Effective Instructional Strategies for Deeper Learning

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Abstract

Deep learning is the result of cognitive engagement with the learning materials. Various strategies have been proposed for promoting cognitive engagement during the learning process. One such strategy is active learning which is an essential element for student engagement to foster deeper learning leading to academic success. However, time limitation of the classroom is a major obstacle in implementing active learning. One solution is the use of the flipped teaching and learning methodology. This paper provides details of strategies to promote engagement and deeper learning in lower level math and aerospace engineering courses at a Historically Black College and University (HBCU). Data on students' motivation and self-regulation was collected using the validated instrument, Motivated Strategies for Learning Questionnaire (MSLQ). Results of the analysis and best practices impacting students' academic performance are shared in this paper. The work is supported by NSF Grant# 1712156.

Introduction

Jobs that traditionally required manual operation of tools and machinery are now being routinely performed by robots. A study by Oxford Economics[1] reported that in the US manufacturing sector, over 260,000 jobs (~2% of the workforce) have been lost to robots since 2000. The same study projected that up to 1.0 million additional jobs in the US will be lost to automation by 2030. These technological and industrial advances are rapidly creating a different category of opportunities resulting from the 'labor-replacement, labor-reinstatement' process[2]. This labor-reinstatement increases the need for science, technology, engineering, and mathematics (STEM) background. However, statistics[2] indicate that the US education enterprise is unable to respond to this labor-reinstatement need. The Smithsonian Science Education Center projected that over 2 million STEM jobs will go unfulfilled in US in 2018[3].

According to the latest report by the National Science Board (2019), not much has changed on the national Science and Engineering (S&E) landscape since 1995, especially in case of underrepresented minorities (https://nsf.gov/nsb/sei/edTool/explore.html). In 1995, 32.4% of all freshmen entering a 4-year college intended to pursue STEM. By 2012, a 13% increase was registered in the number of primarily non-African American freshmen intending to pursue STEM. However, this number remained flat at around 36% from 1995 to 2012 for African-American students. In 2012, even though only 56.1% of 18-24 years old Whites were enrolled in undergraduate degrees, 62.7% of the S&E degrees were received by them. In contrast, only 8.8% of STEM degrees were received by the 14.9% African-Americans enrolled in undergraduate degrees. In 2017, the percentage of African-Americans receiving STEM degrees remained essentially the same at about 8.6%[4]. The percentage of African-Americans receiving undergraduate degrees in engineering and math was even lower (~4.5%) as reported in the report by NSF[5]. Attrition of students from STEM is a major challenge being faced by the US[6]. Data from the Higher Education Research Institute report[7] as reported by Eagan, Hurtado and Chang[8] showed that the 4-year completion rate of undergraduate degree for African-Americans was 13.2% as compared to 24.5% for White students. This gap further widened for 5-year completion rate which was 18% for African-Americans and 33% for Whites.

Thus, while enrollment in STEM is one aspect of the challenge, retention of students in STEM is the other equally important aspect. The President's Council of Advisors on Science and Technology noted[9] that a mere 10% increase in retention in STEM can meet 75% of the targeted one million degrees in the next decade. Retention of students in STEM therefore continues to be the focus of research to understand the complex interaction between student, instructor and institutional characteristics[10,11,12,13,14,15]. The increasing enrollment number of underrepresented groups in STEM has prompted research into factors impacting retention of these demographic groups. Studies have shown high attrition rates for first-generation students[11,16], majority of whom are African Americans. Academic course engagement and degree attainment has also been shown to be correlated[17,18]. In one study[19], a decision point for women leaving STEM was observed to be influenced by Calculus I. Engagement has been identified in these studies as a factor impacting retention.

Several definitions, conceptualizations and dimensions for academic engagement have been reported in literature[20]. Academic engagement dimensions conceptualized in research range from two to four. For example, behavioral, cognitive and affective/emotional have been suggested as the three dimensions of engagement[21]. Deeper learning is associated with cognitive engagement, self-efficacy and motivation[22,23,24]. A cognitively engaging learning environment should be authentic, inquiry-based, and collaborative[25]. Active-learning increases cognitive engagement[26,27]. The traditional lecture pedagogy is not an effective approach to cognitively engage the learners since it is a passive learning environment. Active-learning methods include problem-based learning, project-based learning, collaborative learning, cooperative learning[28]. Active-learning also facilitates an inductive learning environment[29].

While the advantages of cognitive engagement achieved through active-learning are well understood, its implementation is still not as wide spread as one would have expected. There are several challenges in implementing active-learning including class size, physical learning space, and learning materials. However, the biggest impediment to incorporating the active-learning approach in the classroom is the limited duration of the class period. Fortunately, with the availability of low-cost and easy to use technology, the learning environment is fast evolving into a 'flipped' classroom. Instructors can provide media-rich learning materials to the students prior to the class meeting. The face-to-face class time can then be used to cognitively engage students through properly designed active-learning experiences.

This paper provides details of the implementation of strategies to effectively engage students in lower level math and aerospace engineering courses at an HBCU.

Method

Research Design. The study was based on a quasi-experimental within-subject design. The independent variables (dimensions) were Self-Efficacy, Intrinsic Value, Test Anxiety, Cognitive Strategies Use, and Self-Regulation. A semester-long intervention which consisted of active-learning pedagogy was implemented in selected lower level math and aerospace engineering courses.

Participants. The participants were undergraduate students at an HBCU who had registered in the courses in Spring 2019 in which the intervention was implemented. There were 38, 49, 21, 25, and 9 students registered in the MATH107 Pre-Calculus, MATH207 Calculus I, AENG200 Introduction to Aerospace Engineering, AENG242 Aerospace Structures I course, and AENG244 Aerodynamics I courses respectively. All participant students were from groups underrepresented in STEM.

Materials. The instructional materials used in the intervention were (a) Short (8 -12 min) videos of concepts and solution processes of example problems accessible to students prior to class (b) Activities in class that promoted collaborative learning and communication (c) In-class learning materials that used the concepts in problems with real life applications (d) Online and in-class short low-stakes assessments (quizzes), e) in-class exams, and (f) Homework assignments requiring higher order/critical thinking. The Motivated Strategies Learning Questionnaire (MSLQ)[30] which is a 56-item Likert scale (5-Strongly agree, 4-Agree, 3-Neutral, 2-Disagree, 1-Strongly Disagree) survey was used to measure the independent variables.

Procedure. The intervention consisted of three phases, a pre-class phase, an in-class phase and a post-class phase. All the selected courses in which the intervention was implemented had a standard Learning Management System (LMS) structure. A detailed course calendar was included in the LMS which provided the sections/topics to be covered during the semester, the dates of the exams, and the online quizzes and homework due dates. Students were required to watch the short videos for a concept that was to be covered during the face-to-face class meeting. The students were required to take short online graded quiz after watching the videos and before coming to class. The objective of the quiz was twofold, first to ensure that the students watch the videos prior to coming to class, and second, to identify any conceptual challenges being faced by the students. The in-class activities consisted of problem-solving sessions that were based on the concept of the pre-class videos. These problems were designed to have a real-life application flavor. The problem-solving sessions were also collaborative to promote peer learning. In-class quizzes were also administered as a formative assessment tool. Other active-learning opportunities included Jeopardy-style games to engage students. Students were also asked to share and explain their solution to the word problem on the white board. So, students had the opportunity to enhance their communication skills. Exams on the content were also administered in class. Homework was assigned as a post-class activity which included problems requiring critical thinking. The MSLQ survey was administered to the students registered in the intervention courses at the start of the semester, and then at the end of the semester but prior to the final grades.

Results and Discussion

The completion of the MSLQ surveys was voluntary. Hence, many students did not respond to either the pretest or the post-test. Some students did not respond to both pretest and post-test surveys. Data for only those students who responded to both the pre and post surveys were used in the analysis. The data collected from the MSLQ pre-post surveys were analyzed using repeated measures two-tail t-tests to determine if the changes in the independent variables as a result of the pedagogical approach were statistically significant. The means and the p-values for the five independent variables for each of the courses in which the active learning was implemented are shown in Table I.

Dimension	Course	MATH107 (N = 13)	MATH108 (N = 28)	MATH 207 (N =11)	AENG 200 (N = 17)	AENG 242 (N = 8)
Self-Efficacy	Pre	3.80	3.96	3.35	2.98	3.75
	Post	4.20	4.29	3.96	4.58	4.28
	p	0.004	0.022	0.028	0.000	0.017
Intrinsic Value	Pre	3.97	3.94	3.52	3.28	4.07
	Post	4.33	4.28	4.09	4.38	4.51
	p	0.100	0.004	0.046	0.000	0.0002
Test Anxiety	Pre	3.58	3.34	3.50	3.24	3.50
	Post	2.98	2.81	2.52	2.54	2.78
	p	0.004	0.004	0.010	0.007	0.021
Cognitive Strategy Use	Pre	4.15	4.07	3.54	3.93	3.85
	Post	4.41	4.32	4.01	4.34	4.30
	p	0.108	0.000	0.029	0.0006	0.004
Self-Regulation	Pre	3.88	3.79	3.41	3.75	3.75
	Post	4.32	4.07	3.89	4.15	4.17
	p	0.007	0.005	0.024	0.0006	0.028

Table I: Summary of MSLQ Responses

Note that all questions in the Test Anxiety dimension were negative questions, hence lower posttest means indicate reduction in Test Anxiety. As can be observed from Table I, the approach had a positive impact on students in all five dimensions. An increase in posttest means of all the statements/items in the MSLQ was registered. However, the change in the means was not statistically significant ($p<0.05$) for all the MSLQ statements. The results for each of the courses that used the active learning approach are discussed below.

MATH107: Pre-Calculus Algebra

There were only 13 MATH 107 students out of 38 enrolled in the course who responded to both pretest and posttest. The data indicated that the methodology had a positive impact on all dimensions of the MSLQ (Fig. 1). The impact was statistically significant ($p < 0.05$) for the Self-Efficacy, Test Anxiety and Self-Regulation dimensions.

Table II shows the statements with statistically significant change in the means ($p<0.05$) from each MSLQ dimension for Math 107 course.

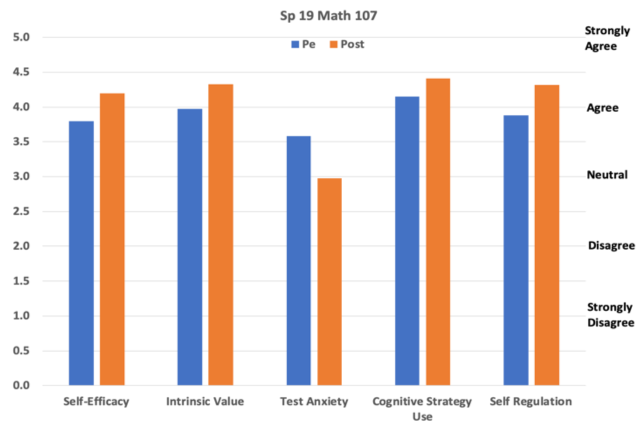

Figure 1. Math 107 – MSLQ Results

MATH 107: Pre-Calculus Algebra		Pretest Mean	Posttest Mean	p
Self-efficacy	I like what I will learn / have learned in this class.	3.692	4.308	<0.005
	I am certain I can understand / have understood the ideas taught in this course.	3.69	4.462	<0.02
Intrinsic Value Dimension	I prefer classwork that is challenging so I can learn new things.	3.62	4.15	<0.02
	I often choose paper topics I will learn something from even if they require more work.	3.23	4.08	<0.01
Test Anxiety	I have an uneasy, upset feeling when I take a test.	3.54	2.69	< 0.01
	I worry a great deal about tests.	3.92	3.38	< 0.005
Cognitive Strategy Use	When I am studying a topic, I try to make everything fit together.	4.31	4.62	< 0.05
Self-regulation	I work on practice exercises, answer end of chapter questions even when I don't have to.	3.54	4.31	< 0.05
	Before I begin studying, I think about the things I will need to do to learn.	4.08	4.77	< 0.01
	I often find that I have been reading for class but don't know what it is all about.	2.54	3.39	< 0.02

Table II. Math 107 Statistically significant MSLQ items

MATH 108: Pre-Calculus Trigonometry

Out of 48 students registered in the course, only 28 students responded to the pre and post MSLQ questionnaire. The data from MATH 108 indicated that the methodology had a positive impact on all dimensions of the MSLQ (Fig. 2). The impact was statistically significant ($p < 0.05$) for all five dimensions.

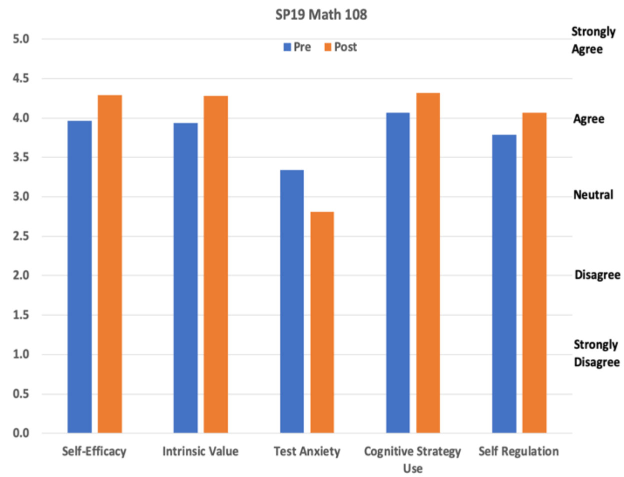

Figure 2. Math 108 – MSLQ Results

The statements registering a statistically significant change in the mean ($p < 0.005$) in each dimension for Math 108 are shown in Table III.

MATH 108: Pre-Calculus Trigonometry		Pretest Mean	Posttest Mean	p
Self-efficacy	I think I will do/did well in this class.	3.78	4.54	<0.005
Intrinsic Value Dimension	I prefer classwork that is challenging so I can learn new things.	3.93	4.36	<0.03
	I often choose paper topics I will learn something from even if they require more work.	3.57	4.10	<0.01
	I like what I will learn / have learned in this class.	3.93	4.36	<0.005
Test Anxiety	I am so nervous during a test that I cannot remember facts I have learned.	3.43	2.93	< 0.02
	I worry a great deal about tests.	3.82	3.04	< 0.002
Cognitive Strategy Use	It is hard for me to decide what the main ideas are in what I read.	3.11	3.68	< 0.02
	I outline the chapters in my book to help me study.	3.46	4.11	< 0.02
Self-regulation	When work is hard, I either give up or study only the easy parts.	3.29	4.04	< 0.01
	I often find that I have been reading for class but don't know what it is all about.	3.05	3.54	< 0.05

Table III. Math 108 Statistically significant MSLQ items

While the responses to all the statements in the Self-Efficacy dimension registered a positive change in the means, only one statement for which a statistically significant change ($p < 0.005$) in the mean was registered.

MATH 207: Calculus-I
The results of the MSLQ survey were similar to MATH 107 and MATH 108 courses. The number of respondents to both pre and post MSLQ surveys was 11 out of 21 students registered in the

course. A positive and statistically significant change at $p < 0.05$ was observed in all dimensions at the end of the course as shown in Fig. 3.

The Math 207 course MSLQ results in which the statements registering a statistically significant change in the mean ($p < 0.05$) for each dimension are noted in Table IV.

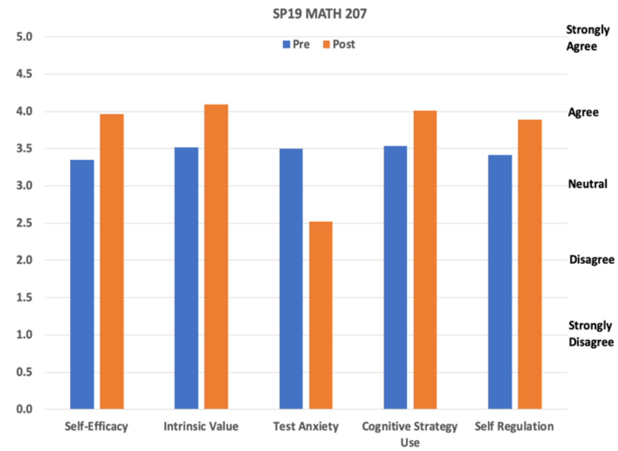

Figure 3. MATH 207 – MSLQ Results

Math 207: Calculus-I		Pretest Mean	Posttest Mean	p
Self-efficacy	I think I will do/did well in this class.	3.09	4.18	<0.001
	I know that I learned the material for this class.	3.36	4.00	<0.03
Intrinsic Value Dimension	It is important for me to learn what will be taught in this class.	3.73	4.45	<0.02
	Even when I do poorly on a test I try to learn from my mistakes.	3.55	4.46	<0.002
Test Anxiety	I am so nervous during a test that I cannot remember facts I have learned.	3.73	2.36	< 0.02
	I have an uneasy, upset feeling when I take a test.	3.64	2.64	< 0.02
Cognitive Strategy Use	When studying, I copy my notes over to help me remember material.	3.36	4.27	< 0.05
	I use what I have learned from old homework assignments and the textbook to do new assignments.	3.55	4.18	< 0.05
Self-regulation	I often find that I have been reading for class but don't know what it is all about.	2.46	3.36	< 0.01
	I find that when the teacher is talking, I think of other things and don't really listen to what is being said.	2.91	3.64	< 0.03

Table IV. Math 207 Statistically significant MSLQ items

AENG 200: Introduction to Aerospace Engineering Lab

The number of students who responded to both the pre and post MSLQ survey was N =17 out of 25 students enrolled in the course. Statistically significant positive changes were measured as a result of the implementation of the active-learning pedagogy. The pretest and posttest means for the five dimensions of the MSLQ are shown in Fig. 4.

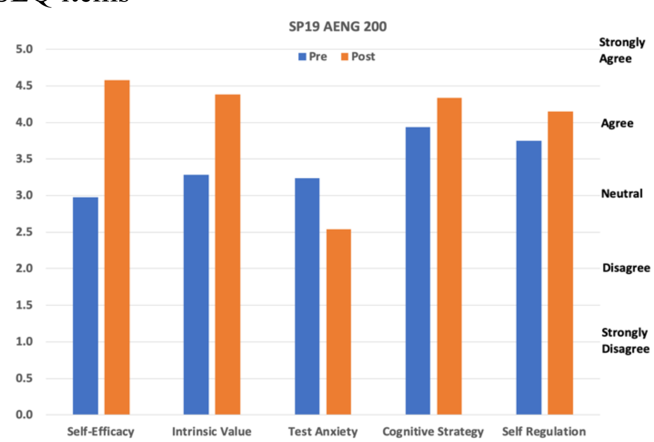

Figure 4. AENG 200 – MSLQ Results

Table V includes several MSLQ items in which students' responses registered statistically significant change in the means ($p < 0.05$).

AENG 200: Introduction to Aerospace Engineering Lab		Pretest Mean	Posttest Mean	p
Self-efficacy	I am certain I will understand / understood the ideas taught in this course.	2.00	4.41	<0.000
	I think I will do/did well in this class.	2.24	4.71	<0.000
	I am sure I will do / did an excellent job on the problems and tasks assigned for this class.	2.06	4.53	<0.000
Intrinsic Value Dimension	I like what I will learn in this class.	1.41	4.41	<0.000
	I think I will be able to use what I learn in this class in other classes.	2.06	4.06	<0.000
	I often choose paper topics I will learn something from even if they require more work.	2.18	3.53	<0.000
Test Anxiety	When I take a test, I think about how poorly I am doing.	4.18	2.23	< 0.02
Cognitive Strategy Use	When I study for a test, I try to put together the information from class and from the book.	3.71	4.24	< 0.03
	When I do homework, I try to remember what the teacher said in class so I can answer the questions correctly.	4.12	4.59	< 0.02
	It is hard for me to decide what the main ideas are in what I read.	2.88	3.77	< 0.05
	When I study, I put important ideas into my own words.	4.00	4.41	< 0.02
	When I study for a test, I try to remember as many facts as I can.	4.06	4.53	< 0.01
	When studying, I copy my notes over to help me remember material.	3.71	4.35	< 0.03
	When I read material for a course, I say the words over and over to myself to help me remember.	3.94	4.41	< 0.05
Self-regulation	When work is hard, I either give up or study only the easy parts. (**Reverse scored**)	3.71	4.41	< 0.02
	I often find that I have been reading for class but don't know what it is all about.	3.00	3.88	< 0.02
	I find that when the teacher is talking, I think of other things and don't really listen to what is being said. (**Reverse scored**)	2.65	3.71	< 0.01

Table V. AENG 200 Statistically significant MSLQ items

Even though only one statement in the Test Anxiety dimension registered a significant change between pretest and posttest, the change in the means in the dimension was statistically significant at $p < 0.05$ indicating a reduction in test anxiety by the end of the course. However, the increase in posttest means was statistically significant in the Cognitive Strategy Use dimension for the largest number of items.

AENG 242: Aerospace Structures-I

The pedagogical approach had a positive impact on the students enrolled in this course (8 out of 9 enrolled students participated in the pre and post MSLQ surveys). All the dimensions of the MSLQ registered a statistically significant change as a result of the intervention as shown in Fig. 5.

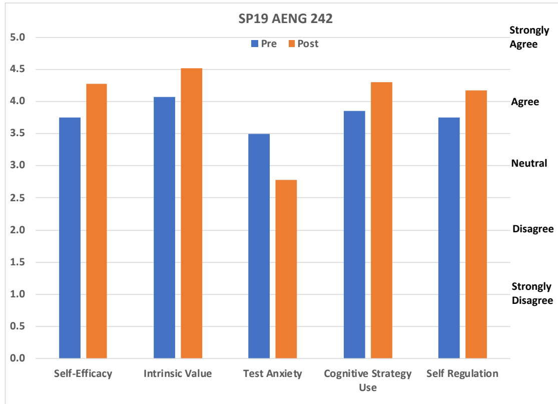

Figure 5. AENG 242 – MSLQ

Several statements in each dimension registered statistically significant changes in the means at the end of the intervention (Table VI).

AENG 242: Aerospace Structures-I		Pretest Mean	Posttest Mean	p
Self-efficacy	I am certain I will understand / understood the ideas taught in this course.	3.25	4.00	<0.05
	I think I will do/did well in this class.	3.50	4.13	<0.05
Intrinsic Value Dimension	I prefer classwork that is challenging so I can learn new things.	3.38	4.13	<0.0005
	It is important for me to learn what will be taught in this class.	4.38	4.88	<0.0005
	I think that what I will learn in this class is useful for me to know.	4.13	4.75	<0.0005
Test Anxiety	I am so nervous during a test that I cannot remember facts I have learned.	3.62	3.00	< 0.05
	When I take a test, I think about how poorly I am doing.	3.25	2.25	< 0.02
Cognitive Strategy Use	When I study for a test, I try to put together the information from class and from the book.	3.88	4.50	< 0.05
	When I read material for a course, I say the words over and over to myself to help me remember.	3.63	4.63	< 0.001
Self-regulation	I work on practice exercises and answer end of chapter questions even when I don't have to.	3.00	3.88	< 0.05

Table VI. AENG 242 Statistically significant MSLQ items

A summary of the statistically significant items of the MSLQ for the various courses is given in Table VII. The shaded cells indicate that the item registered a significant change in that course.

Self-efficacy	MATH 107	MATH 108	MATH 207	AENG 200	AENG 242
I like what I will learn / have learned in this class	■				
I am certain I can understand / have understood the ideas taught in this course	■				
I think I will do/did well in this class.		■	■	■	■
I know that I will learn / have learned the material for this class.			■		■
I am sure I will do / did an excellent job on the problems, tasks assigned for this class.				■	
Intrinsic Value Dimension					
I prefer classwork that is challenging so I can learn new things	■	■			■
I often choose paper topics I will learn something from even if they require more work	■	■		■	
I like what I will learn / have learned in this class		■		■	
It is important for me to learn what will be taught in this class.			■	■	■
Even when I do poorly on a test I try to learn from my mistakes.			■		

I think I will be able to use what I learn in this class in other classes					
I think that what I will learn in this class is useful for me to know					
Test Anxiety					
I have an uneasy, upset feeling when I take a test.					
I worry a great deal about tests.					
I am so nervous during a test that I cannot remember facts I have learned.					
When I take a test, I think about how poorly I am doing					
Cognitive Strategy Use					
When I am studying a topic, I try to make everything fit together					
It is hard for me to decide what the main ideas are in what I read					
I outline the chapters in my book to help me study					
When studying, I copy my notes over to help me remember material					
I use what I have learned from old homework and the textbook to do new assignments.					
When I study for a test, I try to put together the information from class and the book					
When I do homework, I try to remember what the teacher said in class so I can answer the questions correctly.					
It is hard for me to decide what the main ideas are in what I read					
When I study, I put important ideas into my own words.					
When I study for a test, I try to remember as many facts as I can.					
When studying, I copy my notes over to help me remember material.					
When I read material for a course, I say the words over and over to myself to help me remember					
Self-regulation					
I work on practice exercises, answer end of chapter questions even when I don't have to					
Before I begin studying, I think about the things I will need to do to learn					
I often find that I have been reading for class but don't know what it is all about					
When work is hard, I either give up or study only the easy parts.					
I often find that I have been reading for class but don't know what it is all about.					
When studying, I copy my notes over to help me remember material.					
I use what I have learned from old homework assignments, the textbook to do new assignments					
When work is hard, I either give up or study only the easy parts					
I often find that I have been reading for class but don't know what it is all about.					
I find that when the teacher is talking, I think of other things and don't really listen to what is being said.					

Table VII. Statistically significant MSLQ items

As seen from Table VII, a statistically significant change was registered in many items of all the MSLQ dimensions for AENG 200. Student who were more involved in their majors recognized the importance of the course content as observed in the Intrinsic Value dimension item “It is important for me to learn what will be taught in this class.” This result shows that the approach is effective the lower level major course as well. Another interesting observation is that this approach reduces the test anxiety for all students but specifically for math students as indicated by the item “I have an uneasy, upset feeling when I take a test.”.

Summary and Conclusions

The results of the MSLQ suggest that a properly designed active-learning methodology can have positive impact on student self-efficacy, motivation and learning strategies. The analysis also provided useful insight into student attitudes and learning processes. For example, students of MATH 107 who are typically freshmen were not able to recognize the intrinsic value of what they were learning which could impact their learning. They also were not utilizing the cognitive strategies to the level as compared to the students of the other courses who were sophomores. These observations can help the instructors to emphasize the use of cognitive strategies for effective learning. The active-learning approach will continue to be implemented in these courses, and will be expanded to other courses.

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