and plans.

Systematicity. It is the habit of striving to approach problems in a disciplined, orderly and systematic way. They have mental desire to approach the questions in an organized way.

Critical thinking self-confidence. It is the tendency to trust the use of reason and reflective thinking to solve problems. As a family, team, office, community, or society can have the habit of being trustful of reasoned judgment as he means of solving problems and reaching goals.

Inquisitiveness. Inquisitiveness is the intellectual curiosity. It is the tendency to want to know things even though they are not readily available or obviously useful at the moment. It is the curiosity to acquire new knowledge even though application of that new learning is not apparent.

Judiciousness/maturity of judgment. It is the tendency to see problem as complex rather that black and white. It is the habit of making decisions on a timely way not prematurely. It is the tendency of standing firm in one's judgment when there is a reason to do so, but changing one's mind when it is the appropriate thing to do. It is being aware of acceptance of multiple solutions while appreciating the need for closure in certain circumstances.

Learning Theories Involved-Constructivism

Since the 1990's alternative modes of learning and teaching are introduced to promote production and construction of knowledge rather than its transfer. Students are no longer viewed as an "empty vessels waiting to be filled", instead they are viewed as active learners whom need to engage in the learning and construct their own knowledge. Constructivist learning theory is one of emerged active learning theories developed by Vygotsky (1971) and Dewey (1916).

Cognitive information processing theories focus on how people attend to environmental events, encode information to be learned and relate it to the knowledge in memory, and retrieve it as needed. Cognitive information processing is not a theory; it is a generic name applied to theoretical perspectives dealing with the sequence and execution of cognitive events (Schunk, 2007).

Constructivism is a psychological and philosophical perspective stating that individuals form and construct much of what they learn and understand. Constructivism emphasizes integrated curricula where students study a topic in various ways. Constructivist pedagogy and active learning strategies have been shown to improve science attitudes, learning experiences, and critical thinking skills.

Constructive learning activity can be defined as an activity in which learner goes one step beyond than simply engaging in a physical activity and produces some additional output that contains information beyond that provided in the original material. Some of the examples are as following: generating self-explanations, constructing a concept map, asking questions, drawing a diagram, comparing and contrasting cases or examples, and constructing a timeline (Chi, 2009). The constructivist concept of education depends on facilitating student experiences so that students can develop complex, useful understanding of science, technology, engineering, and mathematics (STEM) fields (Montfort, Brown, & Pollock, 2009)

Developmentalist teaching practices, which influenced constructivism, have emerged as a reaction against the harsh educational practices employed in America and Europe in 18th and 19th century. In Matthew's words (2003) developmentalism is a philosophical view that holds the individuals emotional, social, and cognitive development is the result of the progression of natural tendencies which have occurred as a result of natural selection and evolution. Dewey is one of the most influential educators for the progressive education in U.S. Even though his developmentalist theory mainly based on common sense and anecdotes, he opened up a way for his followers such as Jean Piaget, Lev Vigotsky, Carl Rogers, and Abraham Maslow to name a few. Each one of these individuals had their own perspective on human development; they had a consensus on Dewey's progressive approach to education, the purpose of which is to nourish naturally developing tendencies and potential of the child.

Stone (1996) states, according to John Dewey evaluation had equipped men with characteristics that are fit to certain types of experiences that occur naturally and if learning happens when men encounter to these experiences is optimal. Student needs were guide to selection and sequencing of education experiences. His curriculum consisted of the learning experiences that fit the unique pursuit of individuals (Stone, 1996) and knowledge of the formal subject process was purely incidental in the learning process. In contrast to Dewey's work, Piaget's work provided a detailed theoretical explanation based on scientific observation. The Russian psychologist Vygotsky differed from Piaget in emphasis. He argued learning as a result of sociocultural experiences played a greater role in the emergence of mature thinking and behavior.

The most frequent criticism towards experimental teaching methods is their alleged neglect of student thinking; these concerns and current pedagogical emphasis on cognitive processes, higher order thinking skills, critical thinking, and reflective thinking reflect Dewey's view of learning which he expressed in his following words:

> The sole direct part to enduring improvement in the methods of instruction and learning consist in centering upon the conditions, which exact, promote, and test thinking. Thinking is the method of intelligent thinking, of learning that employs and rewards the mind (p.153).

The basic assumption of constructivism is that people are active learners and must construct the knowledge themselves (Schunk, 2007, p. 237). Another constructivist assumption is that instructors should not teach in the traditional sense of transmitting knowledge to students. Instead, they should structure situation in which students can become actively involved with content through manipulation of materials and social interaction. Activities should involve observing phenomena, collecting data, generating and testing hypotheses, and working collaboratively with others.

According to Schunk, “Constructivist perspectives have important implications for instruction and curriculum design. Probably the most important of all is the recommendations to involve students actively in their learning and provide experiences that challenge their thinking and force them to question and rearrange their beliefs" (Schunk, 2007, p. 243).

The cultural-historical aspect of Vygotsky's theory clarifies that learning and development cannot be disassociated from their context. The way people interact with their world objects, people, places, shapes their thinking. The meanings of the words change as they are linked to the world. Another application that reflects Vygotsky's ideas is reciprocal teaching. It involves an interactive dialog between teaching and a small group of students. Initially the teacher forms the dialog but later students take roles of the teacher and begin asking questions. Students also ask questions to check their level of understanding. Once children have acquired basic concepts they can engage in independent learning and discover more advanced principles (Schunk, 2007, p. 247)

Constructivism emphasizes the importance of taking the context of learning environment into account when trying to explain the behavior (Schunk, 2007, p. 255). Organization and structure of the learning environment is highly important for constructivism. How students are grouped for instruction, how work is evaluated and rewarded, how authority is established, and how time is scheduled are some of the examples.

Students who believe abilities are relatively fixed tend to be discouraged when they encounter with a difficulty in the class, because they think there is little they can do to change to situation which consequently may affect their learning adversely. On the other hand, students who believe they have control on their learning are less prone to give up on their learning when they encounter difficulty. Rather than giving up they look for alternative ways to tackle with the problem, change their strategy, seek assistance, and seek assistance. Therefore, students who believe they can improve themselves are willing put more mental effort, rehearse more, use instructional strategies, and employ other tactics to improve learning.

Learning in a constructivist environment does not allow students to do whatever they want; instead, it should create rich experiences that encourage students to learn. Brooks and Brooks (1999) created a comprehensive list of differences between traditional and constructive learning environments (Table 2-3)

Teacher centered approach is more formal, focusing on setting standards for each grade level, in which the whole classroom moves through the curriculum by teacher lead activities (Matthews, 2003). On the other hand, student centered approach is an attempt to follow students interest while integrating materials across subject areas. Constructivist assessment is less concerned about right and wrong answers than about the next step after students answer. This requires authentic assessment which is more difficult compared multiple choice, standard tests (Schunk, 2007, p. 267)

Learning Styles

People learn and think in different ways; therefore teaching methods should be different as well, and should be tailored to targeted student groups (Felder & Silverman, 1988). Learning styles are considered by many to be one factor of success in higher education (Romanelli, Bird, & Ryan, 2009).The importance of learning styles is emphasized in learning and teaching critical thinking. Rudd, Baker, and Hoover (2000) are some of the authors who expressed the importance of determining the presence of a relationship between learning styles and disposition to think critically. They believe once the relationship is determined, college faculty may be able to facilitate the development of critical thinking skills and disposition with this information (Rudd, Baker, & Hoover, 2000; Marks & Sibley, 2011). Also, Myers and Dyer (2011) pointed out that in the platform of agriculture education, learning styles play an important role in development of student's problem solving and thinking skills.

Learning styles are defined as individual differences in approaches to tasks that can make a difference in the way in which and in the efficacy in which a person perceives, learns, and thinks (Sternberg, Grigorenko, & Zhang, 2008). They are also defined as different in which adults and children think and learn (Marks & Sibley, 2011).

> A benchmark definition of learning styles is "characteristic, cognitive, effective, and psychosocial behaviors that serve as relatively stable indicators of how learners perceive, interact with and respond to the learning environment" (cited in Romanelli et al., 2009).

Students of various ethnic and cultural backgrounds attend schools; therefore there is a strong likelihood of different learning styles. How much a student learns in a class depends on how much his learning style and instructors teaching style matches as well as his individual preparation (Felder & Silverman, 1988) Richard Felder, a recognized engineering education researcher, defined student learning styles along with the corresponding teaching style. The author argues that there needs to be a match in order to create most effective learning environment. He also identified dimensions of learning styles of engineering students with help from his colleague Silverman (1988). Below are these five learning dimensions:

- Primary way that information most effectively perceived: *sensory* (external)- sights, sounds, physical sensations, or *intuitive* (internal)- possibilities, insights, hunches.
- The channel external information most effectively perceived: *visual*-pictures, diagrams, graphs, demonstrations or auditory- words, sounds.

- Comfortable organization of information: *inductive*-facts and observations are given, underlying principles are inferred, or *deductive*-principles are given, consequences and applications are deduced.

- The way information processed: *actively*-through engagement, or *reflectively*-through introspection.

- Preferred way toward understanding: *sequentially*-in continual steps, or *globally*-in large jumps (Felder & Silverman, 1988).

Mismatch between the teacher's style of teaching and student's style of learning has been cited as a potential learning obstacle within the classroom and as a reason to use a variety of teaching styles. According to Romanelli, Bird, and Ryan (2009) research emphases the importance of knowing the learning styles of students in terms of having a better understanding of them. Faculty with the knowledge of learning styles can tailor the pedagogy so that it best matches with the learning styles and design courses to meet needs of different learning styles. Consequently, student may become more engaged in the learning process (Marks & Sibley, 2011).

Another benefit of being aware of learning styles is that it may empower students to use various techniques to enhance their learning, which in return may impact overall educational satisfaction. It gives students insight about their learning strengths and weaknesses (Felder & Spurlin, 2005). This might be especially useful when there is a mismatch between students' learning style and instructor's teaching style.

There are many learning style assessment instruments in the literature. Cassidy (2004) provides a detailed review of learning theories, models, and measures. To name some of widely used learning style assessment instruments: Kolb's Learning Style Inventory; Honey and Mumford's Learning Style Questionnaire, and an alternative to LSQ, the Canfield Learning Style Inventory. In this study, however, Felder and Silverman's learning style model was used which was excluded in the study of Cassidy

(Cassidy, 2004). This learning style consists of dimensions, and each one of these dimensions are parallel to other learning style models (Felder & Spurlin, 2005).

According to Felder and Silverman (1988), students learn in many ways: by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing; and drawing analogies and building mathematical models (Felder & Silverman, 1988). The learning style model classifies students according to where they fit on a number of scales pertaining to the ways they receive and process information. Felder and Silverman's model is used in the study for the reason of it being specifically developed for engineering students.

Here are the some precautions that Felder and Spurlin (2005) emphasize when it comes to utilizing the test and analyzing the test results :

- Learning style dimensions are continua rather than either/or categories.
- Learning style profiles show behavioral tendencies and they are not infallible predictors of behaviors.
- Learning style preferences should not be taken as reliable indicators of learning strengths and weaknesses.
- Learning style preferences can be affected by a student's educational experiences.
- The point of identifying learning styles is not to label individual students and modify instruction to fit their labels.

According to learning style theory, conventional instruction in engineering courses favors reflective learners(since students in traditional lecture courses are largely passive, intuitive learners (since emphasis in most engineering courses is on theory and mathematical models), verbal learners (since most of the lectures and textbooks predominately verbal) and sequential learners (since most courses and textbooks follow fairly rigid sequences in their presentation of information and generally little is done to show the big picture) (Felder &Spurlin, 2005).

In 2007, Linzinger Lee, Wise, and Felder conducted a study to test the reliability of Index of Learning Styles. They modified the scale by changing its dichotomous response scale from two to five option response scale to determine whether there will be an improvement in reliability and validity of the test. Results show that original test has acceptable levels of internal reliability and validity; and authors did not advise to change the instrument.

Many students, who have problem with particular course or teacher, mainly tend to place the blame entirely on poor teaching and accept no responsibility for their failures while others tend to take full responsibility, attributing responsibility entirely to their own self perceived inadequacies. Both of these approaches are not appropriate. Understanding what they need and not getting in the class is the first step toward seeking what they need in or out of class. The authors' conclusion is that as long as the test is used to help the instructor to establish balanced course instruction to help students understand their learning strengths and areas of improvement, their analysis suggest that the instruments might be reliable, valid, and suitable.

According to Felder and Silverman (1988), most of the engineering students and most of the engineering professors are incompatible. Many engineering students are visual, sensing, inductive, and active whereas most engineering education is auditory, abstract, deductive, passive, and sequential. This mismatch results with professorial frustration, poor student performance and retention.

Survey

The researcher conducted a survey to measure student's perception of their critical thinking skills. The reason behind this approach was to point out probable difference between how students perceive their critical thinking and their actual critical thinking skills. This comparison will result in increased student awareness about their skills.

As Fowler (2001) states, writing survey questions is no easy matter especially the ones that are indented to determine perceptions, attitudes, and behaviors. The researcher developed the questionnaire under the guidance of highly acknowledged books (Fink, 2008; Fowler, 1995, 2001). Two of these books belong to Fowler, and he describes a "good question as a question that produces answers that are reliable and valid measures of something a researcher is trying to describe." Another issue the author raises is that the purpose of a measurement is usually to provide comparable information about many people or events (Fowler, 1995). By far the largest number of survey questions asked about the respondents' perceptions or feelings about themselves and others. Fowler also lists some rules about designing a good survey questions. Critical thinking perception survey is conducted under the guidance of these rules: questions should be about respondents' firsthand experience, should not be personal, should be checked for researcher bias, one question should be asked at a time, and they should be worded in a way that every respondent is answering the same question. The survey should be designed in a way that reading the questions, following the instructions, and recording the answers as easy as possible for the participants. There are three ways to evaluate the survey questions: focus group discussion, intensive individual interviews, and field pretesting (pilot testing). The researcher aim is to design questions as simple and as clear as possible to avoid possible misunderstandings based on the rules of designing an effective survey (Fowler, 1995).

A survey can be utilized to collect information from people about their knowledge, beliefs, ideas, feelings, health, plans, beliefs, and social, educational and financial background (Kosecoff & Fink, 1998, p. 1). To define the content of a survey you have to define the attitude, belief, or idea being measured. Use standard English, keep questions concrete and close to respondents experience, became aware of words, names and views that may automatically bias your bias, check your own biases, do not get too personal and use a single thought in each question. A reliable survey produces consistent information; a valid survey produces accurate information (Kosecoff & Fink, 1998, pp. 6–7).

Validity is surveys relative freedom from errors of measurement produces by extraneous variables. Random assignment of the subjects to different states of the independent variables increases the internal validity of an experiment; however it has no effect on the external validity. External validity is concerned with the generalizability of the results to the population of interest and it requires random selection of subjects from that population.

The overwhelming majority of surveys rely on forced choice or multiple choice questions because they have proven themselves to be more efficient and ultimately more reliable. Their efficiency comes from being easy to use, score and code for analysis. Also their reliability is enhanced due to uniform data they provide because everyone responses in terms of the same options (Kosecoff & Fink, 1998, p. 12).

A cross sectional survey is one in which data are collected from selected individual at a point in time (Gay, Mills, & Airasian, 2008, p. 176). It is the most popular survey design used in education (Creswell, 2007, p. 389). Likert scale is one of the many items commonly used in questionnaires (Gay et al., 2008, p. 178) which is a summative scale-it aligns people according to how their responses add up. The researcher adopted the cross sectional survey method for this particular study.

Survey length depends on following factors; what you need to know, when you need to know, the amount of time respondents are willing to spend on it and the resources. Questions should proceed from most familiar to least familiar. Relatively easy questions should be placed at the end. Demographic survey questions can be placed at the end of the survey because they can be answered quickly (Kosecoff & Fink, 1998, pp. 28–30).

Summary

Chapter 2 provides literature review on history of engineering education; changing engineering paradigms; requirements of the 21st century, effective teaching methods in engineering; problem based learning, importance of critical thinking to meet the new world requirements; and ways to develop critical thinking, critical thinking measurement instruments; theories involved with critical thinking and active learning; the importance of learning styles in engineering education; and finally the survey design.

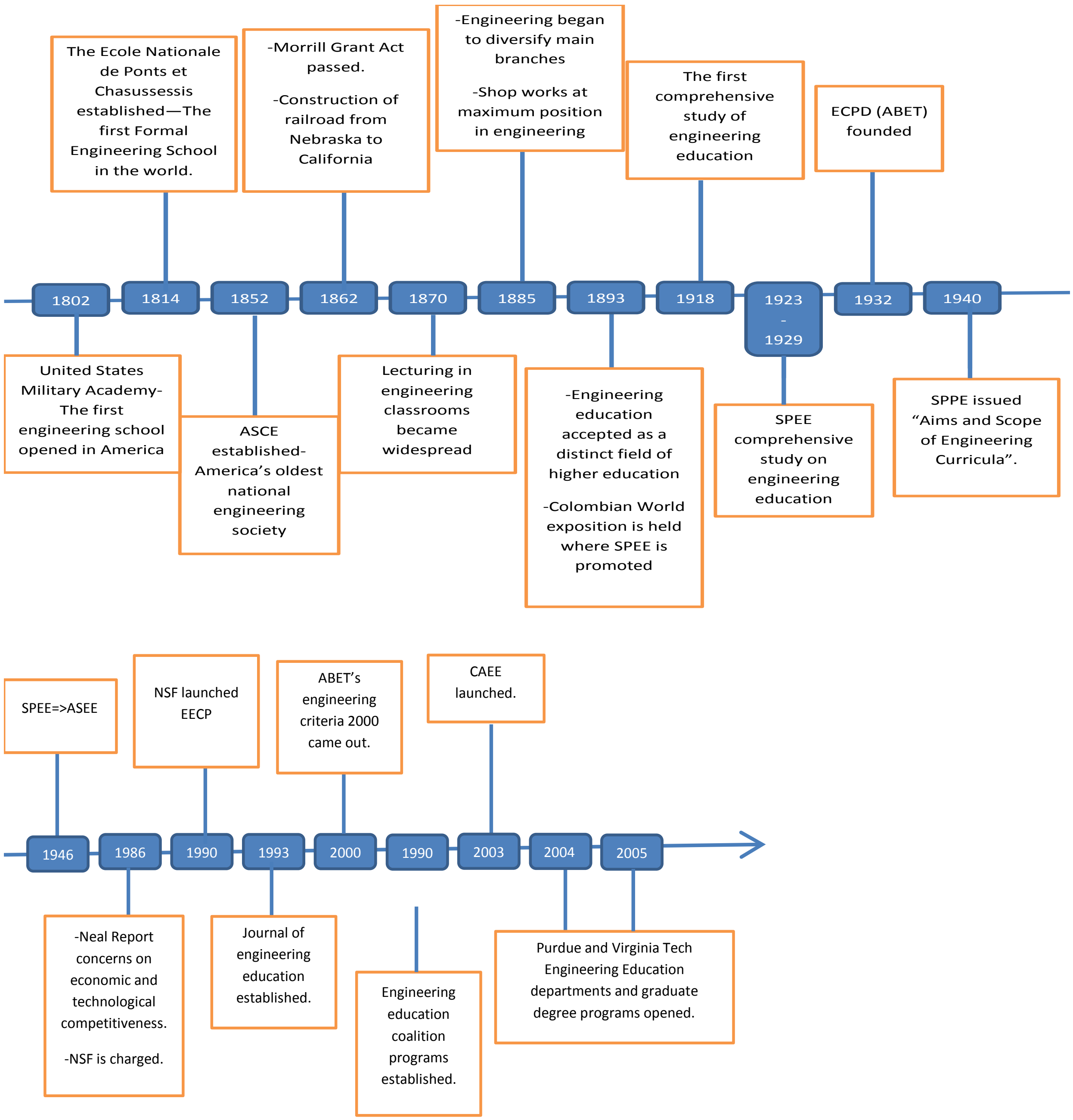


Figure 2-1. History of engineering education

Hard (Technical) Skills

- Ability to apply knowledge of mathematics, science, and engineering
- Ability to design and conduct experiments, as well as to analyze and interpret data
- Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- Ability to identify, formulate, and solve engineering problems
- Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Soft (Professional) Skills

- Ability to function on multi-disciplinary teams
- Aunderstanding of professional and ethical responsibility
- Aability to communicate effectively
- Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- Recognition of the need for, and an ability to engage in lifelong learning
- Knowledge of contemporary issues

Figure 2-2. Hard and soft skills in engineering by ABET

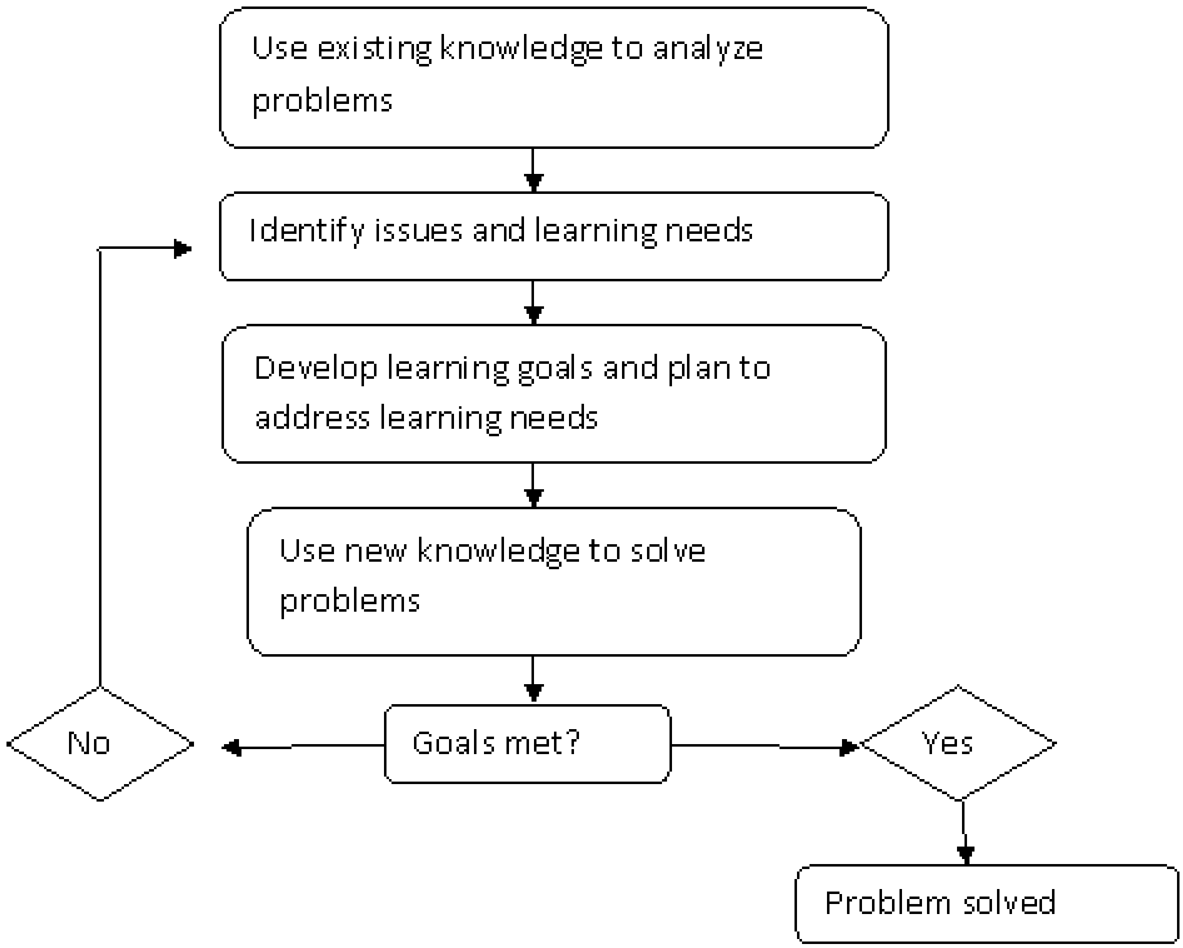


Figure 2-3. Flowchart of PBL process (Kwan, 2009)

Table 2-1. Critical thinking core skills, sub-skills, and dispositions

Dispositions	Cognitive Skills and Sub skills	
Habitually inquisitive		Categorization
Well informed	Interpretation	Decoding Significance
Trustful of reason		Clarifying meaning
Open-minded	Analyzing	Examining ideas
Flexible		Identifying arguments
Fair minded in evaluation		Analyzing arguments
Honest in facing personal biases	Evaluation	Assessing claims
Prudent in making judgments		Querying evidence
Willing to reconsider	Inference	Conjecturing alternatives
Clear about issues		Drawing conclusions
Orderly in complex matters		Stating results
Diligent in seeking relevant information	Explanation	Justifying procedure
Reasonable in the selection of criteria		Presenting arguments
Focused in inquiry	Self-regulation	Self-examination
		Self-correction

Table 2-2. Bloom's taxonomy

Categories	Subcategories
1.0 Remember - Retrieving relevant knowledge from long-term memory	1.1 Recognizing 1.2 Recalling
2.0 Understand – Determining the meaning of instructional messages, including oral, written, and graphic communication.	2.1 Interpreting 2.2 Exemplifying 2.3 Classifying 2.4 Summarizing 2.5 Inferring 2.6 Comparing 2.7 Explaining
3.0 Apply – Carrying out or using a procedure in a given situation	3.1 Executing 3.2 Implementing
4.0 Analyze – Breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose.	4.1 Differentiating 4.2 Organizing 4.3 Attributing
5.0 Evaluate – Making judgments based on criteria and standards.	5.1 Checking 5.2 Critiquing
6.0 Create – Putting elements together to form a novel, coherent whole or make an original product.	6.1 Generating 6.2 Planning 6.3 Producing

Table 2-3. Comparison of learning environment (Brooks, 1999)

Traditional classroom	Constructivist Classroom
Curriculum is presented part to whole, with emphasis on basic skills.	Curriculum is presented whole to part with emphasis on big concepts.
Strict adherence to fixed curriculum is highly valued.	Pursuit of student questions is highly valued.
Curricular activities rely heavily on textbooks and workbooks.	Curricular activities rely heavily on primary sources of data and manipulative materials.
Strict adherence to fixed curriculum is highly valued.	Students are viewed as thinkers with emerging theories about the world.
Students are viewed as “blank slates” onto which information is etched by the teacher.	Teachers generally behave in an interactive manner, mediating the environment for students.
Teachers generally behave in a didactic manner disseminating information to students.	Teachers see the students’ points of view in order to understand students’ present conceptions for use in subsequent lessons.
Teachers seek to correct answer to validate student learning.	Teachers seek the students’ point of view in order to understand students’ present conceptions for use in subsequent lessons.
Assessment of student learning is viewed as separate from teaching and occurs almost entirely through testing.	Assessment of student learning is interwoven with teaching and occurs through teacher observations of students at work and through students’ exhibitions and portfolios.
Students primarily work alone.	Students primarily work in groups.

Table 2-4. Dimensions of learning and teaching styles

Preferred Learning Styles		Corresponding Teaching Styles	
Sensory Intuitive	Perception	Concrete Abstract	Content
Visual Auditory	Input	Visual Verbal	Presentation
Inductive Deductive	Organization	Inductive Deductive	Organization
Active Reflective	Processing	Active Passive	Student participation
Sequential Global	Understanding	Sequential Global	Perspective

CHAPTER 3
METHODOLOGY

As it is stated earlier in the literature review, active learning methods are found to be good teaching instruments to nurture critical thinking. In this study, critical thinking is taught through Problem Based Learning (PBL) method.

The main goal of this study is to determine the effect of PBL teaching method on critical thinking skills, disposition and content knowledge in a class of undergraduate engineering. Furthermore, the correlation between student learning styles and critical thinking; student demographics and critical thinking; and student belief of own critical thinking skills and assessed critical thinking skills is determined. Below is the planned study to reach this goal.

Research Design

The flowchart of quantitative research (Figure 3-1) illustrates steps taken by the researcher when conducting this study.

The problem and need for the research was presented in the first chapter of this document. Literature was reviewed to learn the state of art in the proposed problem area. The goal of the study is to assess the effect of PBL on critical thinking skills and disposition as well as content acquisition. To reach this goal, an experimental pretest-posttest control group design was used in this study. Table 3-1 to shows the structure of the adapted design.

This experiment was chosen because it offers potentially the most useful true experimental research design (Tuckman, 1999). It provides control over the threats to validity and all sources of bias. Having a control group and a treatment group protects over the maturation and history bias; whereas the random assignment of control group and treatment group prevents problems of selection and mortality. By utilizing pretest-posttest control group design, the researcher gathered data from two groups which enabled conducting a comparative study. Comparison of average scores of control and treatment group shows whether treatment had an effect on participants (Creswell, 2007; Gay et al., 2008; Tuckman, 1999).

Independent variables in this study were the type of instructional methods used: PBL and traditional lecture based teaching. Independent variable is defined as a factor that is measured, manipulated, or selected by an experimenter to determine its effect on an observed phenomenon (Gay et al., 2008). Another independent variable in this study is learning styles of participants. Dependent variables of the study are critical thinking skills and disposition. Dependent variable is defined as the factor that is determined and measured to assess the effect of independent variable. It is the factor that changes (increases, decreases, disappears) depending on the presence of an independent variable. The experiment also examines the effect of treatment on acquisition of content knowledge; therefore, the second dependent variable was content knowledge. Class assignments and quiz grades were used to measure content knowledge acquisition.

The instructor of the utilized class was not the researcher of this study which eliminated the teacher bias. One of the construction engineering and engineering management lecturers (Dr. Eileen Pesantes) agreed on participating in the study. She kept teaching both sessions in the experiment, PBL and traditional lecture based classes. The researcher intentionally did not want to be involved in the teaching phase of the experiment to eliminate the new teacher effect from the study. The instructor was not familiar with active learning methods, which brought some challenges, which are discussed later in detail in this document. The researcher needed to give training sessions before the experiment. Instructor and the researcher met three times and each meeting took around an hour. They kept meeting to analyze the implementation process of PBL and discuss options to promote improvement.

Critical thinking can be integrated into the learning environment through one of two models: 1) Stand-alone method in which critical thinking skills are taught as a separate course or unit; 2) Infused instruction method in which thinking skills are integrated into curriculum across subjects and lessons. For this study, infused instruction method was used because the researcher believes when critical thinking is taught in different content, its likelihood of its transformation to new concepts increases. An undergraduate course, CGN 4905-Civil Engineering Practice, was utilized for this purpose. The following rules were applied during development of the problem to implement in the course.

- Problems should be student centered and experiential; therefore I tried to choose an example that would be meaningful for students and would reflect real world challenges. Please see Appendix D for details of the problem that is presented to students.
- Learning environment should be inductive; therefore content should be introduced through the process of problem solving rather than before the problem.
- The problem should be built on previous learning while challenging it. Students were familiar with majority of the terms and concepts that were required to successfully solve the problem.
- Problem should motivate students for further learning.

Research Procedure

The researcher performed a true experimental quantitative study in a civil engineering undergraduate course to examine whether PBL would result in a better critical thinking skills and dispositions as well as content knowledge acquisition.

The California Critical Thinking tests were administered prior to the 4-week long experiment. During a class period, students were asked to take CCTDI and CCTST tests respectively before starting the experiment. This was set as baseline information on the critical thinking skills and disposition for this particular group of students. Students were asked to complete Felder and Soloman's Index of student learning questionnaire before the initiation of the experiment. This questionnaire was used to categorize student by their tendency of receiving and processing information. Participants of the study were also asked to fill out a survey, which was conducted by the researcher. The design of this survey had two purposes: The first was to obtain demographics information and the second was to gather information on student perception of own critical thinking. The survey was conducted online and was distributed via "survey monkey"- an open source website commonly used for survey design. More information about survey and its validity is provided below.

Students were randomly assigned to control group (n=22) and treatment group (n=23). Control group kept receiving traditional lecture based teaching method while experimental group was receiving the PBL method. The treatment group was introduced to the ill-structured problem initial to the theoretical knowledge. Control group and experimental group were subject to same content assessment instruments which were biweekly quizzes, and biweekly homework assignments that were used to evaluate the students' knowledge acquisition of the subject matters taught in PBL.

Class material, which were only lecture notes in this case, were made available to the control group before class period. Treatment group on the other hand did not receive lecture notes until that particular part of the subject was covered in the classroom.

After the 4 weeks of implementation of PBL, students were asked to take the CCTST and CCTDI again to measure whether there is any change compared to research baseline. This time, students were not required to be in an arranged computer lab to take the test. The researcher made the tests available for the students to take at their convenience after consenting with the testing institution.

Following statistical analysis was conducted in this study:

- Correlation between CCTST and student perception of critical thinking survey results
- Correlation between CCTST and CCTDI
- Correlation between learning styles and CCTST and CCTDI
- Independent t- test to compare means of pre-and post-tests of different groups.
- Dependent t-test to compare the means of pre-and post-tests within groups.
- Independent t-test to compare quiz and HW means of two groups.

Sample: Convenience sampling suited the purposes of this study since it was the most practical approach for the researcher. The sample consisted of students who were registered for an on-campus undergraduate course. The total number of students registered for the class at the beginning of the semester was 45. This sample can be considered as a probability convenience sample, since it is a representative of civil engineering students. This course is listed as a required course for all civil engineering undergraduate students, which means it will not attract people only with a particular interest. The researcher explained that the class was going to be a part of the study and answered questions. Participation for the study was voluntary. With the approval of course instructor, extra credits were given to students who agreed on participating in the study. Everybody agreed to participate in the study. However there were students, changing in number depending on the instrument, who failed to take the test without any explanation or desire to not participate in the study. There were some students who took either only pre-test or post-test besides the ones who took neither of them. All of these data points were taken out to protect the validity statistical analysis.

The course of CGN4905-Civil Engineering Practice covers the fundamentals of Civil Engineering professional practice. The course consists of following topics: project management, construction delivery process, business concepts, public policy and administration, and leadership. Since its creation, 2012, this course has been taught in a traditional teaching environment.

Course objectives for the period of time experiment was implemented were as following:

- Students should be able to define and know how to meet client requirements.
- Should be able to define project work plans, scope and deliverables.
- Should be able to prepare budget and schedule of a project.

The class met twice a week for two hour periods which provided a great ground for the experiment. The control group met on Tuesdays and the treatment group met on Thursday. This kept the interaction of students from different groups to a minimum.

Instrumentation

Below is the brief explanation on the structure of instruments that are used in the study.

California Critical Thinking Skills Test (CCTST) and California Critical Thinking Disposition Inventory (CCTDI)

CCTST invites test takers to apply their critical thinking skills to a variety of different situations. Overall score is shown to predict success in work place and in successful completion of education. Test is structured around everyday problem scenarios appropriate to the test taker's age group. Each test item requires test taker to make an accurate interpretation of the presented test question. The test questions range in difficulty and complexity. The instrument typically administered in 45-50 minutes. Critical thinking skills are measured on a seven-scale assessment instrument: 1) percentile ranking of a score to entire population, 2) overall score, 3) analysis, 4) inference, 5) evaluation, 6) inductive reasoning, and 7) deductive reasoning ability. Scores on each of the CCTST categories range between 50 and 100. These scores indicate qualitative ranges: scale scores in the 50-62 range (not manifested), in the 63-69 range (weak), in the 70-78 range (moderate), in the 79-85 range (strong) and in the 86-100 range (strong).

CCTDI was developed by Delphi study to measure the change in critical thinking disposition. It measures following categorical attributes: truth seeking or bias, open-mindedness or intolerance, anticipating possible consequences, proceeding in a systematic or unsystematic way, being confident in the powers of reasoning, being inquisitive or resistant to learning, and mature and nuanced judgment or toward rigid simplistic thinking. Test takers are asked to indicate to which extent they agree or disagree with 75 statements expressing beliefs, values, attitudes and intentions that relate to the reflective formation of reasoned judgments. The test requires no educational preparation. The instrument is not cognitively fatiguing, and it should be administered first when given in conjunction with a measure of critical thinking skills. This test is administered approximately in 20-25 minutes. Scores on each of CCTDI scales range between 10 and 60. These scores can be analyzed as continuous data however they are also indicative of qualitative ranges: scale scores in the 10-29 range (low), in the 30-40 range (ambivalent), in the 40-50 range (positive), and in the 50-60 range (high).

Content validity refers to a test's ability to measure the intended domain. Critical thinking as defined by the Delphi study headed by Facione (1990) is a construct which integrates a number of cognitive maneuvers known to be a component of this type of human reasoning process. In all of the family of California critical thinking tests, test takers are challenged to reasoned judgments based on real life scenarios. CCTST does not test any content knowledge. All necessary information needed to answer a test question is provided in the question itself. The fact that the test does not measure the content knowledge allowed researcher to implement pre-post test research design and measure the development in the critical skills that occurs during this educational implication. Another requirement for a test to be valid is that it needs to present the appropriate range of difficulty to allow the accurate scaling of the scores.

Construct validity is demonstrated by the correlation between the CCTST and other tests that are intended to measure the critical thinking and higher order thinking skills. High correlations between standardized college level entry tests (such as GRE) and CCTST have been demonstrated by researchers (Insight Assessment, 2013).

Criterion validity is the most important consideration in the validity of the test. Criterion validity is the ability of the test to predict some criterion behavior external to the test itself. Scores on various versions of CCTST have been demonstrated to provide a meaningful measure demonstrating the achievement of designated learning outcomes (Insight Assessment, 2013).

The testing instrument has met the threshold for strong internal consistency reliability with a minimum (Insight Assessment, 2013). Tests are constantly observed to maintain this performance in all samples of adequate variance.

Survey

The purpose of conducting the survey was to determine students' perception on critical thinking. Since an individual's perception generally shapes the habitual activities; obtaining information on perception has a value for providing information about their habitual activities. Questions in the survey were prepared under the guidance of core critical thinking skills defined by Delphi report: interpretation, analysis, evaluation, inference, explanation, and self regulation. The researcher aimed to stay as close as possible to these categories and subcategories when conducting questions to keep the validation accurate. There is total of 26 questions. Each skill section has either four or five questions that are indented to measure the core skills in which they are constructed around. Additional to student perception survey, a demographic survey is also conducted to determine the correlation between critical thinking skills and disposition and demographic survey items. The researcher favored toward a simple demographic survey which were given to participants with perceptions survey simultaneously. The demographics survey was presented after the student perception survey to eliminate likelihood of misunderstanding of the purpose of the survey. Survey questionnaire is attached to Appendix B.

Pilot testing the questionnaire provides information about the deficiencies and enables improvement through suggestions. Pilot study in this study was developed by taking previous literature and comments as guidelines. It was conducted to determine whether the wording of the survey was accurate to assess needed information, were there any misleading questions, questions, and were the questions appropriate for the target population.

A pilot study with 5 participants was conducted to detect aforementioned probable problems. According to Gay et al. (2008), having three or four students to complete the questionnaire will help to identify the problems (p. 181). Therefore pilot study number found to be efficient. Students took the test and a couple of questions were re-worded for clarification. It took them about 10 minutes to fill out the survey. The time period of administration was appropriate for the length and type of the survey. Overall, of the participants found the survey was that it was easy to understand and complete which was the main design consideration.

Learning Styles

In 1988, Richard Felder and Linda Silverman formulated a learning style designed to determine the most important learning style difference among engineering students and provide a good basis for engineering instructors to design courses to meet learning styles of students. The questionnaire consists of 44 questions, each having two possible responses. Students are categorized in 4 dichotomous areas: preference in terms of receiving information (sensory or intuitive; visual or verbal), approaches to processing and organizing information (active or reflective) and the rate at which students progress towards understanding (sequential or global). When someone submits a completed ILS online, a profile is immediately returned with the scores of all four dimensions with a brief explanation. Each learning style dimension is associated with 11 forced-choice items, with each option (a or b) corresponding to one or the other category of the dimension (Appendix A).

Data Collection

Data is collected through the following items in this study:

- California Critical Thinking Skills pre-post test
- California Critical Thinking Disposition Inventory pre-post test
- Survey of Student Perception Toward Critical Thinking
- Index of Student Learning Styles Questionnaire
- Course assignments and assessments
- In class observations

Data Analysis

Critical thinking disposition and skill scores were graded by Insight Assessment Company and descriptive statistics were used for analysis. Both scores included the percentile in which each person was categorized. The total score and subscale scores were also provided by the company including the number of participants, mean, median, standard deviation and minimum and maximum scores. Insight assessment does not include test results wherein the test taker attempted less than 60% of the test items or spent less than 15 minutes on the test because these test results are not likely to be valid test attempts. Time limit was set for both of the test by the company. Test results were made available to test takers for their information.

Total scores for survey and learning styles tests were provided by the researcher as well as correlation between student demographics and critical thinking skills. Correlational research was used to determine whether, and to what degree, a relationship exists among the quantifiable variables of research.

Correlation analysis, dependent-and independent t-tests were performed to test null hypotheses. Test results are explained in results chapter.

Limitations

One of the limitations in this study was the number of participants. It was limited to the students who were registered to CGN4905-Civil Engineering Practice course in spring semester of 2013. The result of the study cannot be generalized to the general population of student unless sample size share similar characteristics. The purpose of this study was to examine a specific group of students in one university. The result of quantitative analysis may not be applicable to other samples or to the larger populations. 45 students participated in the study. Even though this number is sufficient for statistical analyses, it is still a relatively small number.

Other possible limitation is the longevity of the study. The research suggests that successful critical thinking interventions may need to occur over a year period of time since the development of critical thinking skills requires practice over a long period of time.

This research focused only on in class experiments to develop critical thinking skills; out of classroom environment activities were not the concern of the study.

The response rate might be another limitation. Response rate varied for each testing instrument and a number of the unsuccessful test taking attempts were needed to taken out of the study, which left the researcher with a smaller usable data size.

Assumptions

This study based on several assumptions. First of these assumptions is that, critical thinking skills can be taught and measured. Second assumption is that critical thinking skills and dispositions improve when attended to a certain teaching method.

Another assumption is the effort of students in both groups made a consistent effort on the CCTDI and the CCTST. The reliability of the tests was not calculated for this particular study. The researcher accepted the reliability of these tests based on previous literature.

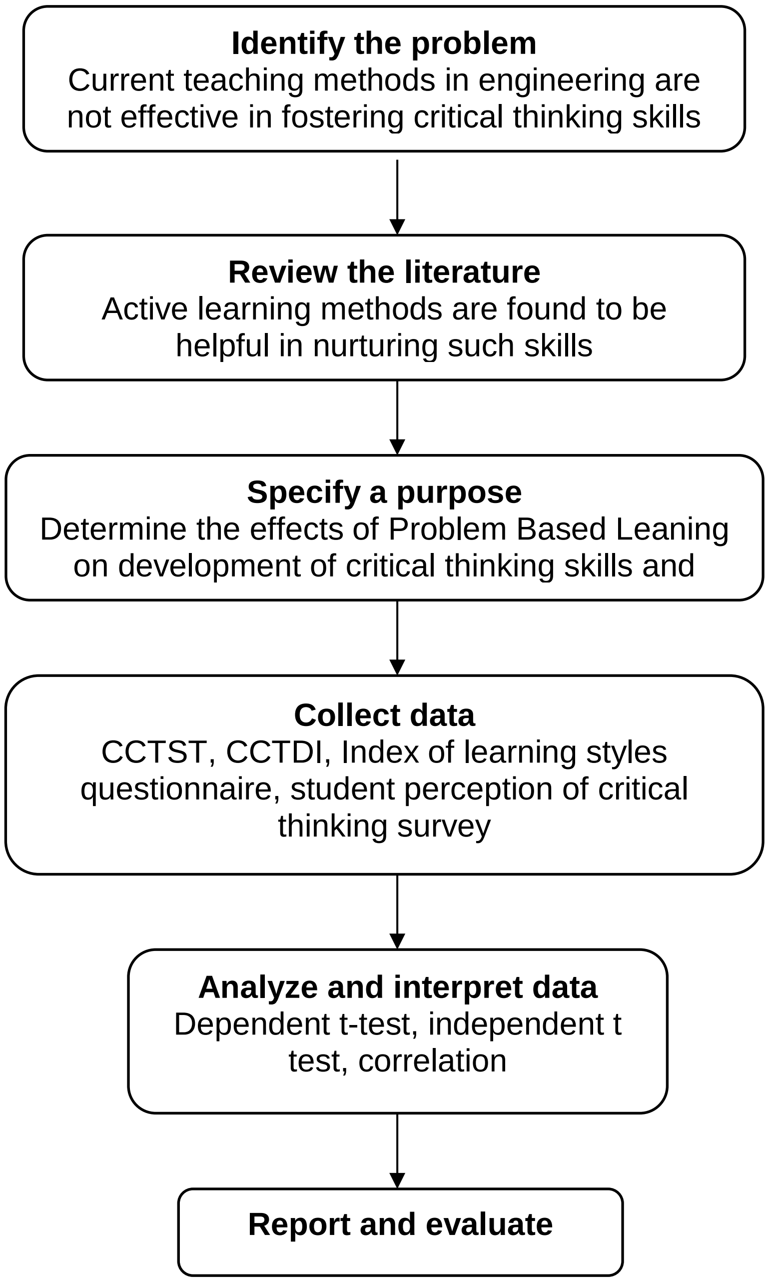


Figure 3-1. Steps of quantitative research process

Table 3-1. True experimental research design

Group	Assignment	Treatment	Pre-test	Post-test
Experimental	Random	Problem based learning	1. CCTDI 2. CCTST	1. CCTDI 2. CCTST
Control	Random	Lecture based learning	1. CCTDI 2. CCTST	1. CCTDI 2. CCTST

CHAPTER 4
RESULTS

Introduction

This chapter includes the survey results, data analysis of test assessment instruments, and in class observations of the experiment.

Demographics Survey Results

The characteristics of the data were based on demographic data consisted of gender, race, age, academic standing, current GPA, whether students took a course solely devoted to critical thinking and whether they took a course in which critical thinking was incorporated. Table 4-1 provides information on student demographics of treatment group and of control group as well as of whole class.

The participation level in the survey was lower than total number of students in the course. Some of the participants did not fill out the survey. The survey was distributed through survey monkey, followed by several reminders. Forty of 45 students completed the demographics and student perception of critical thinking survey. Thirty two (80 %) of these students were male and 8 (20%) were female. This number is an accurate representation of gender distribution in civil engineering department in UF, 22% of students is female. Students were randomly assigned to the groups: treatment group and control group each had, 16 male (80%) and 4 female (%20) students who filled out the survey. The majority of the participants were seniors 28 (70%); the rest of the participants were juniors 10 (25%) and sophomores 2 (5%). Twenty five of the students (62.5%) were White, followed by Hispanic 9 (22.5), Asian/Pacific islander 4 (10%) and African American 2 (5%). Twenty eight students (70%) were ages of 21-24, 7

(17.5%) were ages of 17-20, and 5 (12.5%) were in 25-29. The class average GPA was 3.4.

Twelve students (total 20) that were in the treatment group and 16(total 20) students from the control group stated they took at least one course that was solely devoted to critical thinking Eight students from the treatment group and 11 student from the control group stated they took at least one course in which critical thinking was incorporated.

Student Perception Survey Results

Figure 4-1 illustrates the average student responses about their perception of critical thinking. The questionnaire consisted of 26 questions and utilized a Likert scale of 1(Strongly disagree), 2(Agree), 3(Neutral), 4(Agree), 5(Strongly agree). CCTST subcategories (analysis, interpretation, inference, evaluation, explanation, induction, deduction) served as a baseline for conducting the survey.

Average student response is estimated by averaging students' response to 26 questions. The chart illustrates how often students answered strongly agreed, agreed, neutral, disagree, and strongly disagree to the statements presented in the survey. Among the answered questions 51.16% was agreed to interpreting, analyzing, evaluating, inferring, and explaining subjects as well as are able to self regulate; 25.77% strongly agree; 18.34% neutral; 4.54% disagree; and .19% strongly disagree. Based on the distribution of student's response, it can be concluded that students were convinced they do possess skills to think critically.

Figure 4-2 illustrates categorized version of Figure 4-1. Over 55% of the student response was toward agreeing with the statements that measure their interpretation skills, whereas 46% was agreeing of explanation skills. This figure shows that students' responses are mainly toward having good interpretation skills and relatively less explanation and self-regulation skills.

Learning Styles

Felder and Solomon's "Index of learning style questionnaire" was used to categorize students based on their preferences of primary way of receiving information (sensing-intuitive; verbal-visual), of channel information most effectively received (active-reflective) and of the way information is processed toward understanding (global-sequential).

Scores are on a scale of 11 to 11 with categorized in three ranges of 1-3 is mild, 5-7 is moderate, and 9-11 is strong. When one scores on a scale of 1-3, he is pretty well balanced on two dimensions of that scale. If he scores on a scale of 5-7, he has a moderate preference for one dimension of the scale and learns more easily in a teaching environment that favors this dimension. When the score is on a scale of 9-11, that person has a strong preference for one dimension of the scale; he may have difficulty in learning in an environment that does not support this dimension. For all dimensions, balance of two opposing dimensions is desirable (Felder & Silverman, 1988).

Figure 4-3 shows the learning preferences of civil engineering undergraduate students in Civil Engineering Practice course. Thirteen (30.23%) students are mild-reflective, 12 (27.9%) moderately-active, 8 (18.6%) mild-active, 7 (16.28%) moderate-reflective, 2(4.65%) strong-active, and 1 (2.3%) strong-reflective in terms of processing information. Seventeen (39.5%) students are moderate-sensing, 10 (23.2%) mild-sensing, 8 (18.6%) strong-sensing, 4 (9.3%) mild-intuitive, 3 (7%) moderate-intuitive, and 1 (2.3%) strong-intuitive. Eighteen (42%) students are moderate-visual, 14 (32%)

strong-visual, 12 (26%) mild-visual, and there is no one with a verbal preference as a channel through external information is most effectively received. Nineteen (44%) students are mild-sequential, 11 (25%) moderate sequential, 5 (12%) strong sequential, 5 (12%) mild global, 3 (7%) moderate global in terms of preferred way toward understanding.

California Critical Thinking Test (CCTST) Results

Table 4-2 illustrates the overall CCTST results for both treatment and control group before and after the experiment. There is a slight decrease on the overall average (pre= 79.2, post=78.3) with an increase in standard deviation (pre=6.5, post 7.7) for control group. For treatment group, on the other hand, there is a slight increase in overall average (pre=78.1, post=78.4) with a decrease in standard deviation (pre=8.4, post=6.2). There is slight but insignificant increase in students' critical thinking skills.

The number of students who completed both tests in treatment and control group differed. Some of the participants failed to take to post-test and some who had not taken the pre-test decided and took the post test. These scores eliminated from statistical analysis as they might have skewed the results. Test takers who spent less than 15 minutes to complete the test or who completed less than 60% of the test were taken out of the study. Participant number for each of the analysis is indicated in tables.

Table 4-3 illustrates mean scores for each of the CCTST subscales and total scores were calculated for both groups: control group pre-test (mean=79.2, SD= 6.5) and post-test (mean=78.3, SD= 7.7) and experimental group pre-test (mean= 78.1, SD= 8.4) and post-test (mean= 78.4, SD=6.2). At the beginning of the experiment control group had a higher average score (79.2) with lower standard deviation (6.4) compared to experiment group's mean (78.1) and standard deviation (8.4). By the end of the experiment results for both groups were distributed more equally with control group having average score of 78.3 and treatment group having average score of 78.4.

When control group CCTST results are examined, it can be seen that overall result is decreased from 79.2 to 78.3. All of the subscale results decrease at some level (Table 4-3 and Figure 4-3). Deduction, analysis, and overall critical thinking skills slightly

California Critical Thinking Disposition Inventory (CCTDI) Results

Table 4-4 illustrates the mean scores and standard deviation of the CCTDI test results. Overall, disposition scores were lower in post-test than in pre-test for control and treatment group. Truth seeking subscale decreased in both experimental (pre-mean=35.8, SD=5.9; post mean=35.4, SD=8.1) and control group (pre-mean= 35.9, SD=4.5; post-mean=35.2, SD= 3.8). Open mindedness subscale scores were at the same direction as truth seeking. Analytical skills decreased in the control group (pre-mean=46.6, SD=4.5; post-mean=44.3, SD=4.1) and did not change in treatment group (pre-mean=48.1, SD=3.7; post-mean=48.1, SD=3.9). There was an increase in systemacy scores (pre-mean=39.7, SD=4.6; post-mean=40.5, SD=3.7) in control group however there was a slight decrease in experiment group (pre-mean=41, SD=6.3; post-mean=40.1, SD=6.8). There was also a slight decrease in self confidence scores both in experimental (pre-mean=47.3, SD=5.3; post-mean=47.1, SD=6.3) and control group (pre-mean=45.6, SD=4.7; post-mean=43.6, SD=5.3). Inquisitiveness scores slightly decreased in both groups. Maturity scores increased in control group (pre-mean=39.8, SD=4; post-mean=41.4, SD=4.4) and decreased in treatment group (pre-mean=41.5, SD=4.4; post-mean=39.3, SD=8.6).

Tables from 4-5 to 4-8 have information in detail for mean and standard deviation of both groups.

Table 4-9 includes mean and standard deviation of CCTST results categorized by student demographics. Female students (N=7) scored (mean=77.7) slightly higher than their male (N=29, mean=77) counterparts. CCTST results did not appear to differ by age between juniors (N=9, mean=77.3) and seniors (N=26, mean=77.7).

The familiarity of students with the critical thinking by having a devoted critical thinking course (N=28, mean=77.4) or by critical thinking incorporated course (N=19, mean=77.3) did not affect students CCTST scores. Finally, test average did not change dramatically based on ethnicity of the students (African-American N=2, mean=83; Asian N=4, mean=75; Hispanic N=7, mean=75.4, and White N=23, mean=78).

Research question 1: What is the effect of PBL on critical thinking skills and dispositions in undergraduate civil engineering majors?

Null hypothesis 1: There will be no difference between the pre-and post-testing scores on the CCTST in both groups.

Null hypothesis states that there will be no difference between the means of pre- and post- tests scores of both groups. To test this hypothesis, dependent t-test is performed in Microsoft Excel. Results of the analysis are shown in Table 4-10.

P-value of the control group is p=.38, and since it is larger than the significance level (α=.05), the null hypothesis is not rejected. It was concluded that there was no significant difference between the means of pre-and post-tests of control group. For treatment group, p-value was p=0.63, which is, again, higher than significance level (α=.05), therefore null hypothesis was not rejected. There was no significant difference between the means of pre- and post-tests for treatment group.

Null hypothesis 2: There will be no difference between the pre and post testing scores on the CCTDI.

Dependent t-tests were conducted for control and treatment group to test this hypothesis. P-value for control group was $p=0.8$ (Table 4-11), which was higher than significance level ($\alpha=.05$), therefore, the null hypothesis was not rejected. There were not significant differences in means of CCTDI scores for control group. The p-value of treatment group is $p=0.21$ (Table 4-11). Even though it was lower than control group, it is still higher than significance level ($\alpha=.05$). Therefore, the researcher failed to reject the null hypothesis again. There was no significant difference between the means of CCTDI pre-and post-test of treatment group.

Null hypothesis 3: Critical thinking skills will increase regardless of teaching method.

To test this hypothesis, independent t-test was conducted to determine whether there would be any difference in means of control group and treatment group pre and post tests. P-value for pre test was $p=.87$ and post test was $p=.66$. In both cases p-value was higher than significance level of .05. As a result, the researcher failed to reject the null hypothesis. There was no significant difference between pre-and post-test means.

Null hypothesis 4: Critical thinking disposition will increase regardless of teaching method.

Similar approach was taken as in hypothesis 3. The p-value for CCTDI pre-test was $p=.3$ and for CCTDI post-test was $p=.58$ (Table 4-12). Not surprisingly, in both cases, p-value was lower than significance level. Therefore, the null hypotheses could not be rejected.

Research question 2: Does learning styles play a role in critical thinking disposition?

Null hypothesis 1: There is no relationship between active learners critical thinking disposition.

The researcher compared the CCTDI test scores of strong and moderate active learners and strong and moderate reflective learners with treatment group and with both groups (Table 4-13). These scores reflect the average of overall CCTDI scores of active learners, reflective learners, treatment group and both group’s mean.

Despite of subjects having the lowest CCTDT pre-test scores (pre-mean=294.3, SD=21.8), after the treatment they ended up having the highest average (post-mean=300.5, SD=31.8). Active learners have a better disposition towards critical thinking due to the implemented teaching method. Reflective learners, on the other hand, had a slight decrease in their scores (pre-mean=276, SD=26.2; post-mean=272.5, 26.2).

Research question 3: Is there any difference in content knowledge acquisition between traditional teaching method and PBL?

Null hypothesis 1: Content knowledge acquisition will be equal for both methods.

In order to test this hypothesis, independent t-test was conducted between quizzes and HW assignments. Table 4-14 illustrates the assignment and assessment results for both control and treatment group. P-value was p=.15 for control group and treatment group HW results; and p=.15 for quiz results. Both values were higher than significance level; therefore null hypothesis was not rejected. There were no significant differences between means of HW and quiz results.

Research question 4: Is there a relation between students' perception of their critical thinking and their actual critical thinking?

Null hypothesis 1: There will not be any differences between students perception of own critical thinking and their actual ability.

Table 4-15 illustrates the correlation between students' perception of own critical thinking and CCTST results. Scatter plot of CCTST results and student perception of critical thinking survey results shows the relationship between these two factors. Plots represent students whereas the x axes survey averages and y axes average CCTST results. It is hard to state a relation between students perception of own critical thinking skills and their actual ability. There were students who believed they have strong critical thinking skills between 4 (agree) and 5 (strongly agree) and did poorly on the CCTST (below 70); and there were students whose average were between 3 (neutral) and 4 (agree), and scored over 80 on CCTST.

In Class Observations

As stated earlier, the researcher was present in control and treatment group during the experiment.

Classroom structure*:* Unfortunately this classroom was an auditorium class in which desks cannot be relocated to create a circle layout so that students can face each other.

Treatment group*:* On the first day of the experiment PBL is explained to students and their familiarity with the concept is assessed. Students were not aware of such a learning method, and it was interesting and challenging for them at the beginning. For example, they normally like to sit at the back of the classroom, and were not happy with the idea of getting closer to the front of the classroom initially. Because of the structure of the classroom, it was impossible for students to face each other in a circle group, so they set really close to overcome this problem.

During the experiment, students were asked to work in group towards solution of the problem and share their ideas with the classroom. Initially, the teacher asked them to come to the board and write what they thought the answer is along with explanation. (Figure 4-6)

After each group writing their responses on the board, students were given some time to read what was written and were asked if they wanted to comment on the factors identified by the other groups. They were asked what were their goals, assumptions, and limitations when they needed to construct the house described in APPENDEX D.

They were also asked to group activities that are listed below in two categories C (construction), PC (pre-construction). Then students were asked to assign days to these activities, schedule them and come up with duration for the project. This part of the experiment was challenging for them, however senior students familiarity with the concept help them to some degree. One of the group's bar chart was projected with an overhead and students were directed to find and understand complex relationships between activities. Lecture notes were made available after the class period for treatment group. Student attendance was high.

There were activities many more similar to the ones described above. For the experiment group, after explaining the process of PBL and what is expected of them, students were divided in groups consisting of 4-5 members. Students were grouped with people close to them. The process of the implementation is as described in the research process. In every step of problem solving, students were required to work in groups. The instructor walked around groups to assure that they are on the right track. One of the most exciting thing observed was the student engagement in this process. They were willing to answer the questions, and were getting excited when the teacher walked around and gave them directions if they needed help. Student engagement is one of the critical components of effective teaching environment. Curiosity is an important factor in terms of being a lifelong learner which is what the education system is trying to produce. Being engaged and staying motivated and trying to figure out the solution of the question, making assumptions, thinking about assumptions that are made, knowing their limitations, determining what they need to know to be able to answer the question are vital components of producing critical and creative thinker which the system needs so much. Students worked in teams to accomplish their goal just like how they would need to do it in the real world. It was a collaborative and cooperative experience for them. The teacher walked among the students to ensure every member of the group was actively participating towards answering question. The researcher had an opportunity to interview with some of the students about PBL. Some of the comments were as following:"... this was the first time, I did not lose my interest in the topic", "… I really enjoyed the class today", "…this is pretty cool, and I think it will be better if you have us to do different things each class". Pictures demonstrating some of the in class activities are attached.

Control group: The classroom set up for the control group was not changed. Students kept receiving the knowledge in a way that they would normally do which is traditional lecture based learning. Teacher started by teaching through lecture slides. She explained the concepts while going through slides. Students did not participate in this process. They were either playing with their electronics or, even worse, sleeping in the class. The teacher asked questions to gather students' attention however students were not willing to answer. Student participation was low in this group. Lecture notes were made available before the class period. Student attendance was low.

The researcher was always present in the classroom during the period of this experiment to observe student behavior in different sections.

Nothing new was implemented in the control group. The only difference they had was the number of students in the class. Class attendance was low in this section. Students were spread out to whole classroom. The instructor started going over the lecture notes and commending while processing. She was trying to engage them through asking questions; however students were not willing to answer. They look distracted by their electronics. There were even some students spotted sleeping through the class. Students lacking in paying attention is one of the main complaints of instructors.

Table 4-1. Summary of descriptive characteristics of students by level of treatment

		PBL (n=20)		Traditional (n=20)		Total (n=40)	
		Freq	Percent. (%)	Freq	Percent. (%)	Freq	Percent. (%)
Gender							
	Male	16	80	16	80	32	80
	Female	4	20	4	20	8	20
Class						0	
	Freshman	0	0	0	0	0	0
	Sophomore	2	10	0	0	2	5
	Junior	2	10	8	40	10	25
	Senior	16	80	12	60	28	70
Race							
	African-American	0	0	2	10	2	5
	Native American	0	0	0	0	0	0
	Asian/pacific islander	3	15	1	5	4	10
	Hispanic	5	25	4	20	9	22.5
	White	12	60	13	65	25	62.5
Age							
	17-20	4	20	3	15	7	17.5
	21-24	13	65	15	75	28	70
	25-29	3	15	2	10	5	12.5
	30+	0	0	0	0	0	0

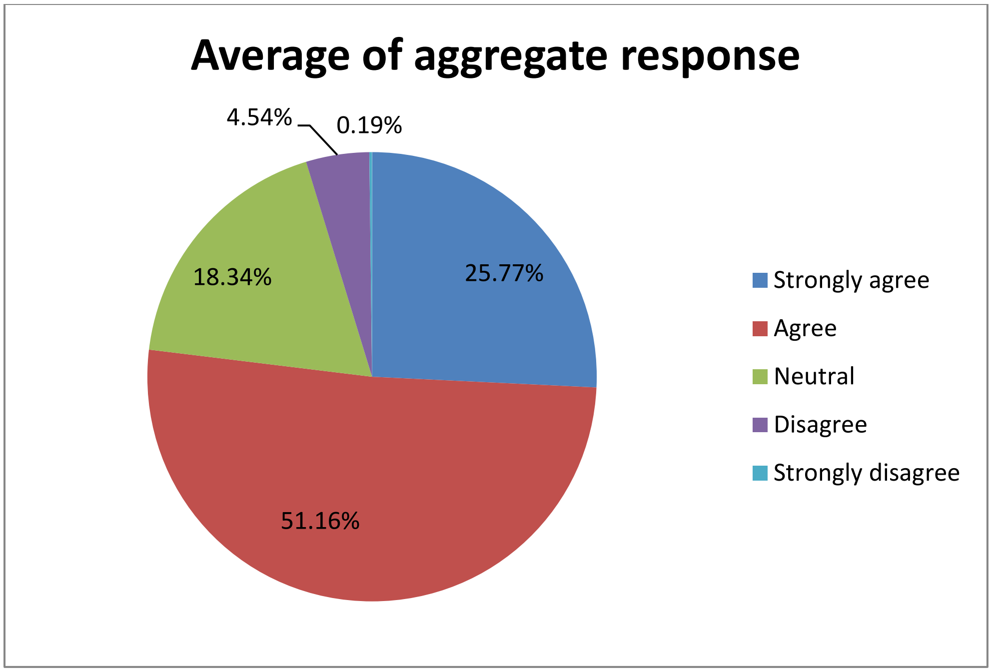


Figure 4-1. Average of student response

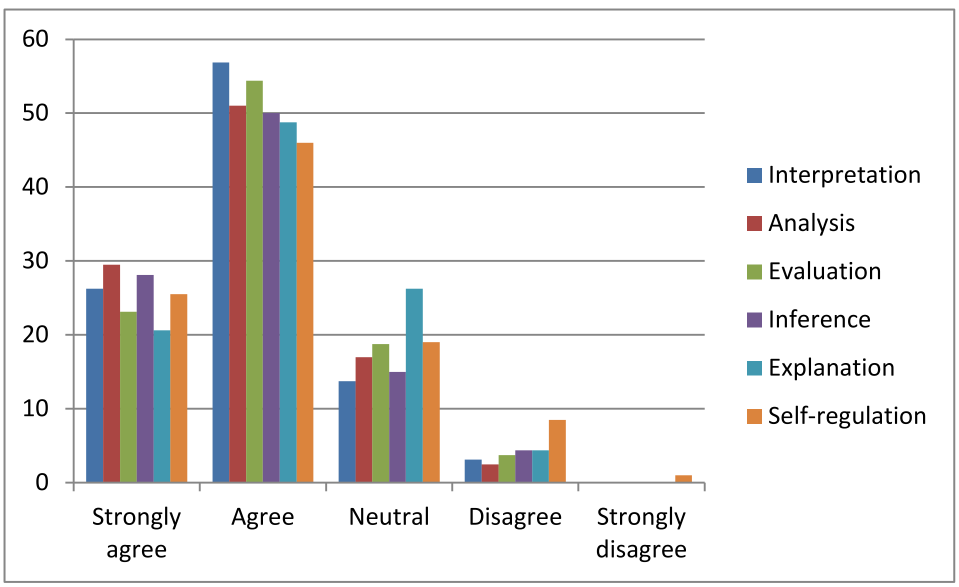
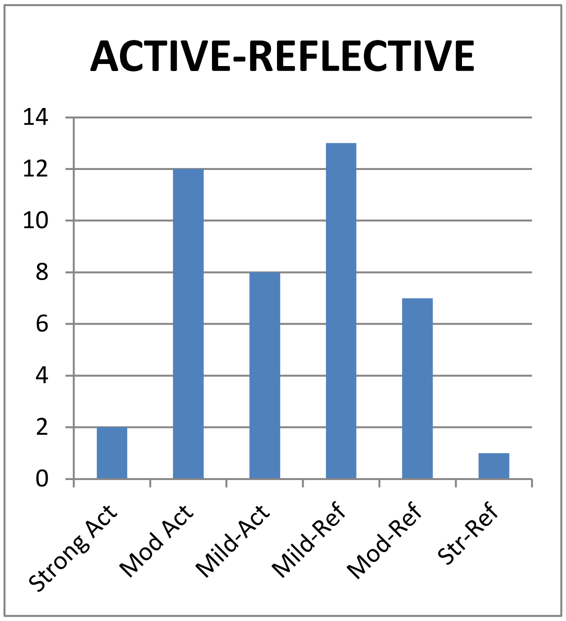
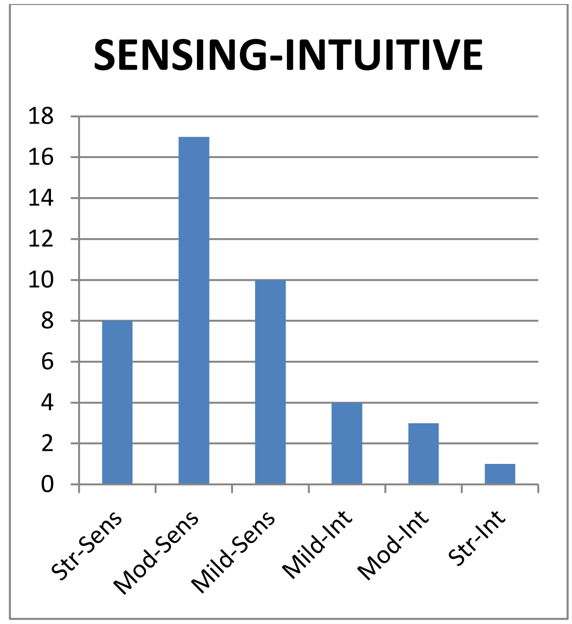


Figure 4-2. Average of student response-categorized



(a)



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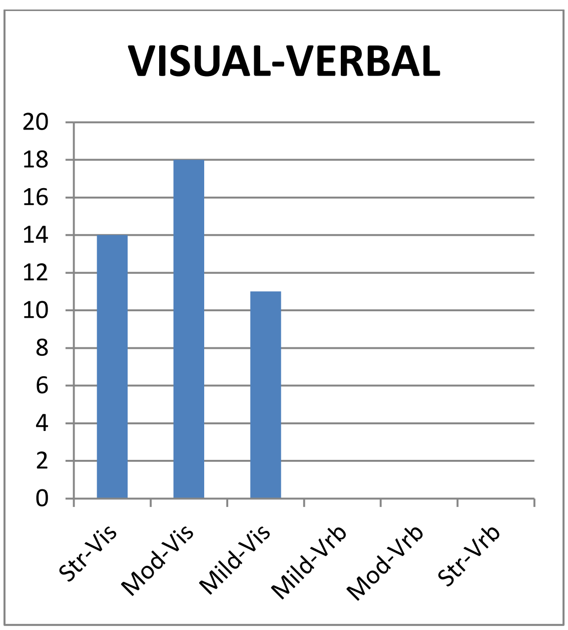

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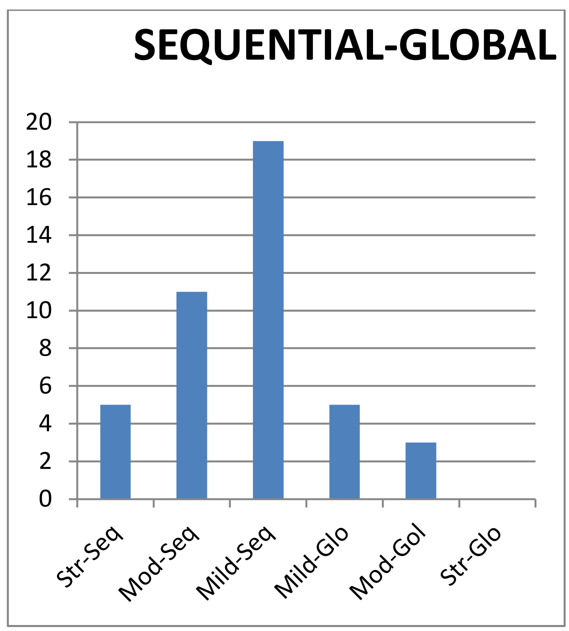


(d)

Figure 4-3. Preferred learning styles-(a) Active-Reflective, (b) Sensing-Intuitive, (c) Verbal-Visual, (d) Sequential-Global

Table 4-2. CCTST overall scores of both groups

	Pre		Post	
	Mean	SD	Mean	SD
Control	79.2	6.5	78.3	7.7
Treatment	78.1	8.4	78.4	6.2

Table 4-3. CCTST pre-and post-test results for control and treatment group

	Control group				Treatment Group			
	Pre (N=18)	SD	Post (N=19)	SD	Pre (N=18)		Post (14)	SD
Overall	79.2	6.5	78.3	7.7	78.1	8.4	78.4	6.2
Analysis	80.6	9.2	80.5	8.6	83.1	8.8	83.9	6.3
Interpretation	83.9	8.8	82.4	7.7	81.4	8	83.1	8.4
Inference	82.9	8.2	82.5	7.9	81.2	7.5	80.8	5.6
Evaluation	76.6	7.1	74.9	9.7	75.4	10.6	75.1	9.5
Explanation	75.9	8.3	74.9	9.4	75.7	10.8	75.6	11.6
Induction	81.9	6.2	80.3	7.3	79.1	7.9	78.9	8.1
Deduction	79.6	7.8	79.3	8.4	80.3	9.6	80.6	5.2

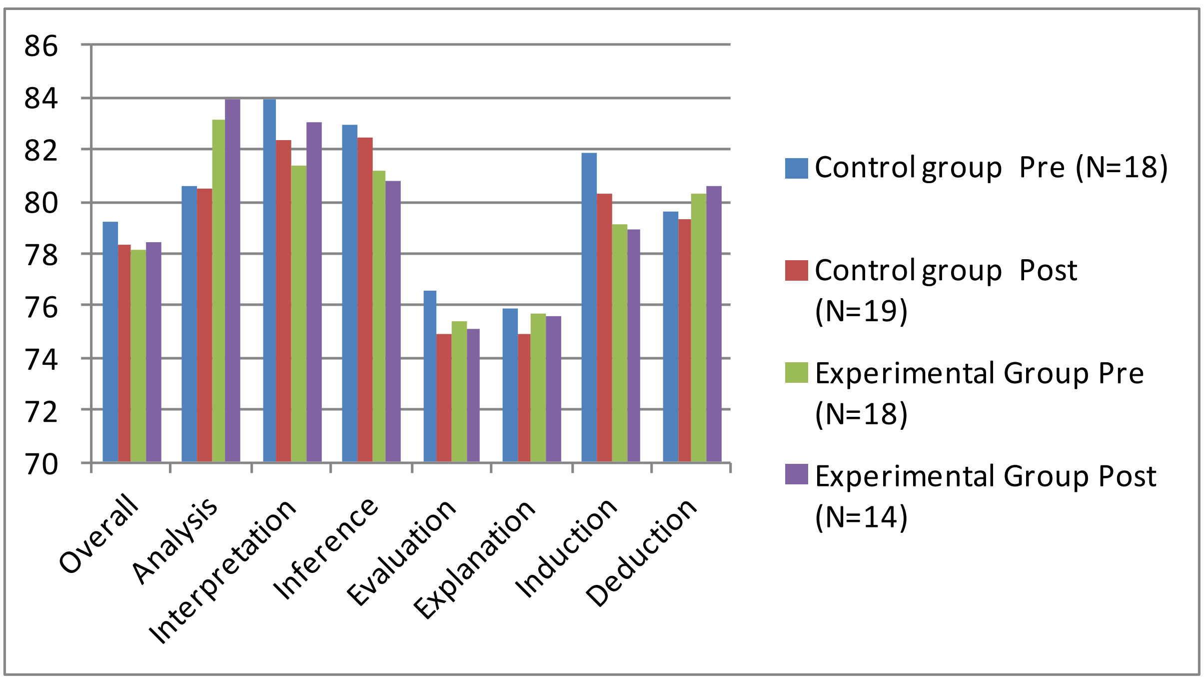


Figure 4-4. CCTST pre-and post-test results for control and treatment group

Table 4-4. CCTDI pre-and post-test results for control and treatment group

	Control group				Treatment group			
	Pre (N=18)	SD	Post (N=20)	SD	Pre (N=22)	SD	Post (N=19)	SD
Truth-seeking	35.9	4.5	35.2	3.8	35.8	5.9	35.4	8.1
Open-mindedness	39.9	5.4	40.1	4.2	41.6	5.3	41.6	6.7
Inquisitiveness	46.1	6.2	44.9	3.9	46.8	6.1	46.7	5.9
Analyticity	46.6	4.5	44.3	4.1	48.1	3.7	48.1	3.9
Systematicity	39.7	4.6	40.5	3.7	41	6.3	40.1	6.8
Confidence in reasoning	45.6	4.7	43.6	5.3	47.3	5.3	47.1	6.3
Maturity and judgment	39.8	4	41.4	4.4	41.5	4.4	39.3	8.6

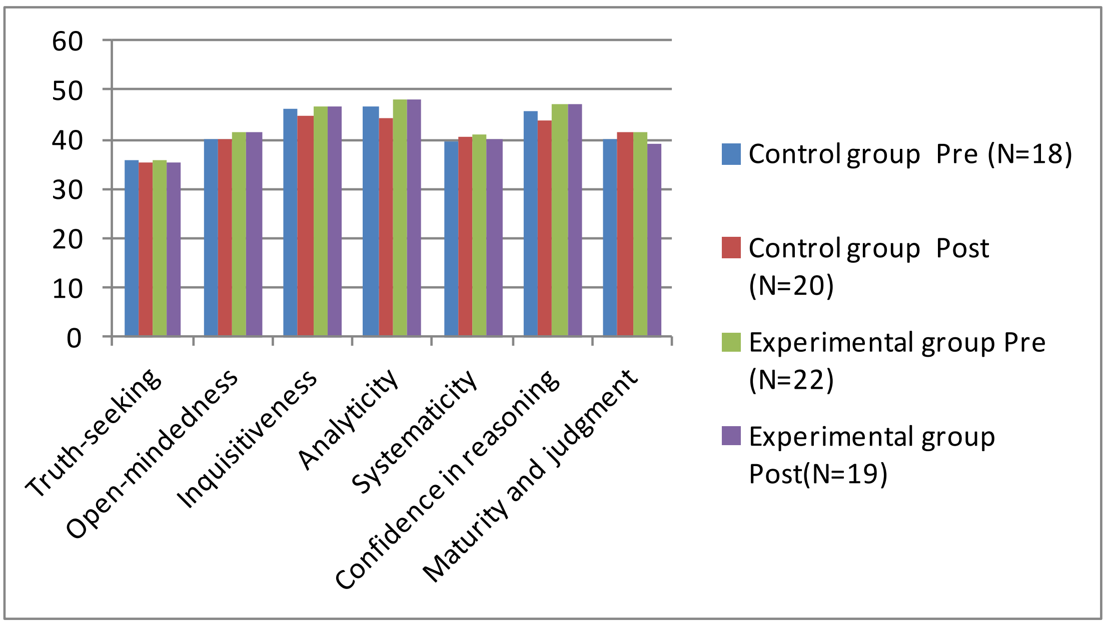


Figure 4-5. CCTDI pre-and post-test results for control and treatment group

Table 4-5. Pre-test results for control group

	N	Mean	Median	SD	Minimum	Maximum
CCTDI						
Truth-seeking	18	35.9	35	4.5	29	45
Open-mindedness	18	39.9	42	5.4	28	49
Inquisitiveness	18	46.1	46	6.2	33	56
Analyticity	18	46.6	45	4.5	41	55
Systematicity	18	39.7	41	4.6	31	48
Confidence in reasoning	18	45.6	46	4.7	37	56
Maturity of Judgment	18	39.8	39	4	34	50
CCTST						
Overall	18	79.2	79	6.5	68	90
Analysis	18	80.6	83	9.2	70	85
Interpretation	18	83.9	87	8.8	61	94
Inference	18	82.9	85	8.2	72	94
Evaluation	18	76.6	78	7.1	63	88
Explanation	18	75.9	74	8.3	61	87
Induction	18	81.9	82	6.2	71	95
Deduction	18	79.6	79	7.8	66	92

Table 4-6. Post-test results for control group

	N	Mean	Median	SD	Minimum	Maximum
CCTDI						
Truth-seeking	20	35.2	36	4	28	43
Open-mindedness	20	40.1	42	4	31	46
Inquisitiveness	20	44.9	45	4	39	54
Analyticity	20	44.3	45	4	37	51
Systematicity	20	40.5	40	4	34	45
Confidence in reasoning	20	43.6	44	5	36	54
Maturity of Judgment	20	41.4	41	4	32	49
CCTST						
Overall	19	78.3	79	8	66	92
Analysis	19	80.5	80	9	65	95
Interpretation	19	82.4	87	8	68	94
Inference	19	82.5	80	8	72	97
Evaluation	19	74.9	75	10	59	92
Explanation	19	74.9	74	9	55	94
Induction	19	80.3	82	7	71	92
Deduction	19	79.3	79	8	66	92

Table 4-7. Pre-test results for treatment group

	N	Mean	Median	SD	Minimum	Maximum
CCTDI						
Truth-seeking	22	35.8	37	5.9	28	46
Open-mindedness	22	41.6	43	5.3	31	52
Inquisitiveness	22	46.8	46	6.1	39	56
Analyticity	22	48.1	48	3.7	37	54
Systematicity	22	41	40	6.3	34	51
Confidence in reasoning	22	47.3	48	5.3	36	56
Maturity of Judgment	22	41.5	41	4.4	32	50
CCTST						
Overall	18	78.1	79	8.4	64	97
Analysis	18	83.1	85	8.8	65	95
Interpretation	18	81.4	81	8	68	94
Inference	18	81.2	82	7.5	69	94
Evaluation	18	75.4	75	11	55	100
Explanation	18	75.7	74	11	55	100
Induction	18	79.1	81	7.9	64	100
Deduction	18	80.3	81	9.6	64	95

Table 4-8. Post test results for treatment group

	N	Mean	Median	SD	Minimum	Maximum
CCTDI						
Truth-seeking	19	35.4	38	8.1	10	49
Open-mindedness	19	41.6	43	6.7	24	53
Inquisitiveness	19	46.7	47	5.9	34	55
Analyticity	19	48.1	47	3.9	39	55
Systematicity	19	40.1	38	6.8	28	54
Confidence in reasoning	19	47.1	46	6.3	30	60
Maturity of Judgment	19	39.3	41	8.6	10	49
CCTST						
Overall	14	78.4	78.5	6.2	66	87
Analysis	14	83.9	85	6.3	70	90
Interpretation	14	83.1	81	8.4	74	100
Inference	14	80.8	80	5.6	69	89
Evaluation	14	75.1	75	9.5	59	88
Explanation	14	75.6	74	11.6	55	87
Induction	14	78.9	79	8.1	66	92
Deduction	14	80.6	79	5.2	69	87

Table 4-9. Descriptive statics of demographics

		Mean	SD	N
Gender				
	Male	77.0	7.5	29
	Female	77.7	6.6	7
Age				
	1=17-20	77.7	7.0	6
	2=21-24	77.7	7.7	26
	3=25-29	75.5	7.0	4
Status				
	1=Freshman	0		
	2=Sophomore	87	N/A	1
	3=Junior	77.3	8.8	9
	4=Senior	77.1	6.8	26
Devoted CT				
	1=Yes	77.4	7.8	28
	2=No	77.4	5.9	8
Incorporated CT				
	1=Yes	77.3	8.6	19
	2=No	78.1	5.8	17
Race				
	1=African American	83.0	5.7	2
	2=American Indian /Alaskan Native		0	0
	3= Asian or Pasific Islander	75.0	6.6	4
	4=Hispanic	75.4	10.4	7
	5=White-non Hispanic	78.0	6.5	23

Table 4-10. Dependent t-test results for CCTST

	Control		Treatment	
	CCTSTPre	CCTSTPost	CCTSTPre	CCTSTPost
Mean	78.67	77.22	78.50	79.20
Standard Deviation	7.25	7.77	4.97	6.37
Observations	18	18	10	10
Pearson Correlation	0.60		0.73	
df	17		9	
t Stat	0.90		-0.50	
P(T<=t) one-tail	0.19		0.31	
t Critical one-tail	1.74		1.83	
P(T<=t) two-tail	0.38		0.63	
t Critical two-tail	2.11		2.26	

***Significance level 0.05

Table 4-11. Dependent t-test results for CCTDI

	Control		Treatment	
	CCTDIPre	CCTDIPost	CCTDIPre	CCTDIPost
Mean	295.00	296.33	301.88	290.18
Standard Deviation	20.55	18.35	24.54	28.97
Observations	18	18	17	17
Pearson Correlation	0.35		0.06	
df	17		16	
t Stat	-0.25		1.31	
P(T<=t) one-tail	0.40		0.10	
t Critical one-tail	1.74		1.75	
P(T<=t) two-tail	0.80		0.21	
t Critical two-tail	2.11		2.12	

***Significance level 0.05

Table 4-12. Pre- and post CCTST and CCTDI independent t-test results

	Pre		Post	
CCTST	Control	Treatment	Control	Treatment
Mean	78.47	78.88	77.95	79
Standard Deviation	7.10	7.98	7.70	6.01
Observations	19	17	20	13
df	32		30	
t Stat	-0.16		-0.44	
P(T<=t) one-tail	0.44		0.33	
t Critical one-tail	1.69		1.70	
P(T<=t) two-tail	0.87		0.66	
t Critical two-tail	2.04		2.04	
CCTDI				
Mean	294.47	301.67	295.29	291.16
Standard Deviation	20.11	23.42	18.44	27.47
Observations	19	21	21	19
df	38		31	
t Stat	-1.04		0.55	
P(T<=t) one-tail	0.15		0.29	
t Critical one-tail	1.69		1.70	
P(T<=t) two-tail	0.30		0.58	
t Critical two-tail	2.02		2.04	

***Significance level 0.05

Table 4-13. CCTDI mean scores of strong and moderate active and reflective learners

	Pre	SD	Post	SD
Active				
Subject mean (N=6)	294.3	21.8	300.5	31.8
Treatment mean (N=17)	305.3	23.3	291.2	29.3
Overall mean (N=30)	298.3	21.9	293.3	23.8
Treatment(-)subjects (N=11)	312.7	22.4	287.2	28.2
Overall mean-subject (N=24)	300.3	22.2	292.3	22.2
Reflective				
Subject mean (N=2)	276.0	26.2	272.5	26.2
Treatment mean (N=17)	305.3	23.3	291.2	29.3
Overall mean (N=30)	298.3	21.9	293.3	23.8
Treatment(-)subjects (N=15)	305.3	23.3	292.5	30.1
Overall (-)subjects	299.3	21.9	293.7	23.8

***Significance level 0.05

Table 4-14. Independent t-test of knowledge acquisition assessment instruments

	Control Hw	Treatment Hw	Control Quiz	Treatment Quiz
Mean	16.87	14.67	8.82	9.19
Standard Deviation	2.97	5.46	.84	.75
Observations	15	18	19	21
df	27		36	
t Stat	1.47		-1.49	
P(T<=t) one-tail	0.08		0.07	
t Critical one-tail	1.70		1.69	
P(T<=t) two-tail	0.15		0.15	
t Critical two-tail	2.05		2.03	

***Significance level 0.05

Table 4-15. Correlation value of CCTST and survey

	CCTSTPre	Survey
CCTSTPre	1	
Survey	0.03773047	1

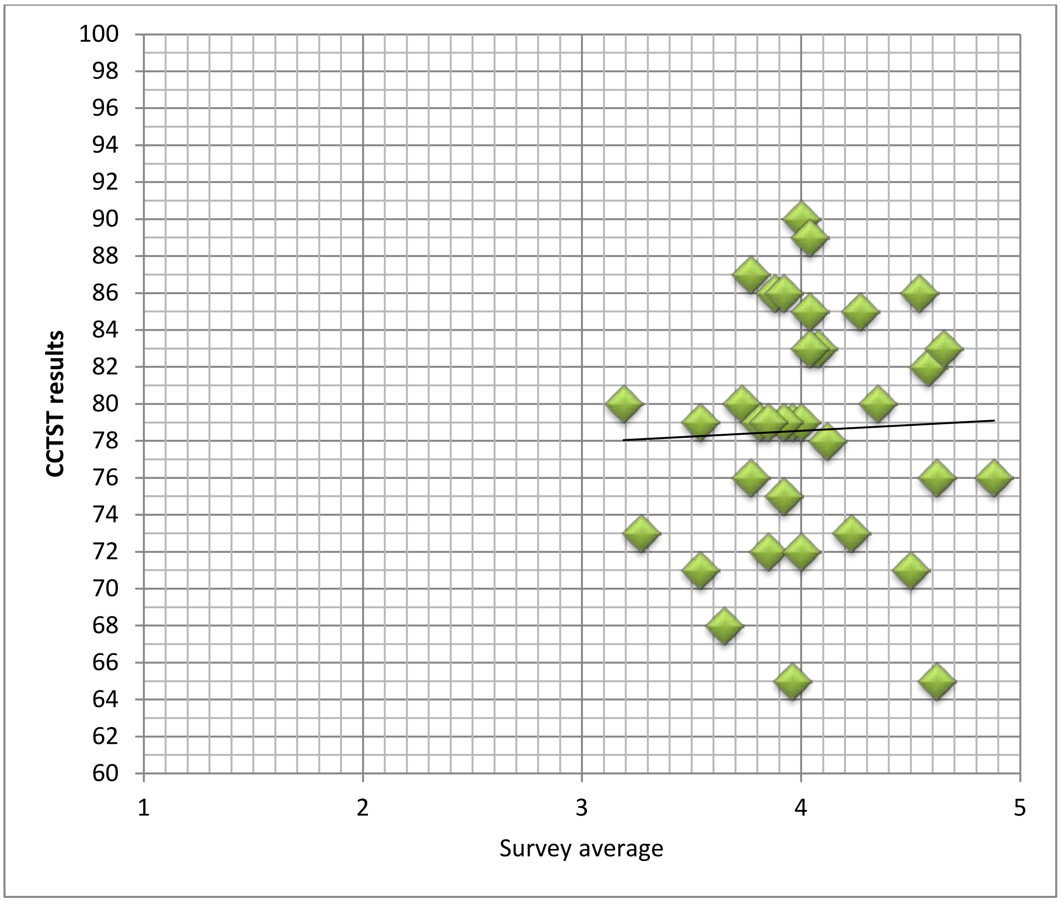
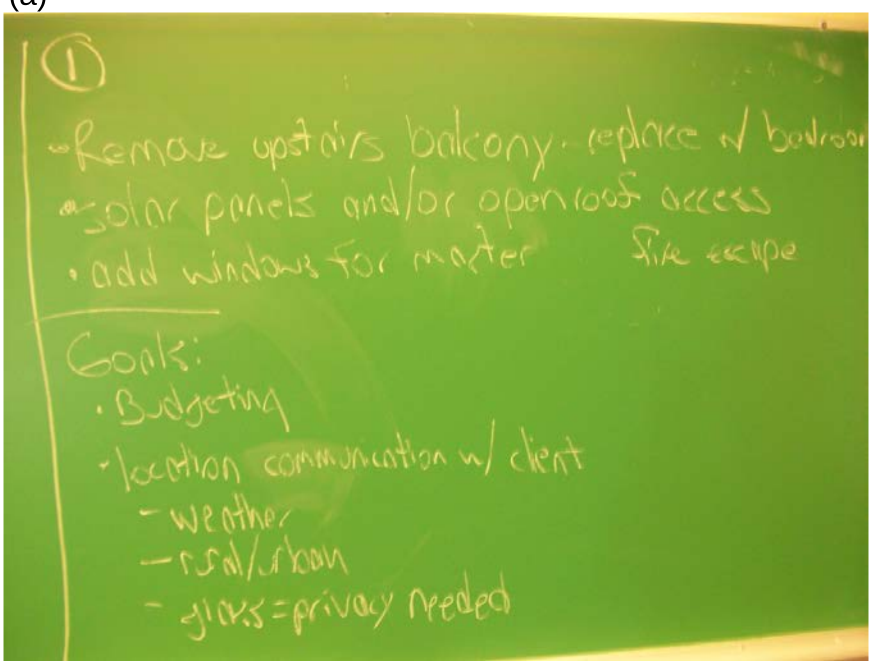


Figure 4-6. Scatter plot of CCTST and survey results

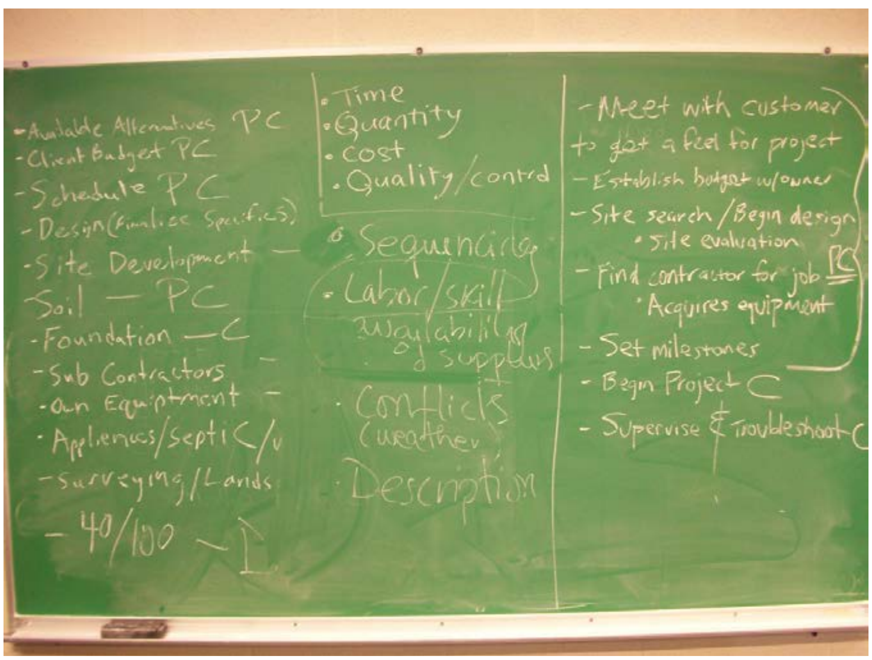
Figure 4-6. In class examples-(a) Group discussion (b) One of the groups' work list, (c) One of the groups' goal list, (d) Combined and categorized lists (Photos courtesy of Dr.Pesantes)

(a)



(b)


Goals
Satisfy the customer
Make profit / Minimize cost
Apply value engineering
Achieve a degree of luxury
Sustainable Project
Goal
(c)


- Available Alternatives PC
- Client Budget PC
- Schedule PC
- Design (Finalize Specifics)
- Site Development
Soil — PC
- Foundation — C
- Sub Contractors
- Own Equipment
- Appliances/septic / v
- Surveying/Lands
- 40/100
- Time
- Quantity
- Cost
- Quality/control
- Sequencing
- Labor/skill
availability of supplies
- Conflicts (weather)
- Description
- Meet with customer to get a feel for project
- Establish budget w/owner
- Site search / Begin design
- Site evaluation
- Find contractor for job PC
- Acquires equipment
- Set milestones
- Begin Project C
- Supervise & Troubleshoot C
(d)

CHAPTER 5
DISCUSSIONS AND FUTURE RESEARCH

The purpose of this study was to determine whether students' critical thinking abilities and dispositions and content knowledge acquisition after implementation of PBL method.

Academics, researchers, and educators have been trying to find a way of teaching that would show a model and provide environments for students to apply and develop critical thinking skills and become lifelong learners as they are an integral part of the requirements of a successful engineer of the new century. Active learning methods have gone under rigorous examinations for their improvement of providing such skills. The research presented describes active learning methods that were found to be effective in engineering course, and committee members and she decided on focusing PBL and implementing it in a civil engineering course. A true experimental pre- and post-test research design was conducted in the Civil Engineering Practice course. The course consisted of 45 students and was a good representative of student demographics. The experiment was four weeks long. Students were asked to take CCTST and CCTDI before and after experiment along with student perception survey and learning styles index at the beginning of the experiment. Results of the experiments were somewhat unexpected; however, this study is not the only one with such results. Some studies with inconclusive results or disfavoring results existent in the literature.

Limitations

Below are some of the factors that the researcher believes might affected the experiment outcome.

Familiarity with the Teaching Method

The researcher believes the importance of dissemination method of teaching techniques. Even though the effectiveness of one method is proven through experiments, unless, the instructor and learning environment are as close as possible to the conditions in the original experiment; it is hard to receive the same results. For this experiment, the researcher believes instructor effect was significant. Firstly, the instructor was not familiar with PBL method; therefore, orientation sessions were given before experiment started as well as outline of PBL steps for the specific course content. Yet, it was relatively difficult for the instructor to take a guide/tutor role as opposed to the more traditional instructor role. Whenever she felt uncomfortable she went back to the instructor role. Even though the researcher was present in the classroom, she was not supposed to and has not interfered with the process. If the instructor was an expert in PBL, it might have changed the results of the data analysis.

The researcher believes, since the experiment is in a short period of time, the instructor being sick and canceling the class for more than a week might be considered as another factor. After having a break students seemed less interested.

Number of Participants

The limited number of participants might affect generalization of findings. The research was particular to a specific group of student (i.e. Civil Engineering) in a specific department area (i.e. Construction Engineering and Management). Also, there were several students who fail to take the test or finish it successfully which reduced the initial number of participants. Increased number of students would provide better sample for statistical analyses and lead to a more accurate conclusion. Increased number of students will allow more comparative studies to be conducted and analyze whether critical thinking skills differ depending on demographics. Also, a department wide experiment, for example, would increase the generalizatbility of the research study.

Longevity of the Experiment

The length of the experiment is important when conducting such an empirical study on teaching methods. It is shown, especially for active learning methods, benefits of implementing certain teaching methods will show up after a long period of time. Since the goal is to teach lifelong skills, it is necessary to expose students to different learning environments and content before assessing for acquisition of these skills.

Future Research

Ideally a longitudinal research would be the most suitable one to determine critical thinking skills, knowledge, and disposition. Having an experiment for a long period of time and assessing the participants would lead to more significant results.

This study example was a convenience example; therefore future experiments with higher number of participants would be more likely to result in more significant results.

Hawthorne effect should be considered for the future research. In this study students were aware of being a part of an experiment, which might have caused them to behave in a different way than they normally would.

The relationship between CCTDI and students learning styles deserves an in depth analysis with more data points.

APPENDIX A
INDEX OF STUDENT LEARNING QUESTIONNAIRE

NC STATE UNIVERSITY

Index of Learning Styles Questionnaire

Barbara A. Soloman
First-Year College
North Carolina State University
Raleigh, North Carolina 27695

Richard M. Felder
Department of Chemical Engineering
North Carolina State University
Raleigh, NC 27695-7905

Directions

Please provide us with your full name. Your name will be printed on the information that is returned to you.

Full Name

For each of the 44 questions below select either "a" or "b" to indicate your answer. Please choose only one answer for each question. If both "a" and "b" seem to apply to you, choose the one that applies more frequently. When you are finished selecting answers to each question please select the submit button at the end of the form.

1. I understand something better after I
   - **(a)** try it out.
   - **(b)** think it through.
2. I would rather be considered
   - **(a)** realistic.
   - **(b)** innovative.
3. When I think about what I did yesterday, I am most likely to get
   - **(a)** a picture.
   - **(b)** words.
4. I tend to

- **(a)** understand details of a subject but may be fuzzy about its overall structure.
- **(b)** understand the overall structure but may be fuzzy about details.

5. When I am learning something new, it helps me to
   - **(a)** talk about it.
   - **(b)** think about it.
6. If I were a teacher, I would rather teach a course
   - **(a)** that deals with facts and real life situations.
   - **(b)** that deals with ideas and theories.
7. I prefer to get new information in
   - **(a)** pictures, diagrams, graphs, or maps.
   - **(b)** written directions or verbal information.
8. Once I understand
   - **(a)** all the parts, I understand the whole thing.
   - **(b)** the whole thing, I see how the parts fit.
9. In a study group working on difficult material, I am more likely to
   - **(a)** jump in and contribute ideas.
   - **(b)** sit back and listen.
10. I find it easier
    - **(a)** to learn facts.
    - **(b)** to learn concepts.
11. In a book with lots of pictures and charts, I am likely to
    - **(a)** look over the pictures and charts carefully.
    - **(b)** focus on the written text.
12. When I solve math problems
    - **(a)** I usually work my way to the solutions one step at a time.
    - **(b)** I often just see the solutions but then have to struggle to figure out the steps to get to them.
13. In classes I have taken
    - **(a)** I have usually gotten to know many of the students.
    - **(b)** I have rarely gotten to know many of the students.
14. In reading nonfiction, I prefer
    - **(a)** something that teaches me new facts or tells me how to do something.
    - **(b)** something that gives me new ideas to think about.
15. I like teachers

- **(a)** who put a lot of diagrams on the board.
- **(b)** who spend a lot of time explaining.

16. When I'm analyzing a story or a novel
    - **(a)** I think of the incidents and try to put them together to figure out the themes.
    - **(b)** I just know what the themes are when I finish reading and then I have to go back and find the incidents that demonstrate them.

17. When I start a homework problem, I am more likely to
    - **(a)** start working on the solution immediately.
    - **(b)** try to fully understand the problem first.

18. I prefer the idea of
    - **(a)** certainty.
    - **(b)** theory.

19. I remember best
    - **(a)** what I see.
    - **(b)** what I hear.

20. It is more important to me that an instructor
    - **(a)** lay out the material in clear sequential steps.
    - **(b)** give me an overall picture and relate the material to other subjects.

21. I prefer to study
    - **(a)** in a study group.
    - **(b)** alone.

22. I am more likely to be considered
    - **(a)** careful about the details of my work.
    - **(b)** creative about how to do my work.

23. When I get directions to a new place, I prefer
    - **(a)** a map.
    - **(b)** written instructions.

24. I learn
    - **(a)** at a fairly regular pace. If I study hard, I'll "get it."
    - **(b)** in fits and starts. I'll be totally confused and then suddenly it all "clicks."

25. I would rather first
    - **(a)** try things out.
    - **(b)** think about how I'm going to do it.

26. When I am reading for enjoyment, I like writers to
    - **(a)** clearly say what they mean.
    - **(b)** say things in creative, interesting ways.

27. When I see a diagram or sketch in class, I am most likely to remember
    - **(a)** the picture.
    - **(b)** what the instructor said about it.

28. When considering a body of information, I am more likely to
    - **(a)** focus on details and miss the big picture.
    - **(b)** try to understand the big picture before getting into the details.

29. I more easily remember
    - **(a)** something I have done.
    - **(b)** something I have thought a lot about.

30. When I have to perform a task, I prefer to
    - **(a)** master one way of doing it.
    - **(b)** come up with new ways of doing it.

31. When someone is showing me data, I prefer
    - **(a)** charts or graphs.
    - **(b)** text summarizing the results.

32. When writing a paper, I am more likely to
    - **(a)** work on (think about or write) the beginning of the paper and progress forward.
    - **(b)** work on (think about or write) different parts of the paper and then order them.

33. When I have to work on a group project, I first want to
    - **(a)** have "group brainstorming" where everyone contributes ideas.
    - **(b)** brainstorm individually and then come together as a group to compare ideas.

34. I consider it higher praise to call someone
    - **(a)** sensible.
    - **(b)** imaginative.

35. When I meet people at a party, I am more likely to remember
    - **(a)** what they looked like.
    - **(b)** what they said about themselves.

36. When I am learning a new subject, I prefer to
    - **(a)** stay focused on that subject, learning as much about it as I can.
    - **(b)** try to make connections between that subject and related subjects.

37. I am more likely to be considered
    - (a) outgoing.
    - (b) reserved.

38. I prefer courses that emphasize
    - (a) concrete material (facts, data).
    - (b) abstract material (concepts, theories).

39. For entertainment, I would rather
    - (a) watch television.
    - (b) read a book.

40. Some teachers start their lectures with an outline of what they will cover. Such outlines are
    - (a) somewhat helpful to me.
    - (b) very helpful to me.

41. The idea of doing homework in groups, with one grade for the entire group,
    - (a) appeals to me.
    - (b) does not appeal to me.

42. When I am doing long calculations,
    - (a) I tend to repeat all my steps and check my work carefully.
    - (b) I find checking my work tiresome and have to force myself to do it.

43. I tend to picture places I have been
    - (a) easily and fairly accurately.
    - (b) with difficulty and without much detail.

44. When solving problems in a group, I would be more likely to
    - (a) think of the steps in the solution process.
    - (b) think of possible consequences or applications of the solution in a wide range of areas.

When you have completed filling out the above form please click on the Submit button below. Your results will be returned to you. If you are not satisified with your answers above please click on Reset to clear the form.

Submit Reset

Dr. Richard Felder, felder@ncsu.edu

APPENDIX B
STUDENT PERCEPTION SURVEY

PART 1. Student Perception of Critical Thinking Skills

The purpose of this questionnaire is to obtain information about your perception towards critical thinking. No personal information will be collected and you will not be graded upon your answers. Please indicate to what extent you agree or disagree with each of the following statements.

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
Interpretation					
1.1. I can accurately categorize any type of information.					
1.2. I can recognize when two ideas are related to each other.					
1.3. I can detect a person's purpose when asking a question.					
1.4. I can easily paraphrase what a person said while preserving that person's intended message.					
Analysis					
2.1. I know when a conclusion is based on opinion rather than facts.					
2.2. I can break up a given assignment into smaller, more manageable tasks.					
2.3. I can detect the similarities and differences between two opinions.					
2.4. I can determine whether an article is written for or against a claim.					
2.5. I can easily understand the main idea of a specific task that I am working on.					
Evaluation					
3.1. I can assess if a claim is likely to be true or false based on my knowledge and information easily					

available to me.					
3.2. I can identify fallacies in an argument.					
3.3. I can judge if a given argument is relevant to the situation at hand.					
3.4. I can determine whether an argument relies on false assumptions.					
Inference					
4.1. I always look for evidence to support my argument.					
4.2. I always ask questions until I am clear about an argument.					
4.3. I can formulate alternatives to a problem.					
4.4. Given a series of alternatives, I can determine which one should be applied to a given situation.					
Explanation					
5.1. I can clearly state my reasons to support a view point.					
5.2. I can keep a mental log of the steps followed in working through a long problem.					
5.3. I can clearly state my reasons for accepting a claim.					
5.4. I can clearly explain the reasons behind my decisions in any situation.					
Self-regulation					
6.1. To ensure that I successfully complete a project, I compare the finished product to the original specifications.					
6.2. I can judge to what extent my learning is influenced by deficiencies in my knowledge.					
6.3. I can identify my reasoning processes in coming to a conclusion.					
6.4. I always do self examination to determine if there is a mistake in					

my thinking.					
6.5. After self examination, if possible, I correct my mistakes.					

PART 2. Student Demographic Survey

The following information is being gathered only for statistical purposes. Please answer the questions below. You have a right to not answer to any of the questions.

1. Please indicate your gender.
   a. Male
   b. Female
2. Please indicate your race.
   a. African American
   b. American Indian/Alaskan Native
   c. Asian or Pacific Islander
   d. Hispanic
   e. White-non Hispanic
3. Please indicate your age.
   a. 17-20
   b. 21-24
   c. 25-29
   d. 30 or older
4. Please indicate your student status.
   a. Freshman
   b. Sophomore
   c. Junior
   d. Senior
   e. Other (specify)
5. Have you ever taken a critical thinking course or (or a course with a similar name) that is devoted to teach critical thinking skills and abilities?
   a. Yes
   b. No
   If yes, how many?

6. Have you ever taken courses that incorporated critical thinking into regular course work?
   a. Yes
   b. No
   If yes, how many?

7. What is your cumulative GPA?

APPENDIX C
CONSENT FORM

UF | Institutional Review Board
UNIVERSITY *of* FLORIDA

PO Box 112250
Gainesville, FL 32611-2250
352-392-0433 (Phone)
352-392-9234 (Fax)
irb2@ufl.edu

DATE: April 4, 2013

TO: Sevcan Agdas
PO Box 116580
Campus

FROM: Ira S. Fischler, PhD, Chair
University of Florida
Institutional Review Board 02

SUBJECT: **Approval of Protocol #2013-U-0116**
Effect of Problem Based Learning on Development of Critical Thinking Skills and Dispositions

SPONSOR: None

I am pleased to advise you that the University of Florida Institutional Review Board has recommended approval of this protocol. Based on its review, the UFIRB determined that this research presents no more than minimal risk to participants, and based on 45 CFR 46.117(c), An IRB may waive the requirement for the investigator to obtain a signed consent form for some or all subjects if it finds either: *(1) That the only record linking the subject and the research would be the consent document and the principal risk would be potential harm resulting from a breach of confidentiality. Each subject will be asked whether the subject wants documentation linking the subject with the research, and the subject's wishes will govern; or (2) That the research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context.*

The IRB authorizes you to administer the informed consent process as specified in the protocol. If you wish to make any changes to this protocol, ***including the need to increase the number of participants authorized***, you must disclose your plans before you implement them so that the Board can assess their impact on your protocol. In addition, you must report to the Board any unexpected complications that affect your participants.

This approval is valid through **February 1, 2014**. If you have not completed the study prior to this date, please telephone our office (392-0433), and we will discuss the renewal process with you. **Additionally, should you complete the study on or before the expiration date, please submit the study closure report to our office. The form can be located at** http://ib.ufl.edu/irb02/Continuing_Review.html It is important that you keep your Department Chair informed about the status of this research protocol.

ISF:dl

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Protocol Title: Effect of Problem Based Learning on Development of Critical Thinking Skills and Dispositions

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research Study:

The purpose of this research study is to determine whether one of the active teaching methods, problem based learning, has any effect on development of critical thinking skills and dispositions as well as on course content acquisition.

What you will be asked to do in the study:

If you decide to participate in this study, in addition to regular course work, you will be asked to:

Take a test of Learning Styles

Take a survey of Student Perception of Critical Thinking

Take a pre-test of California Critical Thinking Skills Test

Take a post-test of California Critical Thinking Skills Test

Take a pre-test of California Critical Thinking Disposition Inventory

Take a post-test of California Critical Thinking Disposition Inventory

By agreeing to participate in this study, you are allowing us to use your aforementioned test results and exam scores in this study.

Time required:

The total time required to take 1.) Learning styles test is about 10 minutes; 2.) Survey of Student Perception of critical thinking is about 15 minutes; 3.) California Critical

Thinking Skills Test (CCTST) is about 20 minutes; and 4.) California Critical Thinking Skills Disposition Inventory (CCSDI) is about 45 minutes.

Risk and Benefits:

This research does not involve potential physical, psychological, or economic harm. We do not anticipate that you will benefit directly by participating in this survey; however, data from this study may be used to improve the instructional methods in civil engineering classes. Also, by the end of this study you might gain awareness of your critical thinking and learning process which might lead you toward being more self-directed learners.

Confidentiality:

Your identity will be kept confidential. Your information will be assigned a code number as data points. When the study is completed, your record will be destroyed. Your name will not be used in any report.

Compensation:

The tests you will take will be counted as extra credit assignments for CGN4905-Civil Engineering Practice course. Each will count as 1 point towards final grade.

Voluntary participation:

Your participation in this study is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:

You are free to withdraw or discontinue your participation in the survey at any time without consequence. Your participation in this study is completely voluntary. There is no penalty for not participating.

Whom to contact if you have question about the study:

Principal Investigator: Sevcan Agdas, Graduate student, Department of Civil and Coastal Engineering, 460 Weil Hall, Phone: (352) 392-9537 X1532

Supervisor: Dr. Ralph Ellis, Associate Professor, Department of Civil and Coastal Engineering, 460 Weil Hall, Phone (352) 392-9537 X1485

Whom to contact about your rights as a research participant in this study:

IRB-02 Office, Box 112250, University of Florida, Gainesville, Fl 32611-2250, Phone: (352) 392-0433

Agreement:

By clicking the button below you accept that: you have read the procedure described above, you voluntarily agree to participate in the procedure and you have received a copy of this description.

ACCEPT

APPENDIX D
GUIDE FOR PBL IN CLASS IMPLEMENTATION

Before beginning the experiment, there was a need for explanation about the teaching method since none of the students has had information about it. The role of the student, the role of the teacher, the reasoning behind this method is explained in the class. Sample of in class problem cases:

Introduce the problem:
You are a design build company and one day a client walks in and tells you that he wants a house built similar to the ones in the pictures. This picture is the only information you have about the house.

- Now look at the picture and write down the known information about the project (1mins). Don't give them so much time since there isn't that much information given.
- Now write down your goals. What do you want to accomplish with this project? (Again I don't think they need that much time for this part. After each group discussion ask one of them from their group to come to the board and write down what they found
- What they need to know to be able to deliver what the client is asking? These are also called learning goals. We are looking for an answer something like, "we need to plan our project". I am pretty sure they will come up with planning and scheduling answer. If the quantitative and qualitative task attributes do not come right away, you can ask them how they would write it down if there are supposed to be more organized and are expected to write down all the details they can think of within the limited time. Here, you need to give them at least 6-7 minutes because it will take time.
- After they write down their planning tasks, you can ask them something like "what do you think your assumptions here? And what are your limitations? How do you think you can overcome these limitations? Here we are trying to push them towards the understanding of leveling.
- If you want them to give you activities grouped in before and after construction starts, you can lead them to think about those processes by asking "Is planning and scheduling enough to carry out a project. What else do you think you might need? In which order would they be in? At which stages of project you should be getting them?
- For the use of schedules: "what do you think you can use a schedule for in a company?" give them a couple of minutes to think it over and come up with answers.
- How would you represent the task in a schedule if you need to show the client how much time it will take? What do you think you would need to include or exclude? Give them couple of minutes to think and ask them to draw it on the board. Ask why they thought it was appropriate.
- After this, you can ask them, what are their assumption about the relationship between activities? What would happen if they wait until each activity is finish?

Can they actually do it? Is it actually possible with every activity? Give them time to talk it over and probably they will come up with the answer of FS, SS, FF. relationships. Probably not the same wording.

- To get them think about the critical activities: you can ask something similar to this: “Do you think all the activities are equally important and cannot be moved around in the schedule? “

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BIOGRAPHICAL SKETCH

Sevcan Agdas received a Bachelor of Art degree in Education in 2006 from Hacettepe University in Turkey. She received her Master of Science degree in Construction Engineering and Engineering Management Program from Civil and Coastal Engineering in 2010 from University of Florida. Her research agenda focuses on engineering education, distance education, sustainability education, active learning methods, critical thinking, and faculty development. She worked as a teaching assistant throughout her MS and PhD education.

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