AC 2007-3115: RE-ENGINEERING ENGINEERING: TEACHING STUDENTS HOW TO THINK CRITICALLY

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RE-ENGINEERING ENGINEERING: TEACHING STUDENTS HOW TO THINK CRITICALLY

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Abstract

Teaching and learning in the American school system should be directed toward creating self-guided, independent thinkers. Teachers who are committed to creating a critical thinking environment realize that the primary purpose of all education is to teach students how to learn effectively. More importantly, institutions of higher education, specifically those whose mission statements include educating students who may not be as academically prepared as their peers, may want to consider re-engineering their curricula so that they can produce self-guided independent thinkers.

This mixed methods research study will examine the affect of critical thinking instruction in a critical thinking course on minority engineering students' cognitive skills at Morgan State University (MSU). Morgan State University is a historically black college and university (HBCU) in Baltimore, Maryland. The diverse student population consists of approximately 6,000 students, with more than 500 students enrolled within MSU's School of Engineering. When conducting a critical thinking pilot course during the spring 2006 semester at Morgan State University, results from a pre- and post-assessment showed 50% improvement in students' critical thinking performance.

Purpose

The Center for Advanced Microwave and Research Applications (CAMRA) is a NASA-sponsored University Research Center (URC). Its mission is to produce a significant number of students who obtain advanced degrees in STEM disciplines. In order to satisfy these requirements, CAMRA's educational engineering researchers are implementing and assessing novel and innovative programs and interventions.

Initially, during the summer 2005, CAMRA, through its summer bridge program, the Pre-Accelerated Curriculum in Engineering Program (PACE), hypothesized that a course on critical thinking could elevate information processing and, as a result, increase academic outcomes in STEM courses. To further this engineering education research study, the researchers conducted a pilot course during the Spring 2006 semester with CAMRA Scholars, which consisted of freshmen, sophomore, and junior students, where both quantitative and qualitative data were gathered.

Methods and Findings

CAMRA Scholars participated in a 10-week critical thinking course, which met once per week for 1.0 hour. Students were given the Watson Glaser Critical Thinking Appraisal Form A assessment as a pre- and post- assessment to determine if the formal critical thinking course improved or enhanced students' critical thinking skills. Bloom's Taxonomy was used as a framework to help students differentiate between lower and higher order thinking skills. This course was considered a pilot course for the researcher's dissertation topic.

While 75% of the students improved their post – assessment scores compared to their pre-assessment scores, data analyses – descriptive and inferential statistics were performed, using the raw scores found in the Watson-Glaser Manual for a small college in the Northeast geared toward early entry.

Key words: Critical Thinking; STEM Education and Minorities

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Introduction

Growing interest and concern around the quality and effectiveness of colleges and universities regarding new measures of student outcomes and development continues to be discussed[1] (Aper & Hinkle, 1991). In that vein, the critical goals of higher education are to cultivate critical thinkers [2] (Tsui, 1998).

Students attend higher education institutions with an expectation and anticipation that they will benefit from knowledge acquisition and develop an expertise in a designated discipline. The role of higher education is becoming increasingly demanding, especially given the criticism the K-12 educational system is not preparing students to think beyond rote memorization[3] (Darling-Hammond, 2000). Learning in higher education institutions, however, is thought to be qualitatively different from learning at earlier levels of education[4] (Dubuc, 1999).

While more than ever before Americans are highly educated, Tsui (1999) suggests to assume that they are necessarily better educated may not be true [5]. Initiatives, policies, and programs by government agencies including the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF), have focused their attention on educational disparities among those who are in the pool of the higher educated, especially where those disparities zero in on African American students studying science, technology, engineering, and mathematics.

According to a January 2007 report provided by NSF, in 1994, out of the 95.9 % of science and engineering Bachelor's degrees awarded, only 8.4% of African Americans received Bachelors degrees, while 65.1% of Caucasians had received the same degree (NSF, 2007) [6].

The percentage of African Americans obtaining Master's and Doctorates declined further. During the same year, 1994, 6.3% African Americans out of the 70.2% of the science and engineering degrees awarded, received a Master's degree, compared to 45.9% of Caucasians who earned a Master's. Out of the 59.8 recipients of doctoral degrees in 1994, African Americans were awarded 2.8% doctoral degrees level compared 45.7% of Caucasians (NSF, 2007) [6].

As a precursor to understanding those disparities, examining the history of higher education is useful. Overall, the American education system was designed to assimilate and control a highly selective group of people – white males in proper morals and manners, which primarily included Bible instruction [7, 8] (Cohen, 1988; Gordon & Browne, 2004). Minorities and women's educational needs were not taken into consideration when policies and procedures were established for higher education institutions in America.

The education of non-white males did not emerge until the late 19th and early 20th centuries. Congress passed the Morrill Land-Grant Act in 1862, which provided federal land to states to open up colleges and universities. One black college was opened under this act [9] (Peltak, 2003).

Of note is that the history of African Americans' educational attainment mirrors the social, economic, political, and cultural climate created and influenced by the specific eras of the American history. While today, African Americans are making strides in obtaining a higher education, the *Journal of Blacks in Higher Education* (JBHE, 1999) indicated that 14.9 percent of blacks ages 30 to 34 had earned a college degree, displaying the fact that more than 85 percent of young black adults had not completed college [10]. A continuing shortfall of black students remains evident when the percentages of blacks and whites enrolled full-time in four-year, private, predominantly white universities are compared to each other [10] (JBHE, 1999).

The shortage of blacks earning college degrees affects the nation as a whole. Reported achievement gaps by Fleming, Garcia & Morning (1995); Fleming & Morning (1998); McDonald & Powell (1998); Lee (1986); Garibaldi (1997); Perry, Steele & Hilliard (2003); and Jibrell (1990), have demonstrated that White students scored 30 percent higher than Black students taking the National Assessment of Educational Progress (NAEP) science and reading and writing scores [11, 12, 13, 14, 15, 16, 17]. Minority students are being excluded from critical thinking instruction in most urban schools; these issues are shifting our focus on African Americans and the colleges and universities serving them. What colleges and universities may examine are refinement of academic skills and therefore the role critical thinking skills play a role in developing talent, especially scientific talent [18] (Fleming, Garcia, & Morning, 1996). Tsui (1999) believed more time is needed on teaching students how to think instead of teaching them what to think[5].

Cognitive Development and Critical Thinking Skills

The examination of cognitive development, critical thinking skills, and teaching approaches to make learning meaningful and relevant are not novel educational research topics. Researchers have made contributions to the literature on the theory and practice regarding cognitive development and critical thinking skills.

However, when examining minority engineering students who attend HBCUs, explanatory research was not found regarding the relationship between critical thinking skills abilities and critical thinking skill development. Teaching critical thinking skills, especially in higher education, seems to have received limited attention when it specifically applies to minority students [19] (Legare, 2002). Zeroing in on building academic skills with the African American population, especially in the STEM network, can provide a building block for development and training of such populations.

Current literature supports two methods of increasing students' critical thinking skills: (a) providing a single course in critical thinking and (b) embedding critical thinking into an existing curriculum [2]. Minority students need to learn how to think critically and professors need to be equipped to teach students how to think critically. Teachers had vague ideas about critical thinking and little to no training in terms of developing their students' thinking skills [20]. Academic preparation for minority urban students continues to be challenging for educators in K-12 and also by implication for higher education environments.

Problem Statement

The problem addressed in this study seeks to explore if critical thinking scores from a pre- and post- assessment will improve as a result of an intervention, namely a stand-alone critical thinking course with a predominantly African American engineering student population at Morgan State University in Baltimore, Maryland. Discovering the impact of critical thinking skill developments using statistical analyses may address the need for implementing engineering education programs and services within schools of engineering across the country. In addition, enhancing critical cognitive development and thinking skills could prepare and motivate minority students to pursue advanced degrees in engineering, thereby potentially increasing the overall retention rates on the undergraduate level.

Conceptual Framework

This researcher is focused on an approach to critical thinking and the cognitive development abilities of students from a constructivist theoretical framework. Constructivism provides a transactional model of teaching where students are actively engaged in tasks that are designed to create a personal meaning [8]. The learner constructs knowledge and learns through adaptation, instead of knowledge being transferred from the teacher to the learner. The primary constructivist theorist, Lev Vygotsky, considered the child as a whole, taking into consideration the child's family, culture and his community. Moreover, Vygotsky's thesis that human mental functions were social in origin, introduced the distinctions between lower and higher mental functions.

For this study, Bloom's Taxonomy was used as a model and framework for students to be able to conceptualize the differences between higher and lower order thinking skills. The assessment categories in the Watson-Glaser Critical Thinking Appraisal were also used to help students distinguish between higher and lower order thinking skills.

Role of Higher Education

The role of higher education is becoming increasingly demanding, especially given that the K-12 educational system is not preparing students to think beyond rote memorization. Fowler (2003), documented from *The Nation's Report Card* report in her dissertation that students have command of lower-level rote skills, but have difficulty using what they know to interpret an experiment, and comprehend a text. Students can not apply what they know in a flexible and spontaneous way to solve ill-structured and ambiguous problems (Fowler, 2003) [21].

Tsui (2003, p.320) found that institutions of higher education have contributed to inequitable distribution of "educational capital" by making possible the advancement of certain skills and talents, including the development of critical thinking skills [22] (Tsui, 2003). Studies have shown that graduates of prestigious higher education institutions gleaned better rewards in the labor market because received a superior educational training because as Tsui (2003) suggested, selective institutions were more likely to promote advanced thinking skills [22].

Findings from a 1995 follow-up survey from the Cooperative Institutional Research Program (CIRP) revealed that the ability to think critically was rated as the second most important life skill by individuals who had been freshmen nine years before 1995. When rating the importance of critical thinking by education level, income, and occupation, additional data showed that people in high-status occupations, earning higher incomes with more education, judged the ability to think critically more important than those people in low-status occupations, earning lesser incomes, with less education (Tsui, 2003) [22].

According to Tsui (2003) critical thinking skill development was linked to class origins. Disparities were found in educational, cultural, and social capital when comparisons were made between students from higher socio economic status backgrounds and those from lower socio economic status backgrounds. Parents from the elite class tended to be engaged in professional, white-collar positions where there was a demand or the allowance of frequent exercise of critical thinking skills and decision-making opportunities (Tsui, 2003) [22].

Moreover, Tsui (2003) contends that all higher educational institutions should enhance critical thinking skill development to their students and should be held accountable to providing this service. Tsui (2003) found that students entered selective and nonselective higher education institutions with varying levels of critical thinking skills, which widened during the college years. Presumably, those students at nonselective institutions possessed weaker critical thinking skills and were in need of greater improvement than those at selective institutions [22]. There was a great urgency for nonselective higher education institutions to pursue critical thinking skill development. Tsui (2003) questioned that if these students were not provided critical thinking skill during the last phase of their formal education, then when were they going to receive this service [22]?

Unlike Tsui (2003), Pascarella and Terenzini's (1991) in their review of 20 years of research concerning the impact of college on students found that institutional selectivity may have trivial impacts on the gains of individual students' cognitive development. Instead, programmatic initiatives and teaching quality seem to have more of an impact on student learning and cognitive growth and development [23]. They did not however study the impact of particular learning programs on students.

Braxton, Milem, and Sullivan (2000) found that faculty classroom behaviors within higher educational institutions can be linked to student departure [24]. Tinto (1993) discovered that there was a problem with student departure at higher education institutions since two-year colleges lose almost half of its students and four-year institutions lose about one-fourth of its students at the end of their first year [25]. Active learning, which included activities such as class discussion, debates, questions asked by faculty, role playing, cooperative learning, and course examination questions, can enhance student knowledge, comprehension, and retention of course content [24].

Students who were engaged in frequent active learning activities perceived gains in knowledge and understand and were more likely to persist in matriculating through an undergraduate curriculum because they viewed their collegiate experience to be personally rewarding [24]. The goals of higher order thinking activities were associated with active learning activities since students had to use a deep level approach when learning course content, which resulted in students using higher order thinking skills [24].

In order to increase the quality of undergraduate college education, Nordvall & Braxton (1996) proposed that colleges and universities increase the academic rigor and standards by requiring a higher level of understanding for course content [26]. A review can be conducted by assessing the current level of understanding for course content and using the Bloom's Taxonomy as a model to determine the level of questions asked in class and on examinations [26].

Critical Thinking and Engineering

Improving American competitiveness in a global world is becoming more and more vital. Critical thinking plays a significant role in developing scientific talent [11]. Traditionally, historically black colleges and universities (HBCUs) have made a disproportionate contribution to science degrees awarded to African American students[27]. In 1991, HBCUs awarded 48% of bachelor's degrees to African Americans. Government and industry appeared to sponsor special programs to increase the participation of minorities in science technology, engineering and mathematics. The number of minorities earning doctorate degrees in science and engineering remained low, considering 949 PhDs was awarded to African American, American Indian and Latinos in 1994.

A decade before the terrorists attacks in the United States, Atkinson (1990) urgently stated that there was a national crisis for supply and demand of engineers and strategies needed to be developed in order to recruit and retain students in science and engineering [28]. Between 1960 and 1980, 4% of 22-year-olds received bachelor's degrees in the natural sciences and engineering [28]. Post *9/11* caused the demand for engineers to increase tremendously. Special recruitment efforts and initiatives by some universities to attract minority students to engineering are underway. Carey (1977) stated that there was a drastic disproportion in the number of black engineers in the U.S. because few people encourage minority students to master mathematics, physics or science [29].

Methods

CAMRA students participated in a 10-week critical thinking course during the spring, 2006 semester. This course met once per week for 1.0 hour. Students were given the Watson-Glaser Critical Appraisal Form A, which consisted of 80 questions as a pre- and post- assessment to determine if a formal critical thinking course could enhance students' critical thinking skills. Bloom's Taxonomy was used as a framework to help students differentiate between lower and higher order thinking skills. The students compared the hierarchical structure from Bloom's Taxonomy to identify and positioned the critical thinking categories from the Watson-Glaser assessment, which included: inferences, recognition of assumptions, deductions, interpretations and evaluation of arguments (see Figure 1).

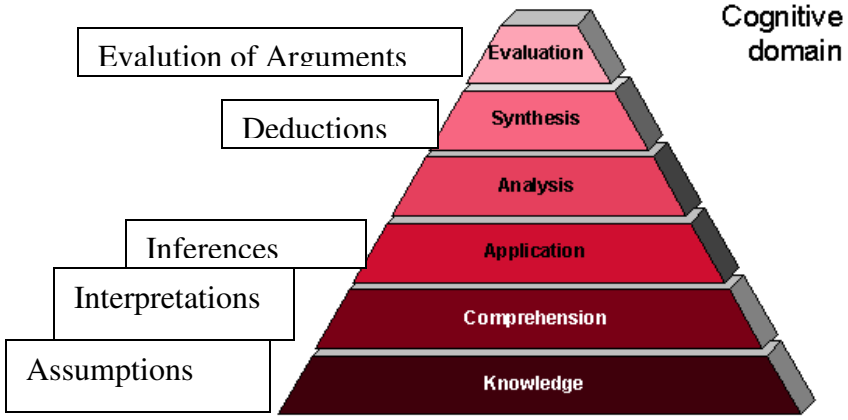

Figure 1: Bloom's Taxonomy and Watson-Glaser critical thinking categories.

The critical thinking definitions that were discussed and used as class debates are listed below.

1. Robert Ennis
    a. Critical thinking is reasonable, reflective thinking that is focused on deciding what to believe or do.

2. Richard Paul
    Critical thinking is that mode of thinking about any subject, content or problem in which the thinker improves the quality of his or her thinking by skillfully taking charge of the structures.

3. National Council for Excellence in Critical Thinking Instruction
    a. Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action.

    b. In its exemplary form, critical thinking is based on universal intellectual values that transcend subject-matter divisions: clarity, accuracy, precision, consistency, relevance, sound evidence, good reasons, depth, breadth, and fairness.

The two areas that were focused on in the critical thinking class were inferences and assumptions. Students received practice in making inferences and recognizing assumptions through class discussions and sample worksheets. They analyzed short essays, a newspaper article and discussed the author's purpose; key questions the author was addressing; and made inferences and assumptions. Students reviewed and discussed different learning styles and attributes of adult learners. Some materials were taken from the Foundation on Critical Thinking in Berkeley, California.

Although 25 students were enrolled in the critical thinking course, 12 students, consisting of 50% juniors and 50% seniors, were successful in completing both the pre – and post – assessments.

Hypothesis

This engineering education research project is related to the first author's dissertation topic: Critical Thinking Instruction and Minority Engineering Students at a Public Urban Higher Education Institution. Since this critical thinking course was a pilot study, only one hypothesis statement is applicable from the original dissertation research study design.

Hypothesis

H_{01} – There is no significant difference in critical thinking test scores after the intervention.

H_{a1} – There is a significant difference in critical thinking test scores after the intervention.

Data Analysis

To determine whether a significant increase in critical thinking test scores occurred, t-tests were used, with $P < .05$.

Findings

Findings from the data analysis suggest that there was a slight increase in the raw scores on the pre- and post-assessment data of the Watson-Glaser Critical Appraisal Form A. A t-test comparing the means of the raw scores of the pre – and post – assessments showed there was a slight increase. The results conveyed that 9 of the 12 students increased their critical thinking raw scores, showing a 75% increase, when comparing the pre – and post – assessments.

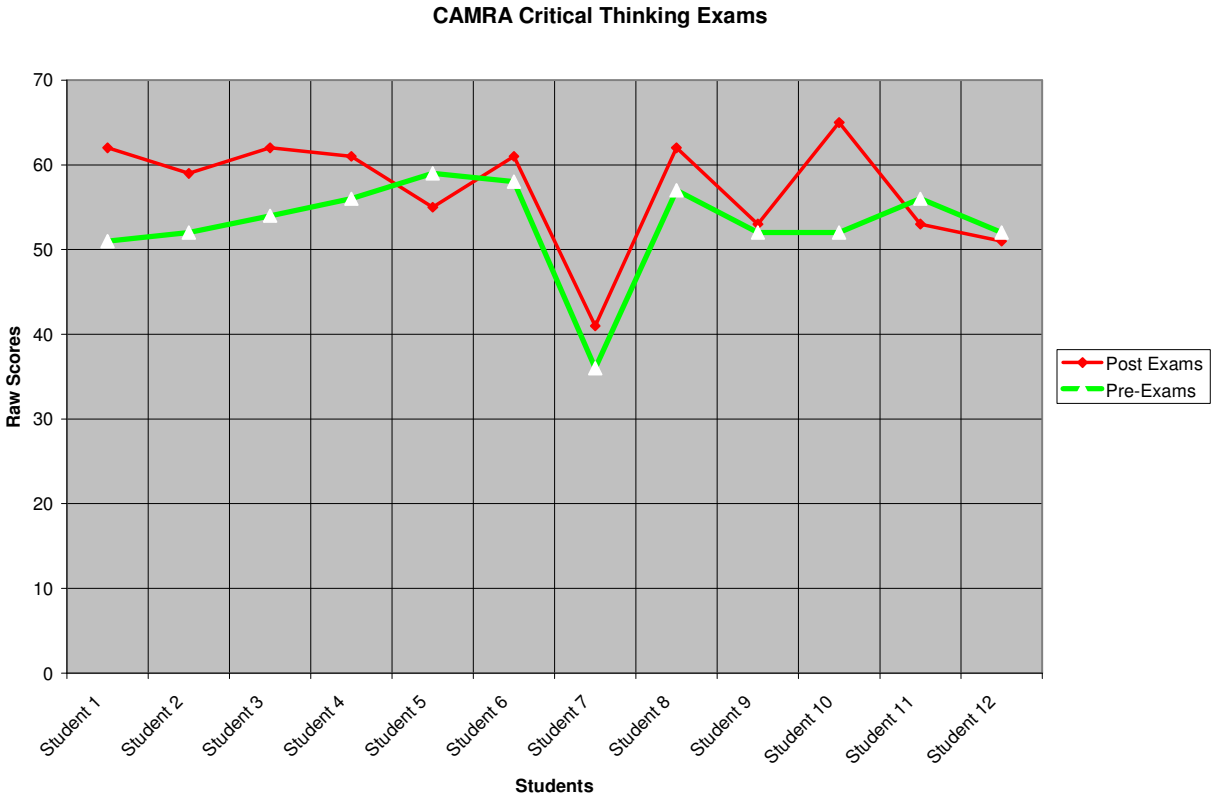

Figure 2: Comparison of pre – and post – assessment scores.

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	57.08333	52.91666667
Variance	45.7197	35.71969697
Observations	12	12
Pearson Correlation	0.663814	
Hypothesized Mean Difference	0	
Df	11	
t Stat	2.738115	
P(T<=t) one-tail	0.009648	
t Critical one-tail	1.795885	
P(T<=t) two-tail	0.019296	
t Critical two-tail	2.200985	

Table 1: t-Test comparing the two means from raw scores.

Summary

While the data analysis showed there was a slight increase in critical thinking scores when means of pre – and post – assessment raw scores were compared using a t-Test, the sample size was relatively small and limiting – N=12. Further research and analyses will be conducted as the primary author progresses with her dissertation research study.

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