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Female and Minority Students Benefit from Use of Multimedia Case Studies*

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Students need to acquire professional skills before entering the workforce in order to achieve career success and this is particularly important for female students and minorities. This article draws upon engineering education literature and student learning theories to understand the interconnected relationships among student characteristics (gender and race), instructional methodologies and gains in Higher-Order Cognitive Skills (HOCS) and the achievement of learning outcomes using the 4-P model of student learning. The model was tested for students enrolled in an undergraduate introduction to engineering course at a southeastern U.S. university and a historically black college and university (HBCU) for five semesters, where students participated in experimental (multi-media case studies) and control (round table discussions) sections. Both female and minority students achieved better learning outcomes, particularly in grade performance, after working on multimedia case studies. All students perceived improvement in HOCS and learning outcomes in a multimedia case study learning environment. These results support the use of multimedia case studies in classrooms to increase students' engagement in learning and exposure to real-world experiences, thereby building their professional skills. The widespread adoption and implementation of multimedia case studies is also likely to encourage more female and minority students to pursue careers in engineering.

Keywords: 4-P (presage-pedagogy-process-product) model; professional skills; higher-order cognitive skills (HOCS); engineering education; multimedia case study pedagogy; achieving learning outcomes

1. Introduction

Past studies have clearly established the need for engineering programs to integrate professional skills into engineering courses [1–4]. Practitioners have indicated that an engineer in the workplace must not only possess strong technical skills, but must also have professional skills including the ability to think critically and creatively, make appropriate decisions, and solve problems [5]. Thus, engineering programs that emphasize the acquisition of higher-order cognitive skills (HOCS) before entering the workforce give their students a better chance of success once they embark upon their professional careers [1, 4, 6–9]. These HOCS imply an improved ability to identify, integrate, evaluate and interrelate concepts within a project, and thus enable engineers and managers to make appropriate decisions in the complex problem-solving situations commonly found in today's fast-paced workplace [6, 10]. However, preparing their students for the world of work with an education that encompasses HOCS presents a major challenge for instructors [10].

One method that has been identified as helping instructors communicate HOCS in the field of engineering education is the use of multimedia case studies in the classroom [11]. Research has shown that multimedia case studies improve engineering students' learning effectiveness and enhance their professional skills. Students play the roles of engineers and managers when working on these case studies within a multimedia format, thereby acquiring some of the necessary HOCS [11]. Several studies have highlighted the benefits of the case study method, which not only brings the excitement of problem solving into classrooms, but also trains students to think and make the types of decisions faced by practitioners dealing with real-world problems and deadlines [11–16]. This led to the formulation of our first research question: *Does the use of multimedia case studies improve HOCS, thereby causing improvements in learning outcomes?*

Cultural differences, such as ethnicity and gender, often present challenges with regard to learning achievement in the engineering classroom, because students who come from different social and cultural backgrounds tend to have different attitudes about instructional pedagogies and instructional materials [17]. A number of researchers have discussed the impact of gender and race on the development of professional skills and how these are linked to academic achievement [18–25]. For example, Mbarika et al. [18] showed that female students and minorities may be retained in engineering programs as a result of the use of information technol-

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ogy and new instructional pedagogies in the classroom, while Marra et al. [23] found that female students may experience debilitating anxiety in engineering courses and careers due to the stereotype or categorization of these fields as being predominantly male. It is therefore necessary to take gender- and race-specific attitudes into consideration when designing learning environments, leading to the second research question: *Does the use of multimedia case studies by female and minority students produce different learning outcomes in an undergraduate engineering course?*

In order to answer the research questions, we conducted an experiment in an introductory engineering course at a southeastern U.S. university and a historically black college and university (HBCU) over a three-year period. In Section 2 we formulate a 4-P model of the student learning process (presage-pedagogy-process-product) and explain each of the components. In Section 3 we develop the research hypotheses and in Section 4 we describe the research methodology used to test these hypotheses, develop measures, design the sampling methodology and administer the surveys. In Section 5 we analyze the data collected using hierarchical multiple regression and present the results. In Sections 6, 7, 8, and 9 we discuss the research findings, limitations, future research, contributions and implications of this research for engineering educators and practitioners.

2. Theoretical model

2.1 The presage-pedagogy-process-product model (4-P model)

In order to understand the learning process that enables engineering students to acquire proficiency in professional skills and broaden their expertise [26–27], we began by applying the 3-P model (presage-process-product) developed by Biggs and Moore [28] to explain the factors affecting students' learning outcomes. "Presage" encompasses the characteristics that exist prior to engagement in learning, such as a student's gender, learning style, behavioral tendency, and race [28]. "Process" focuses on the student's deep learning, which is based on motivation driven by interest in the course material and understanding of the relationship among concepts [28–29]. "Product" represents the students' learning outcomes [30], describing what students are expected to know and to be able to do at the end of a course [20]. Presage and process characteristics intersect to determine the product, which means that learning styles or student interest in a subject can affect their learning achievement [29]. To test whether this 3-P model is also applicable to engineering education, we reviewed the literature in engineering and computer education journals and present a summary of the relevant articles in this section.

These studies employed the 3-P model as a theoretical foundation to illuminate the students' learning process and identified significant relationships among the three Ps. Franklin et al. [2] surveyed students from three different majors to investigate which professional skills were relevant for their professional careers and should therefore be addressed in engineering curricula. Rosenberg-Kima et al. [25] believed that matching computer-based agents' race and gender to participant preferences was particularly effective in improving those students' attitudes and beliefs in engineering-related fields. Nemanich et al. [30] tested the 3-P model and evaluated the impacts of pedagogies (i.e., classroom and online teaching approaches) on learning enjoyment and performance for undergraduate engineering students. Kember et al. [31] reported that using web-based learning environments encouraged a deep approach to learning and enhanced learning outcomes. Leung et al. [32] examined the relationship among geographic differences, learning motivation and student satisfaction with teaching based on the 3-P model.

These studies not only demonstrate the close interrelationship among the presage, process and product factors, but also led to the identification of a new factor, Pedagogy, which describes any conscious activity designed to enhance the learning of another person [33], and explored its impact on the learning process and outcomes [2, 25, 30–32]. For example, Nemanich et al. [30] pointed out that the relationship between student ability and learning performance tends to be weaker among students in a classroom learning environment than among students in an online learning environment. Leung et al. [32] used three different teaching approaches (i.e., lectures, tutorials and laboratory sessions) to test their student learning process model and found that learning motivation is related to most of the teaching approaches. Thus, these studies agree that an explicit focus on pedagogy provides a significant conceptual advancement on the original 3-P model.

More recently, Chubin et al. [34] and Brownlee and Berthelsen [35] have argued that all teaching and learning should combine content and pedagogy, encouraging instructors to rethink the meaning of learning and the faculty's role in it, which will ultimately create more effective ways to tap into the interests of students. Chubin et al. [34] pointed out that pedagogy plays an important role in engaging the current batch of Generation Net students. All of these articles concur that the 3-P model is applicable in engineering education but insist on the need to include pedagogy as an additional factor. Therefore, we have added pedagogy to the 3-P model as a fourth factor, renaming this extended model the 4-P model.

2.2 Presage factors: Gender and race issues

Previous research has shown that gender differences among students can act as either facilitators or barriers to the engineering learning process and learning approach [18–25]. Female students are generally underrepresented in engineering classrooms, which may result in less consideration of their unique learning needs [20–25]. McMasters [5] indicated that current engineering education programs are failing to attract a diverse group of students to enroll in the program, especially females and minorities. Education researchers and academicians have long debated the reasons for the differing academic achievements among ethnic groups [23]. In 2010, of the engineering bachelor's degrees attained in the United States, African Americans received only 5.3% of the total, compared to 70.61% for Caucasians, 10.95% for Asian Americans, 5.6% for foreign nationals, 6.91% for Hispanic Americans, and 0.59% for Native Americans [36]. The percentage of engineering degrees earned by African American students was effectively flat from 2007 to 2010 [37]. The National Action Council for Minorities in Engineering reported that not only were only 5% of the students enrolled in engineering programs African American in 2010, they were also less likely to complete their degrees [38]. These large disparities might be tied to the significant underrepresentation of minority students and the use of instructional materials in engineering programs [39]. Therefore, we chose gender and race as the two variables to examine under the presage factor.

2.3 Pedagogy factor: The use of multimedia case studies and round table discussions in engineering education

In the past two decades, scholars have frequently advocated the use of multimedia-based instructional materials to support engineering education [40–43]. Multimedia-based courses materials use sound, video, two- and three-dimensional graphics and text delivered on a CD-ROM, a DVD and/or a website [12, 40] as learning media and multimedia case studies in particular have been shown to have a major impact on engineering students' learning effectiveness and outcomes [12–16]. Multimedia case studies in engineering courses provide problem-based cases, best practices and real world examples to illustrate what engineers do in the workplace and to provide students with realistic engineering experiences [11, 44–47]. Case studies that incorporate multimedia aids can make learning more interesting and effective for students than written case studies in engineering courses [11]. Other researchers have advocated the use of multimedia case studies to help students improve their professional skills. For example, Mbarika et al. [45] and Mehta et al. [48] emphasized the utility of multimedia case studies in enhancing students' learning motivation and, in turn, improving their decision-making and problem-solving skills. Bradley et al. [49] found that engineering students participating in multimedia case study lessons with students enrolled in other majors such as business performed particularly well in communicating complex technical concepts and solving engineering problems as part of a team.

Another instructional methodology considered in this research is round table discussions. A round table discussion involves problem-based learning that teaches a way of thinking, and combines group discussion with writing, verbal communication and analytical thinking [50]. The design of a round table discussion relies on applying knowledge that a student has acquired through his or her classes. The round table discussion format consists of a traditional classroom setup in which the instructor leads the class using material from textbooks and students thoughtfully work their way to a number of solutions based on what they have learned in earlier lectures [50]. The use of round table discussions has been introduced in the field of engineering and science education to complement the traditional lecture format and facilitate students' learning achievement. For example, Flynn et al. [51] found that using a round table discussion in engineering courses helped students to clarify any misunderstandings about engineering concepts and allowed the students to discuss the solutions instructors had developed. They noted that students in a round table discussion group can learn not only from the instructor but also from the ideas put forward by their classmates. Nekvasil [50] concluded that round table discussions fill the gap between the knowledge learned in lectures and hands-on experimental labs and the need to be able to apply what was being learned and that instructors who teach science topics with round table discussions can help learners to reach a higher level of proficiency with the subject and gain practice in organizing the facts that connect pieces of knowledge and then verbalize the information to their partners.

Based on these considerations, we chose multimedia case studies and round table discussions as the moderating variable to be examined in this study under the pedagogy factor.

2.4 *Process factor: Higher-Order Cognitive Skills (HOCS)*

In order to identify the major professional skills required of engineers, we conducted an extensive review of the literature [1, 4, 5, 7, 8, 52–54]. Most of these studies emphasize that a critical professional skill is the acquisition of higher-order cognitive skills (HOCS) in the engineering field, which include critical thinking, decision-making, and problem solving skills [1, 4, 5, 7]. For example, the Boeing Company listed the attributes of an engineer they look for in their potential employees, emphasizing that an engineer in the workplace must be able to think both critically and creatively when they encounter engineering problems and have the ability and self-confidence to make appropriate decisions when faced with a rapidly changing situation [5]. Sánchez et al. [1] looked at how academics, graduates and employers rated the order of importance of different professional skills and found that analyzing and summarizing problems and applying knowledge to practice are of primary importance to all three groups.

Biggs and Moore [29] note that process factors involve the learning experience of an individual. With regard to HOCS, their development must deeply embed in a learning process that requires the learners to absorb new knowledge or concept by forming the hypothesis, generating the possible solutions, integrating and analyzing the information [48]. Facilitating HOCS aims at improving learners' analysis, problem identification, critical evaluative thinking, system thinking, reasoning, synthesis, making connections skills and ultimately resulting in improved learning [48-49]. Therefore, we treat HOCS as a process variable for this research and we evaluate their impact on actual learning outcomes (e.g., student grade).

2.5 *Product factor: achieving learning outcomes*

Student learning outcomes are a crucial way to assess student learning achievement in educational research and hence are part of the ABET engineering accreditation process [55, 56]. Learning outcomes are defined as what students are expected to know and how well the students think they have done, and thus serve as indicators of the skills, knowledge and behaviors that students have gained as a result of participating in the learning process [56]. A comprehensive evaluation of engineering learning outcomes involves a multiple assessment method that is better suited to the assessment of professional skills than a single assessment [57]. Prus and Johnson [58] have proposed a set of six methods: assessing professional skills-tests and examinations, measures of attitudes and perceptions, portfolios, performance appraisals, behavioral observations, and external examiners.

In this research, we utilized three indictors for achieving learning outcomes: student grades, attitudes toward engineering and benefits of engineering. The student grade is a type of performance appraisal that is used to measure pre-operationalized abilities in a real-world setting [59]. A performance appraisal is a valuable, authentic assessment method because it provides a direct measure of what has been learned during the class and is more effective for evaluating certain behaviorally based skills [4]. Shuman et al. [4] also suggested that engineering courses should provide abundant performance-oriented assignments, such as design projects and open-ended assignments, which offer accurate approaches for student outcomes assessments. In our research, student grade evaluations included a traditional assessment (paper-and-pencil test) and an authentic assessment (a competency-based test evaluated by oral presentations of case studies, design projects and round table discussions). We opted for this comprehensive assessment for evaluating student achievement because it is particularly conducive to assessing professional skills. Therefore, student grade was chosen to be the first product factor in the research model.

Attitudes toward the subject have been shown to influence students' learning outcomes, encompassing both the student's attitude toward the subject being taught and whether the student believes he or she will be able to learn the materials [60]. This includes emotional response to learning, confidence in learning new material, responsibility, accomplishment, and understanding of cross-disciplinary work, all of which contribute to the evaluation of professional skills [61]. Student cognition, which can include attitude, satisfaction and motivation, may directly impact how well a student learns a problem-solving technique in the field of engineering [62-63]. Additionally, Shuman et al. [4] highlighted the importance of attitude assessment in engineering education, reporting that many employers consider an employee's attitude toward engineering work as an important measure of their contribution to the company. Student attitude toward engineering is not easily assessed, but can be evaluated by a self-report survey [63].

Therefore, attitude toward engineering was chosen to be the second product factor here, utilizing a learning assessment questionnaire taken from Sankar and Clayton [60].

The third learning outcome of this research model is benefits of engineering, which is a type of cognitive learning outcome. Pridmore et al. [10] identified three categories of cognitive learning outcome for assessing learning achievement, namely evaluation, application and comprehension. Evaluation concentrates on learners' perceptions of understanding basic concepts and the ability to identify, integrate and evaluate issues, make decisions, and improve problem-solving skills. Application focuses on the learners' perceptions of their ability to apply theory to real-world problems. Comprehension focuses on the learners' perception of their ability to identify, integrate and evaluate multidisciplinary issues. In our research, the benefits of engineering include the students' self-confidence in their ability to learn engineering topics, their ability to apply engineering concepts to real-world problems, their ability to find interdisciplinary connections (e.g., between engineering and management) and their ability to improve their writing and communication skills. These items can reveal whether the students acquired professional abilities such as dealing with the difficult issues involved in real-world problems and working in multidisciplinary teams. Therefore, benefit of engineering was chosen to be the third product factor in this research model.

2.6 Research model

We developed a 4-P research model based on the literature review, shown in Fig. 1. We identified gender and race as critical presage factors, gains in HOCS as the process factor, and achieving learning outcomes as the product factor. Pedagogy was constrained to instructional methodologies alone and the students who used the multimedia case study pedagogy were considered the experimental group and the students who used the round table discussion pedagogy as the control group. Achieving learning outcomes included student grades, attitudes toward engineering and benefits of engineering as the product factors.

3. Hypotheses development for the moderating role of instructional methodology

We developed a set of hypotheses based on the 4-P model and used different instructional methodologies as the moderating factor, as shown in Fig. 1. These hypotheses are described below.

3.1 The impact of instructional methodology between gains in HOCS and achieving learning outcomes

From an industry perspective, employers expect students to develop their HOCS in the engineering program so that they are capable of making appropriate technical decisions to achieve organizational goals once they enter the actual work environment. However, the difficulty involved in teaching HOCS in the classroom is a serious concern for university education [10] and it is therefore necessary to study whether different instructional methodologies can lead to improvements in HOCS and hence better learning outcomes.

Previous studies have highlighted the effectiveness of specific instructional methodology to communicate HOCS and enhance learning achievements. For example, Mbarika et al. [44] and Mbarika [64] found that the use of multimedia instructional materials improves students' perceived HOCS when learning engineering issues. Bradley et al. [49] concluded that the use of problem-based learning increases student learning motivation and student understanding, encourages collaborative learning, and develops HOCS. Gider et al. [53] demonstrated that the case study method also enables students to gain useful knowledge and hands-on experience in teamwork and enhances their ability to solve practical problems. Not all researchers are convinced of the utility of this approach, however. Several researchers have argued that multimedia instructional materials may in some cases result in students' failure to develop HOCS and gain maximum learning outcomes. Dillon and Gabbard [65] reviewed the results of 35 experimental studies of multimedia use in educational tasks and concluded that the benefits of multimedia are limited to learning tasks that rely on repeated manipulation and information searches and are differentially distributed across learners depending on their ability. Orr et al. [66] also

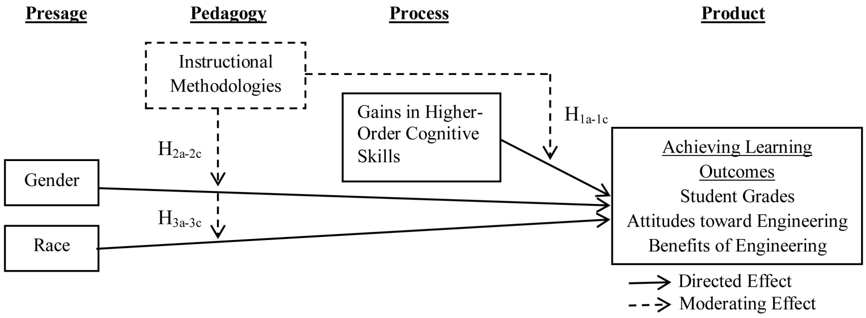

Fig. 1. 4-P Research Model with Instructional Methodologies as Moderators.

thought that using multimedia-based instruction in technology-related courses may not positively impact learning achievement.

Based on the literature, the impact of instructional methodology on the relationship between HOCS and learning outcomes has received both positive and negative critiques. To address this issue, this study examined the moderating effect of instructional methodologies on the relationship between HOCS and achieving learning outcomes using two methods: round table discussions and multimedia case studies. We hypothesized that:

> Hypothesis 1a: The relationship between gains in HOCS and student grades will be more pronounced among students using the multimedia case study pedagogy than among students using the round table discussion pedagogy.
>
> Hypothesis 1b: The relationship between gains in HOCS and attitudes toward engineering will be more pronounced among students using the multimedia case study pedagogy than among students using the round table discussion pedagogy.
>
> Hypothesis 1c: The relationship between gain in HOCS and benefits of engineering will be more pronounced among students using the multimedia case study pedagogy than among students using the round table discussion pedagogy.

3.2 The impact of instructional methodology on gender and achieving learning outcomes

A great deal of the recent literature has suggested that the impact of gender differences should be considered when designing learning environments for engineering courses [18, 21, 67–68]. Gender has been shown to have a distinct impact on learning performance, even if instructors control for similarity in the amount of experience [67]. According to a report on women's experiences in college engineering (WECE) [68], female students in engineering programs have more interest in work-life issues than male students. The authors therefore suggested that female students would feel less anxiety in learning when the instructors employed real-world cases to communicate engineering concepts. Mbarika et al. [18] developed a student learning model to research the relationships between gender and higher-level cognitive skill improvement, collecting information from 99 male and 41 female students via a questionnaire. The results of this study revealed that female students valued learning performance more highly than their male counterparts, suggesting that improvements in the learning process triggered by multimedia case studies are more important for females. This study provided evidence that females and males perceive the learning effect of multimedia case studies differently.

The approach to learning used in multimedia case studies contrasts markedly with that of the round table discussion setting, which provides support for the processes that contribute to learning by encouraging interactions with instructors and other students in the classroom [50]. Amelink and Creamer [21] suggested that creating learning environments that emphasize student interactions during team work such as the classroom setting of a round table discussion could make a difference in students' satisfaction in their engineering major and in their interest in pursuing an engineering career, especially in female students.

Hence, our study examined the moderating effect of instructional methodologies on the relationship between gender and achieving learning outcomes. We hypothesized that:

> Hypothesis 2a: Compared to the round table discussion pedagogy, the improvement in student grades experienced by females compared to males will be increased when students are taught using the multimedia case study pedagogy.
>
> Hypothesis 2b: Compared to the round table discussion pedagogy, the improvement in attitudes toward engineering experienced by females compared to males will be increased when students are taught using the multimedia case study pedagogy.
>
> Hypothesis 2c: Compared to the round table discussion pedagogy, the improvement in benefits of engineering experienced by females compared to males will be increased when students are taught using the multimedia case study pedagogy.

3.3 The impact of instructional methodology on race and achieving learning outcomes

Researchers have long debated the reasons for the differences in academic achievement between minority students and non-minority students [25]. One of the reasons often cited is the difference in cognitive styles and learning approaches of minority students compared to non-minority students [69–70]. Several studies have described learning styles for minority groups, arguing that African-American students tend to: view objects in a holistic perspective rather than in isolated parts; prefer intuitive to deductive or inductive reasoning; approximate concepts of space, number, and time rather than aiming at precise values; attend to personal stimuli rather than nonsocial or object stimuli; and rely on nonverbal as well as verbal communication [71–72]. This difference in learning style has been attributed to the different social and cultural norms and economic challenges facing minority students [73–74], which inevitably has an impact on their learning attitudes and academic performance.

Several studies have revealed that the use of multimedia case studies in historically black colleges and universities has been very successful, and instructors have perceived an improvement in simulating real-world decision making, as well as promoting critical thinking and team-work in an academic environment [75–77]. For example, Halyo and Le [75] indicated that multimedia case study pedagogy may be particularly effective for African-American students who prefer interactive learning environments and whose general learning style might be categorized as "learning by doing" and visual learning. Barba [78] and Rosser and Kelly [79] agreed that female students and ethnic minorities were more enthusiastic about problem-based learning approaches in their courses, probably because these teaching practices maximize gender and ethnic equity.

Hence, our study examined the moderating effect of instructional methodologies on the relationship between race and achieving learning outcomes. We hypothesized that:

> Hypothesis 3a: Compared to the round table discussion pedagogy, the improvement in student grades experienced by minorities compared to Caucasians will be increased when students are taught using the multimedia case study pedagogy.
>
> Hypothesis 3b: Compared to the round table discussion pedagogy, the improvement in attitudes toward engineering experienced by minorities compared to Caucasians will be increased when students are taught using the multimedia case study pedagogy.
>
> Hypothesis 3c: Compared to the round table discussion pedagogy, the improvement in benefits of engineering experienced by minorities compared to Caucasians will be increased when students are taught using the multimedia case study pedagogy.

4. Methodology

In order to test the 4-P model, we conducted an experiment for five semesters at a southeastern U.S. university and an HBCU with students enrolled in an introduction to engineering course. The subjects involved, materials used, measurement developed, and statistical analysis tools used are described in this section.

4.1 Experimental design (multimedia case study vs. round table discussion)

Each semester, the students were enrolled in multiple sections of the same course at both universities. Half of these sections were designated as control groups and the other half as experimental groups. The control groups were taught using the round table discussion pedagogy and the experimental groups using the multimedia case study pedagogy. The similarities and differences between the multimedia case study pedagogy and the round table discussion pedagogy, with detailed course content, are presented in Table 1.

The students in the control group engaged in face-to-face lectures and round table discussion in the introductory engineering courses in Fall 2010 and Spring 2011. The instructor had 14 weeks to cover approximately 12 topics and there were 2 examinations in each semester. During the course, students

Table 1. Similarities and Differences between Experimental and Control Groups

	Multimedia Case Study Pedagogy (Experimental Group)	**Round Table Discussion Pedagogy (Control Group)**
Teaching method	Lecture and multimedia case study	Lecture and round table discussion
Timeline	Theory on concepts covered by case study 1 lab where students analyze case study and another lab sessions where they made a presentation 3 multimedia cases/course 12 lecture classes/course 3 design project classes/course	Theory on concepts covered by case study 1 lab where students did research and another lab where they conducted a round table discussion 3 round table discussions/course 12 lecture classes/course 3 design project classes/course
Course Contents (Differences)	The names of multimedia case studies: Chick-fil-A choice of operating systems, Della Steam Plant and STS 51-L Challenger design	The topics of round table discussion: effective/ineffective communication; engineering decision making; earthquake preparation and safety; discussion of engineering ethics with the example of Hyatt hotel bridge collapse; create a short power point on an engineering subject of choice; the method of communication; discussion of engineering safety; robot loops and squares; robot sensors and navigation
Course Contents (Similarities)	• The topics of lecture: journey of engineering and top ten achievements; communication; team work; engineering design; introduction to robots; representation of technical data; engineering statistics; engineering ethics; unit conversion; Lock Out Tag Out and industrial safety and other guest lectures • The topics of design project: design of pasta tower; design and test paper parachute; design and test plastic boat	

were given two classes per week to learn each topic. The first class was taught through traditional lectures with the aid of a textbook and occasional guest lectures to provide real-world examples for certain topics. In the second class, students were given a discussion topic and asked to discuss their various points of view on the subject in a round table discussion group and then present the views orally to the remaining students in the class. The purpose of the round table discussions was to enable students to gain engineering experience and practice decision-making skills utilizing engineering principles.

The multimedia case study was integrated into the course structure in the experimental group. The experimental group analyzed three case studies, *Chick-fil-A Choice of Operating Systems*, *Della Steam Plant* and *STS 51-L Challenger Design,* in the introductory engineering courses in Spring 2010, Fall 2011 and Spring 2012. These case studies can be downloaded from www.liteecases.com. Each case study was carefully chosen for its relevance to course objectives. The students in the experimental group had no prior experience in using multimedia-based case studies. During the multimedia case study class, students watched the multimedia CD-ROM case studies that introduced the case study's background and the engineering concepts involved and were then assigned roles for their later presentation in the first week (2 class sessions). In the second week (1 class session), using the technical and business information provided in the case study, students made a team-based oral presentation (around 15 minutes long) defending the roles they had been assigned. There was no face-to-face discussion about the case studies with the lab instructor. The lab instructor helped the students when they had questions and evaluated their presentations.

Three design projects were also included in the curricula: "design of pasta tower", "design and test paper parachute" and "design and test plastic boat." For example, in the paper parachute project, students were required to build a paper parachute to gently lower a load from a height of 8 feet. The amount of time taken by the designed parachute to reach the floor was measured by the instructor. These projects, chosen to supplement the course lectures and give students experience in problem-solving by applying engineering concepts, were implemented in both the control and experimental groups.

4.2 Development of measures

The independent variables in this study were gender, race and HOCS. First, the presage factors in the 4-P model, gender (male/female) and race (Caucasian/Minority) were coded as dummy variables consisting of two categories (0 or 1). Improvements in HOCS were then coded on a five-item scale adapted from the scale used in Hingorani et al. [6]. The items from the scale identified the extent to which instructional materials helped the students build their decision making and problem solving abilities during the course. The improvement in HOCS served as the process factor in the 4-P model.

The dependent variable in this study, achieving learning outcomes, was measured using student grades, attitude toward engineering and benefits of engineering [60, 80]. Student grades were based on the comprehensive scores received by the students on quizzes and tests administered during this course and the evaluation received for the presentation of the case studies and projects. Before using student grade as an outcome variable in our data analyses, multiple steps were required to normalize the data between course instructors and institutions. For example, the cumulative point total at the HBCU was always equal to 1000 but the point totals at the southeastern U.S. university for each of the five semesters were 1075, 940, 1000, 810 and 830. The first step of the normalization process therefore consisted of normalizing the student grades for each semester to a 1000 point scale. Next, slightly different amounts of extra credit were given between the two universities. In order to account for this difference, we used the Equation (1) to make the grades at the HBCU equivalent to those at the southeastern U.S. university:

$$\text{Adjusted HBCU grade} = (\text{HBCU Grade}/\text{HBCU Mean}) \times \text{Mean from southeastern U.S. university} \tag{1}$$

The resulting data were used for all subsequent mean comparisons and regression analysis. Attitudes toward engineering and benefits of engineering were based on an analysis of a questionnaire that the students completed at the end of the course. The items from the scale identified what the students would be expected to know and to be able to do at the end of the course. Participants rated items from the constructs of professional skills and achieving learning outcomes on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The dependent variable in this study served as the final component of the product variable in the 4-P model.

Table 2 lists the constructs and items used to measure the factors in the research model. The survey instrument utilized in this study has been used and refined extensively by several authors and demonstrates high construct validity [18, 45, 49, 60]. Cronbach alpha scores were computed for each dimension in order to identify whether the items

Table 2. Proposed Measures and Their Cronbach Alpha Values

Constructs	**Dimensions**	**Items**	**Sources**
Professional Skills	Gains in Higher-Order Cognitive Skills (Alpha = 0.864)	Please rate the extent to which instructional materials helped you in class: • Identify engineering tools that will assist me in decision making • Learned how to inter-relate important topics and ideas • Learned how to identify various alternatives/solutions to a problem • Improved my problem solving skills • Learned how to sort relevant from irrelevant facts	Hingorani et al. [6]; Sankar and Clayton [60]
Achieving Learning Outcomes	Attitudes toward Engineering (Alpha = 0.903)	Please rate your learning experiences during the course: • Engineering is irrelevant to my life (r) • Increased my appreciation for engineering • Engineering is highly technical • I can learn engineering • Engineering skills learned will make my more employable • All instructional materials from course were integrated in a way that made it easier to learn new engineering concepts • All instructional materials used in this course emotionally engaged me in learning the topics • I would hire engineers to help with decision making if I ever were to become a high ranking official in a company	Sankar and Clayton [60]
	Benefits of Engineering (Alpha = 0.872)	Please rate your learning experiences during the course: • Increased my self-confidence • Increased sense of accomplishment in learning • Helped me assume a greater responsibility for personal learning • Enhanced my belief that interdisciplinary focus is important in engineering • Improved in applying engineering concepts to real situations • Improved my writing skills due to doing the assignments • Improved my informal communication skills due to doing the assignments	Alavi et al. [80]; Mbarika et al. [45]; Pridmore et al. [10]

Note: "(r)" denotes that an item must be reverse coded before analyzing data (i.e., 5 = 1, 4 = 2, 3 = 3, 2 = 4, 1 = 5).

belonged together within a dimension. The Cronbach alpha values were deemed close enough to the 0.9 criterion, representing an excellent level [81].

4.3 Sample selection and collection

Participants were enrolled in five different semesters of an introduction to engineering course at a southeastern U.S. university and an HBCU. At the beginning of each survey, students entered a four-digit identification code that was created and distributed by their course instructor. This code was later used during data analyses to match survey results from multiple questionnaires and course grades. Data from the experimental groups were combined with data from the control groups when making comparisons and conducting analyses regarding the potential differences between round table discussion pedagogy and multimedia case study pedagogy.

The sample for this study involved a total of 696 students enrolled in Introduction to Engineering courses during five consecutive semesters. Unfortunately, the data used in our analyses were subject to a number of missing data points. These missing data resulted from two sources. Several students provided no response to our surveys, and a small number of students used the incorrect identification code, preventing a match between their course grade and survey responses. To account for the missing data in our analysis, we applied the process of listwise deletion, removing a record entirely if a relevant data point was missing for a particular analysis. Therefore, our analyses used different sample sizes for each analysis, which limited the interpretation of the findings to some extent. For clarity, the tables in the results section reflect the sample sizes used in each analysis.

4.4 Data analysis method

In order to test our hypotheses, we used hierarchical multiple regression analysis as recommended by Cohen et al. [82]. A multiple regression model accounts for the variance in an interval dependent variable based on linear combinations of interval, dichotomous, or dummy independent variables [83]. Multiple regression can establish that a set of independent variables explains a proportion of the variance in a dependent variable at a significant level (through a significance test of R^2), and can establish the relative predictive importance of the independent variables (by comparing beta weights). Therefore, our analysis consisted of the following two steps [82]: one measure of the dependent variable was regressed on the independent variable and moderating variable, after which interaction (i.e., moderating) variables were entered in the second level of analysis. When the regression coefficient of the interaction term is significant, a moderating effect is supported. This analysis also facilitates the examination of a potential direct influence of the moderator variable in the first step and the extent to which the moderator influence is present in the second step.

5. Results

5.1 Descriptive statistics

We examined each variable mean and the standard deviations for males and females, Caucasians and minorities, and individuals in both round table discussion and multimedia case study classrooms. The resulting means and standard deviations are shown in Table 3. Our findings indicate that all the means for multimedia case studies were significantly higher than those for the round table discussion with the exception of student grades, where no statistical difference was observed. The difference between the grades of male and female students was statistically significant, while the difference between Caucasian and minority students was marginally significant. It is important to note that about 130 students who did not perform well on either of the instructional methodologies failed to provide their gender or race in their responses, which is why the means for instructional methodologies is lower than the means shown for the gender and race columns.

5.2 The results of the hierarchical multiple regression analysis

The results of the hierarchical multiple regressions are divided into three sections in order to examine the impact of gain in HOCS, gender and race individually. These are described in turn below.

5.2.1 Gains in higher-order cognitive skills

The results for the interaction effects between gains in HOCS and instructional methodologies are shown in Table 4. The interaction between gains in HOCS and instructional methodologies, with regard to explaining students' grades, was not significant ($\beta = -0.032$, $p = 0.853$), so Hypothesis

Table 3. Means and Standard Deviations of Variables

	Gender		**Race**		**Instructional methodologies**	
	Males	**Females**	**Caucasian**	**Minority**	**Round table discussion**	**Multimedia case study**
Variables	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)
Sample size (N)	361	169	345	184	390	272
Gains in HOCS	3.20 (0.90)	3.27 (0.82)	3.21 (0.84)	3.24 (0.96)	3.12 (0.89)	3.37*** (0.84)
Student grades	943.39 (72.31)	965.46** (79.51)	945.11 (48.56)	960.33† (108.68)	925.74 (155.79)	916.03 (132.58)
Attitudes toward engineering	3.43 (0.79)	3.47 (0.70)	3.49* (0.72)	3.35 (0.83)	3.30 (0.75)	3.64*** (0.73)
Benefits of engineering	3.12 (0.79)	3.09 (0.82)	3.12 (0.74)	3.11 (0.91)	3.02 (0.83)	3.25*** (0.74)

Note: All tests are two-tailed. † p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 4. The Effect of Gains in Higher-order Cognitive Skills

	Dependent variable: Achieving learning outcomes		
Variables	**Student grades (H_{1a})**	**Attitudes toward engineering (H_{1b})**	**Benefits of engineering (H_{1c})**
N	530	537	537
Gains in HOCS	0.077†	0.766***	–0.822***
Instructional methodologies	0.143***	–0.111***	–0.027
Gains in HOCS × Instructional methodologies	–0.032	**0.222***	**0.269****
F	4.215**	297.374***	391.495***
ΔR^2	0.000	0.003*	0.005**
Overall R^2	0.023	0.626	0.688
Adjusted R^2	0.018	0.624	0.686

Note: All tests are two-tailed. †p<.10, *p<.05, **p<.01, ***p<.001.

1a was not supported. The interaction effect between gains in HOCS and instructional methodologies, with regard to explaining students' attitudes toward engineering ($\beta = 0.222$, $p = 0.035$) was significant and positive, however, thus supporting Hypothesis 2a. Interaction effects explained 0.3% of the variance in attitudes toward engineering ($\Delta R^2 = 0.003$, $p = 0.035$). The interaction effect between gains in HOCS and instructional methodologies, with regard to explaining students' benefits of engineering ($\beta = 0.269$, $p = 0.005$) was also significant and positive, thus supporting Hypothesis 3a. Interaction effects explained 0.5% of the variance in benefits of engineering ($\Delta R^2 = 0.005$, $p = 0.005$).

5.2.2 Gender

The results for the interaction effects between gender and instructional methodologies are shown in Table 5. The interaction effect between gender and instructional methodologies, with regard to explaining students' grades ($\beta = -0.194$, $p = 0.013$) was significant. Interaction effects explained 1.1% of the variance in student grades ($\Delta R^2 = 0.011$, $p = 0.013$). The grades of the female students were significantly higher than the grades of the male students in classes taught using multimedia case studies (969.75 versus 927.26), while the female students' grades were not significantly higher than their male counterparts in classrooms using round table discussions (963.27 versus 956.22). This result implies that, compared to the round table discussion pedagogy, the improvement in student grades experienced by females compared to males increases when students are taught using the multimedia case study pedagogy. Therefore, Hypothesis 2a was supported.

There was no interaction effect between gender and instructional methodologies, with regard to explaining students' attitudes and benefits toward engineering, so neither Hypothesis 2b nor Hypothesis 2c were supported.

5.2.3 Race

The results for the interaction effect between race and instructional methodologies are shown in Table 6. The interaction effect between race and instructional methodologies, with regard to explaining students' grades ($\beta = -0.153$, $p = 0.056$) was marginally significant. Interaction effects explained 1% of the variance in student grades ($\Delta R^2 = 0.007$,

Table 5. The Effect of Gender

	Dependent variable: Achieving learning outcomes		
Variables	**Student grades (H_{2a})**	**Attitudes toward engineering (H_{2b})**	**Benefits of engineering (H_{2c})**
N	528	535	535
Males	359	363	363
Females	168	172	172
Gender	0.123**	0.046	–0.006
Instructional methodologies	0.119**	–0.227***	–0.144
Gender × Instructional methodologies	**–0.194***	–0.017	–0.015
F	7.984***	9.637***	3.28**
ΔR^2	0.011*	0.000	0.000
Overall R^2	0.044	0.052	0.021
Adjusted R^2	0.038	-.046	0.016

Note: All tests are two-tailed. † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 6. The Effect of Race

	Dependent variable: Achieving learning outcomes		
Variables	**Student grades (H_{3a})**	**Attitudes toward engineering (H_{3b})**	**Benefits of engineering (H_{3c})**
N	528	535	535
Caucasians	344	344	344
Minorities	184	191	191
Race	0.082†	–0.066	0.009
Instructional methodologies	0.121**	–0.213***	–0.142***
Race × Instructional methodologies	**–0.153†**	–0.068	–0.114
F	5.542***	10.116***	4.353**
ΔR^2	0.007†	0.001	0.004
Overall R^2	0.031	0.054	0.024
Adjusted R^2	0.025	0.049	0.018

Note: All tests are two-tailed. † $p < 0.10$, *$p < 0.05$, **$p < 0.01$, *** $p < 0.001$.

p = 0.056). The grades of minority students were marginally higher than the grades of their Caucasian classmates in classes taught with multimedia case studies (960.31 versus 930.06), while there was no significant difference in classrooms using round table discussions (960.34 versus 957.68). This result implies that, compared to the round table discussion pedagogy, the improvement in student grades experienced by minority students compared to Caucasian students increases when students are taught using the multimedia case study pedagogy. Therefore, Hypothesis 3a was supported.

There was no interaction effect between race and instructional methodologies, with regard to explaining students' attitudes and benefits toward engineering, so neither Hypothesis 3b nor Hypothesis 3c were supported.

6. Discussion

The analyses identified four major findings:

- The mean grades of female students were significantly higher than the mean grades of male students in the multimedia case study learning environment.
- The mean grades of minority students were marginally higher than the mean grades of Caucasian students in the multimedia case study learning environment.
- Students perceived improvement in HOCS in the multimedia case study learning environment were significantly greater than in the round table discussion learning environment.
- The use of multimedia case studies led to improved HOCS and learning outcomes (i.e., attitudes toward engineering and benefits of engineering) compared to round table discussions.

The first finding revealed that female students perform better in classrooms using multimedia case studies than do males, with females receiving average grades of 969.75, and males receiving average grades of 927.26. Female students appeared to place a high value on the improvements in actual learning outcomes triggered by the use of multimedia case studies in the classroom. This finding is consistent with Mbarika et al. [18], who reported that female students believed they were better able to understand new engineering concepts when using the multimedia case studies, enjoyed opportunities to work with male students, and were challenged in solving problems. A handful of other studies have asserted that female students are less attracted to engineering issues, which may lead to poorer learning achievement than male students [5, 84–86], but these results do not support this, instead indicating that the multimedia case studies are more appealing to female students, thus increasing their intention to learn and improving their learning achievements. Indeed, our results agree with those reported by Marra et al. [23], who indicated that a strong sense of self-efficacy, particularly among female engineering students, can help them retain interest in learning engineering and enable them to become practicing engineers. One way of improving students' self-efficacy, as proposed by Cheung et al. [87] and Tompson and Dass [88], is the use of multimedia case studies that incorporate real-world examples and encourage critical thinking. This approach is likely to boost female students' feelings of self-efficacy and alter their mental framework to increase their self-confidence in learning. Therefore, learning via multimedia case studies may be particularly effective for female students' engagement with course content and may help them learn the engineering concepts in engineering courses more readily.

The second finding is that, minorities performed better in classrooms using multimedia case studies than do Caucasians, with minorities receiving average grades of 960.31, and Caucasians receiving average grades of 930.06. This discovery confirms the findings of several studies [75–77], who reported that minority students were highly engaged in these multimedia case studies. This may be because minority students tend to prefer interactive and problem-solving learning environments and their learning style can often be categorized as visual learning [75]. Therefore, multimedia case studies may facilitate minority students' engagement with the course content more effectively than either textbooks or round table discussions, as evidenced by student grade performance.

The third finding is that students perceived improvement in HOCS in the multimedia case study learning environment was significantly greater than in the round table discussion learning environment (3.37 versus 3.12). This finding reaffirms the results of studies by Mbarika et al. [44] and Mbarika [64] in which the use of multimedia instructional materials improved students' learning in engineering issues as well as their HOCS. As previously noted, HOCS represent a portfolio of skills that encompass the abilities needed to identify, integrate, evaluate, and interrelate concepts within a project and then make appropriate decisions in a given problem-solving situation. This implies that one way to teach HOCS may be to provide a learning environment in engineering courses that allows students to apply engineering concepts to their projects, make decisions, and solve problems within projects. On the other hand, traditional instructional methodologies such as lecture-based and round table discussion methods are often better for communicating technical knowledge of engineering [51], even if they do not always help students understand how to apply engineering knowledge to practice. Traditional instruction approaches do not provide sufficient hands-on applications of engineering subjects, which may lead to engineering graduates being underprepared when they enter the profession [89]. Based on this finding, therefore, students may improve (a) their ability to make appropriate decisions, (b) their ability to think critically about engineering issues, and (c) their ability to apply the knowledge acquired within their discipline to solve practical problems in a multimedia case study classroom.

The fourth finding is that students in a multimedia case study learning environment exhibited improved attitudes towards engineering compared to those taking part in round table discussions. Students in the multimedia case study classrooms perceived higher benefits of engineering than those in the round table discussion groups. This finding confirms the view of Pridmore et al. [10] that the multimedia case study method captures students' attention and is exciting, provokes interest in engineering and promotes an environment in which students feel conformable engaging in an open discussion and thus improves their learning outcomes. However, although most studies assert that the multimedia case studies learning approach is positive, a few studies have suggested that there is a negative effect of multimedia instructional methods on learning achievement [65, 90]. For example, Dillon and Gabbard [65] have argued that there are many overlapping concepts when instructors use multimedia instructional materials and textbooks at the same time, so most students fail to gain a solid understanding of the concept from multimedia videos, thus limiting the benefits of multimedia material. A possible explanation for the limited effect of multimedia is that most multimedia materials merely focus on transferring textbook content into the new multimedia format. In contrast to traditional multimedia materials, the multimedia case study method of problem-based learning requires learners to engage in the problem-solving process as they analyze and solve one or more real-world cases, thereby building their professional skills [10]. Also, these cases are likely to provide additional insights as a supplement to textbooks and other instructional materials, enabling students to understand the complexity of given topics, consider alternatives through dialogue with others, and justify decisions. Therefore, the multimedia case study method may have surmounted Dillon and Gabbard's [65] doubts regarding the efficacy of using multimedia materials in engineering classrooms.

7. Limitations

There are several limitations to this study. First, the sample size used in each analysis in the results section is different since information on students who did not provide data for individual variables was dropped from the analysis. As the research team collated all the responses at the end of the three-year project and did not conduct intermediate analyses, this made it difficult to fill in missing values (such as gender and race) for about 130 of the responses. The sample size for each analysis shown for the different product variables in Tables 2, 3, 4, and 5 therefore varies. We believe that this does not affect the study results, although it does make it harder to make strong inferences. This is a serious limitation of the current research. The second limitation affecting this study is that the student grades came from a comprehensive assessment that included quizzes, tests and an evaluation received for the presentation of the case studies and project. The evaluation for the project presentation was based on actual observations by instructors, and because of observer subjectivity, this evaluation is inevitably more controversial than standardized testing. The third limitation is that the results of this study are limited to a comparison between two teaching pedagogies, namely round table discussions and multimedia case studies, in introductory engineering courses. These effects may be different or may not occur at all when using other instructional materials. Finally, the participants of this research were from a national university and a regional university. The regional university, HBCU, was selected to increase minority representation within the sample. The representativeness and generalizability of the sample may therefore be limited.

8. Implications and future directions

This study makes several contributions to the engineering education literature. First, the 4-P model of student learning offers novel insights into how the pedagogy factor affects the relationship between the presage and product factors and the relationship between the process and product factors. The 4-P model has been tested for engineering education in this paper, but when applied in other disciplines the results may differ. However, the 4-P model is likely to present a useful framework for other disciplines such as mathematics, chemistry or medicine and provide a worthwhile addition to the theory and body of knowledge needed for educational planners and facilitators in those fields.

The second contribution of this research is that an increased understanding of the effect of gender and race differences on student learning can help instructors design better instructional methodologies and courses and, thus, create more suitable learning environments. The female and minority students in our study performed better and perceived more effective learning in the multimedia case study environment than in the round table discussion environment. This may imply that these students perceive the content of case studies to be more relevant to their future work needs. Additionally, this research contributes to the broader literature on retaining minorities and females in engineering programs by using multimedia case studies that are more likely to support their success. Minorities and female students may be attracted to and retained in the field of engineering by this approach, because it focuses on training in problem-solving and decision-making and also connects to real-world contexts.

The third contribution of this research is that multimedia case studies could play a vital role in enhancing professional skills, improving the performance of students in higher education engineering programs and, hence, elevating the overall quality of engineering education. Moreover, this insight can be applied at any institution or program that is interested in producing graduates with proficient professional skills and in improving student learning achievements in engineering or other STEM (Science, Technology, Engineering and Mathematics) disciplines.

We have identified a number of directions for future work as follows. First, it is important to find a way of evaluating students' perceptions of self-reported learning outcomes more accurately. Although a reasonable assessment was used in this study, more comprehensive assessment methods should be developed. These assessments are likely to consist of a combination of qualitative and quantitative surveys, such as in-depth interviews and observations or adding open-ended questions in the survey, in order to provide better suggestions to instructors and lead to further improvements in instructional methodology. Second, there is a need to improve the collection of data to minimize gaps in the future. This requires that the dataset be examined every semester and missing values filled in wherever possible. Third, the use of multimedia case studies for future research may not be limited to introductory engineering courses, so it is recommended that educators replicate this method in other core engineering classes, which may raise the quality of engineering programs. Fourth, based on the 4-P model, the relationships among these factors pose some interesting questions for future research: Do other presage factors such as learning styles, behavior tendencies, or personalities lead to different learning outcomes? Does the use of multimedia case studies have an impact on other related professional skills such as the ability to work in multidisciplinary teams, the recognition of the need for lifelong learning, or the understanding of professional and ethical responsibility?

9. Conclusions

This study evaluated the perceptions of students who took part in multimedia case studies and compared them to the perceptions of their fellow students who took part in round table discussion classes. Our findings revealed that both female and minority students perceived better learning outcomes, particularly in grade performance, after working on the multimedia case studies. Students also perceived better improvement in HOCS and learning outcomes, especially in their attitudes toward engineering and the benefits of engineering in a multimedia case study learning environment. We hope that our work will encourage instructors to consider incorporating multimedia case studies in their classrooms so as to increase students' engagement in learning and communicating real-world experiences, thereby building their professional skills. Furthermore, the widespread adoption and implementation of multimedia case studies may well motivate more female and minority students to pursue engineering programs successfully.

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