Innovative Learning Strategies to Engage Students Cognitively

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Abstract

The role of cognitive engagement in promoting deep learning is well established. This deep learning fosters attributes of success such as self-efficacy, motivation and persistence. However, the traditional chalk-and-talk teaching and learning environment is not conducive to engage students cognitively. The biggest impediment to implementing an environment for deep learning such as active-learning is the limited duration of a typical class period most of which is consumed by lecturing. In this paper, best practices and strategies for cognitive engagement of students in the classroom are discussed. Several lower level math and aerospace engineering courses were redesigned and offered during the academic year at a historically black university. The learning strategies in these redesigned courses included the "flipped" pedagogical model which allowed the integration of the active-learning strategy in the classroom. The research study is to determine the impact of these redesigned courses on student academic performance and persistence in STEM courses. The efficacy of the design of the flipped approach was also investigated. A between-group quasi-experimental research design was used for comparing student academic performance in traditional classroom (control group) and redesigned classroom (intervention group). A within-subject, repeated measures design was also used to assess the impact on the students' self-regulated learning. A validated instrument was used to measure the effect of the redesigned learning environment on the motivational beliefs and self-regulated learning. Data on the academic performance of the students were collected. Analyses of these data indicated a significant impact on student academic performance. A positive change in student motivation and self-regulated learning was observed. Data analysis also validated the design of the intervention. This research is supported by NSF Grant# 1712156.

Introduction

The US science, technology, engineering and mathematics (STEM) workforce is facing multiple challenges. There is a decreasing interest in the K-12 students to study STEM. According to a 2018 report [1], the percentage of 13-17 years old boys interested in stem declined from 36 in 2017 to 24 in 2018. On the other end of the spectrum, the industry's need for a STEM-educated workforce is burgeoning with an expected growth of almost 7% in the next five years with 3.5 million STEM jobs to be filled by 2025 [2]. The gap between need and availability is increasing rapidly. The number of unfilled STEM jobs has been projected to be 2.4 million by the end of 2019 [3].

Sandwiched between these two challenges is the challenge of retention of undergraduate students in STEM fields. According to a Department of Education report [4], almost 50% of undergraduate STEM majors do not continue in STEM. According to the 2012 report by the President's Council of Advisors on Science and Technology [4], a mere 10% reduction in STEM attrition would "generate three quarters of a million STEM degrees." There are several reasons for students moving out of STEM majors. One of the reasons for the large attrition (40% - 60%) of students in STEM has been identified as "poor teaching" [5]. Considerable research has been conducted on this construct of "poor teaching". The impact of the mismatch between the teaching and learning styles has been identified as a reason into "poor teaching" [7] – [9] . However, there are research studies which at best consider this construct of "styles" to be controversial [10] – [12]. Other studies have proposed to move from a deductive teaching style to an inductive teaching style [13] – [17]. Several methods of inductive teaching and learning have been identified such as project-based learning, problem-based learning, inquiry learning, case-based learning [17]. All these methods fall in the general category of active-learning shifting the paradigm from chalk-and-talk to that of a guide-on-the side. While *surface learning* is associated with memorization or rote-learning, *deep understanding* requires an active-learning approach [18]. The result of an active-learning environment is a deeper engagement of the students with the learning process. If the learning activities are properly designed, students can be engaged in all three dimensions i.e. cognitive, affective and behavioral [19]. Active-learning should incorporate authentic learning (real life problems) and inquiry (observations, data collection, data analysis, data interpretation) [20], [21].

The implementation of active-learning strategies in the classroom obviously requires time which currently is used up for lecturing which relegates the learner to a passive learner. As a result of the lecture the teacher hopes that student would have learned and understood that is being taught and will be able to demonstrate by solving the homework problems. Of course, as mentioned previously this is not the case, at least for a large percentage of the students. Thus, an essential component of an active-learning environment is to be able to free up class time for activities that emphasis critical thinking. The availability of low-cost and easy to use technology now provides the opportunity to move the elements of the content which is at the knowledge and understanding levels [22] to be moved out of the classroom in the form of short video-lectures, annotated PowerPoints etc. to be studied by the students prior to coming to class while the class time is utilized for active-learning (The Flipped Classroom). However, even the out-of-class material cannot be for passive study e.g. merely watching a video in the flipped class does not mean that content is being learned. The out-of-class materials must include elements of active-learning albeit commensurate with the level of the content. Of course, during the design of the learning environments, important aspects of constructivism and scaffolding cannot be overemphasized.

This paper provides details of the design, implementation and assessment of learning strategies that were implemented in lower level math and aerospace engineering courses that used the active-learning approach at a Historically Black Colleges and Universities (HBCU).

Method

The implementation methodology consisted of designing three aspects of the pedagogy which were pre-class preparation, in-class activities, and post class activities. These three aspects were aligned with the levels of the modified Bloom's taxonomy [22]. The pre-class preparation materials were at the remembering and understanding level, the in-class activities involved the students in applying and analyzing, and the post-class work challenged the students to evaluate and create (e.g. design). The approach was implemented in four math courses (Pre-Calculus Algebra (Math 107), Pre-Calculus Trigonometry (Math 108), Pre-Calculus Algebra and Trigonometry (Math 110), and Calculus I (Math 207)), and four aerospace engineering courses (Introduction to Aerospace Engineering (AENG 100), Introduction to Aerospace Engineering Laboratory (AENG 200), Aerospace Structures I (AENG 242), and Aerodynamics I (AENG 244)) during 2018-19 academic year. There was no specific recruitment policy other than the regular course prerequisite and that the students were informed during the first day of class about the course delivery methodology.

Materials

As mentioned above, learning materials were prepared for each of the three phases for the course delivery methodology. The first step was designing a standard learning management system (LMS) structure for each course. A detailed course calendar was developed providing the students with the important dates for formative assessments such as in-class quizzes and tests. Each section of the syllabus was further subdivided into logical units. The instructor prepared a 10 to 12 minutes video for each covered logical unit. A clear and short description of each posted section and each video included expected learning outcomes from that section or video. The videos were prepared using an iPad or a Wacom tablet by the instructors with explanations, links to other reference materials etc. Separate and short videos for example problems were also developed explaining the solution process. All these materials were uploaded to the LMS at least three days prior to the class meeting. The pre-class materials were followed by short graded quizzes that were also uploaded to the LMS. The graded quizzes served two purposes; firstly, the students are encouraged to carefully study the learning materials so as to get a good grade in the quizzes, and secondly the instructor receives some useful information on what is needed to be clarified in the class meetings. The in-class materials and activities included work-out and real-world problems for individual and/or group work. The students are then engaged in the class with peer-to-peer discussion or explanation of the solution by a student to the class using the white board. The workout problems were selected such that student strengthened their recognition of the unknown quantities, the data, the relationship between the known and unknown variables, and the understanding of the solution process. These problems were encapsulated in a real-world situation at a cognitive level that supported analyzing and application. The post-class problems required the students to do some comparisons and designs (i.e. trade-off between various values of parameters). Students were also assigned projects and they were required to present their work as a group in class.

Several assessments instruments were used to determine the effectiveness of the approach. The pre-class and the in-class quizzes, in-class exams, and post-class homework/projects were used to determine the learning of the content materials. The Motivated Strategies for Learning Questionnaire (MSLQ) [23], a validated instrument was administered at the start of the semester and then at the end of the semester, but prior to the announcement of the final grades, to understand the impact of the methodology on the students' self- efficacy, intrinsic value, test anxiety, cognitive strategies use, and self-regulation. The responses were registered on a 5-point Likert-type scale with Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D), and Strongly

Disagree (SD). A "flipped classroom" questionnaire to determine the attitudes of the students towards the methodology was also administered at the end of the semester.

Participants

The participants were undergraduate students at an HBCU. The number of students (N) enrolled in each traditional course is given in the relevant academic performance chart (Figs. 1-8). Student participation in the MSLQ pretest and posttest was voluntary and it doesn't affect a grade in the course. Therefore, some of these students enrolled in the intervention courses either didn't respond to the pretest or posttest of the MSLQ and so they were not included in the analysis. The number (N) given in the relevant chart (Figs. 9-16) for each of the intervention course corresponds to the number of students who responded to both the pretest and posttest administration of the MSLQ.

Results and Discussion

The academic performance of the students in the active-learning (flipped) and traditional course was compared to determine the impact of the strategies for effective engagement. To reduce the influence of instructor, the comparison was done for the courses taught by the same instructor. The pre-post responses to the MSLQ provided insight into the impact of the intervention on the self-efficacy, intrinsic value of the course, test anxiety, use of cognitive strategies, and self-regulation strategies.

The comparison for the math courses is shown in Figs. 1-4. A clear impact on the academic performance of students as a result of the intervention was observed. In general, a higher passing rate was observed for the intervention classes.

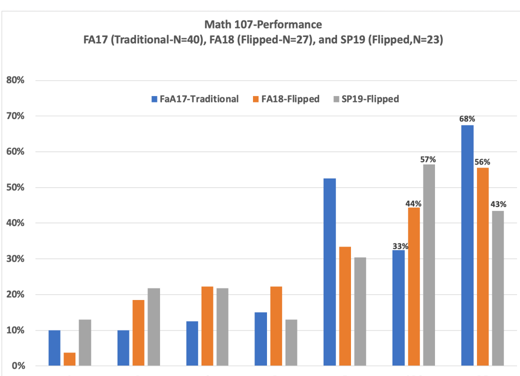


Figure 1. Math 107 Performance Comparison.

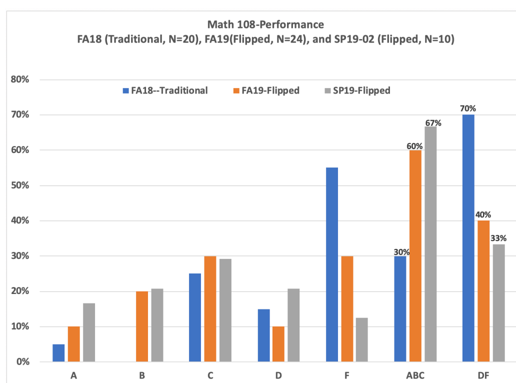
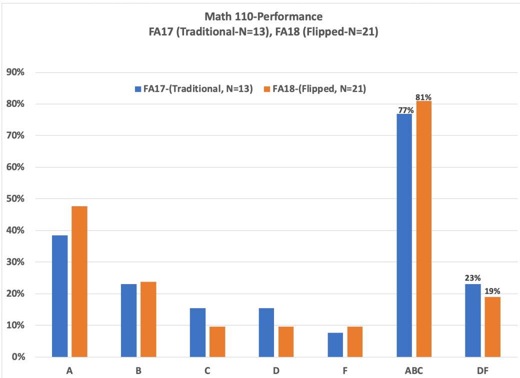


Figure 2. Math 108 Performance Comparison



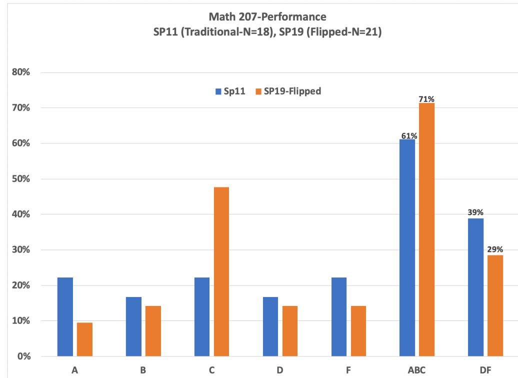
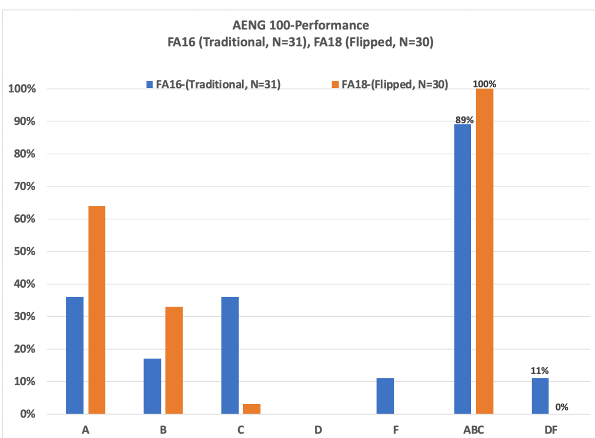


Figure 3. Math 110 Performance Comparison

Figure 4. Math 207 Performance Comparison

The smallest difference between the traditional delivery and the flipped delivery was observed for Math 110. This could be because the students of the traditional delivery class were provided access to some of the learning videos that were being developed for the planned flipped delivery of the class. However, a large increase in the passing rate with A, B, and C letter grades (33% in a traditional Fall 2017, 44% in a flipped Fall 2018, and 57% in flipped Spring 2019) was observed in Math 107. And in Math 108 course even a larger increase in the passing rate (30% in a traditional Fall 2018, 60% in a flipped Fall 2019, and 67% in flipped Spring 2019) was observed.

The comparative academic performance of students in the aerospace engineering courses are shown in Fig. 5 – 8. The intervention groups improved student academic performance as compared to the control group. While there was not much change on the passing rates, a distinct move towards higher grades was observed in all the courses as seen in the charts.



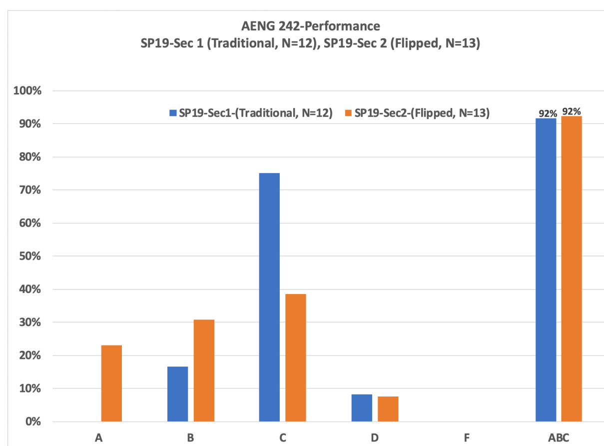
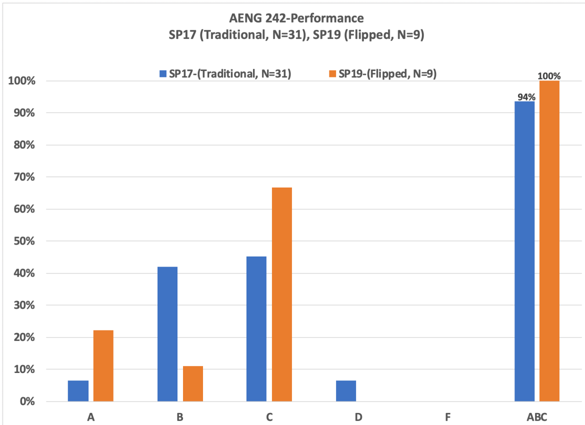
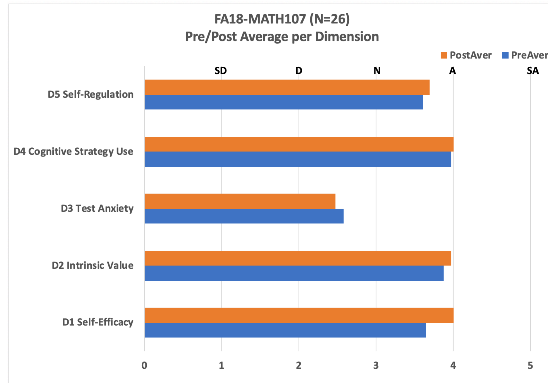


Figure 5. AENG 100 Performance Comparison

Figure 6. AENG 200 Performance Comparison





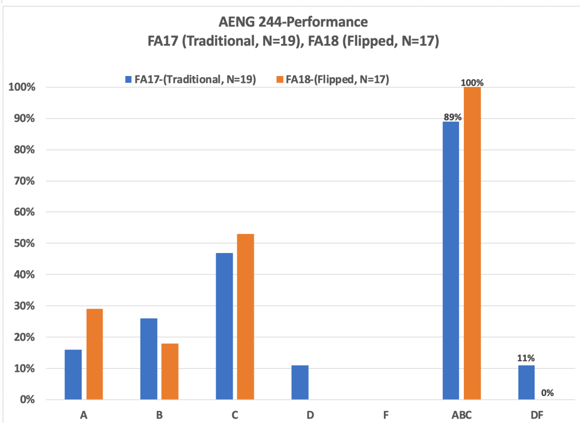


Figure 7. AENG 242 Performance Comparison.

Figure 8. AENG 244 Performance Comparison

The average of the responses to each of the five dimensions (Self Efficacy, Intrinsic Value, Test Anxiety, Cognitive Strategy Use, Self-Regulation Strategies) of the MSLQ for Math 107, Math 108, Math 110, and Math 207 are given in Figs. 9 – 12. In general, the students enrolled in these courses self-reported an increase in their self-efficacy, recognizing the intrinsic value of the course, a reduction in test anxiety, better use of cognitive strategies for learning and increased self-regulation by the end of the semester.

It was also observed that the change in each dimension was proportional to the time spent in college. In other words, the changes were smaller for students who were in the first semester, i.e. enrolled in Fall 2018 Math 107 (Fig. 9a), compared to all the other semesters (Figs. 9b, 10-12).

Figure 9a. Math 107 MSLQ Average Responses

A reduction in test anxiety was registered in all courses. Note that the items in the test anxiety dimension were negative, i.e. disagreement indicated a reduction in test anxiety which is the desired result.

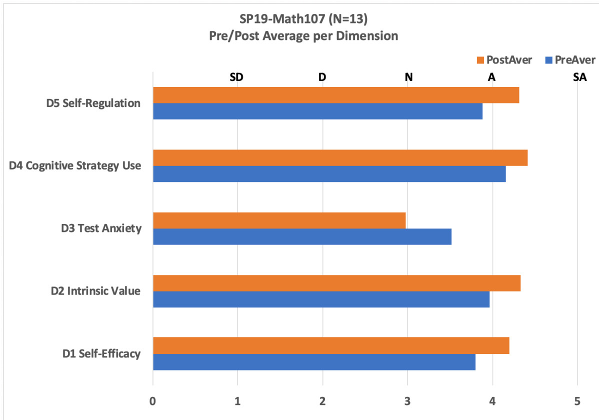


Figure 9b. Math 107 MSLQ Average Responses

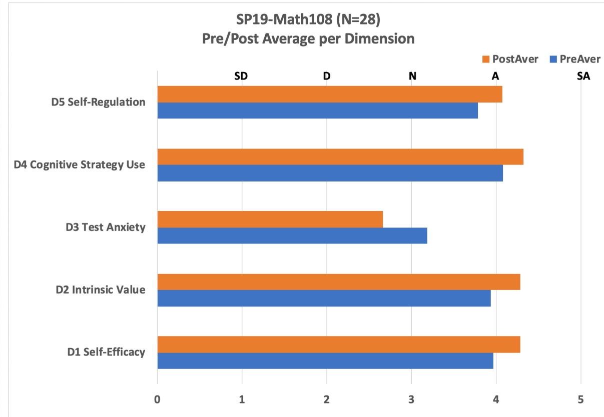


Figure 10. Math 108 MSLQ Average Response

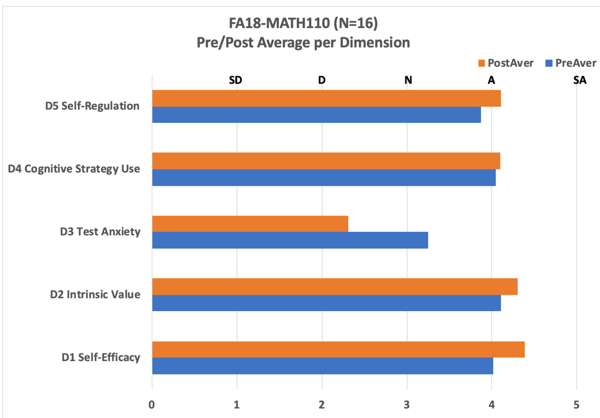


Figure 11. Math 110 MSLQ Average Responses

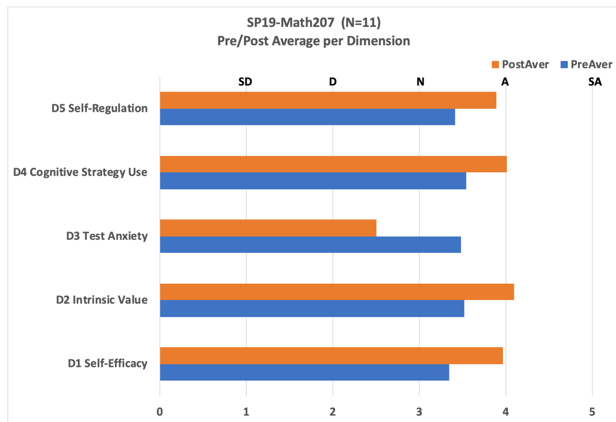


Figure 12. Math 207 MSLQ Average Responses

The average of the responses to each of the five dimensions of the MSLQ for the four aerospace engineering courses (AENG 100, AENG 200, AENG 242, AENG 244) in which the strategies for effective engagement were implemented are given in Figs. 13-16.

It was noted from the average responses (Figs. 13-16) that the students improved their self-efficacy, and recognition of the intrinsic value of the courses by the end of the semester. A reduction in test anxiety was also observed. The largest increase in self-efficacy was noted in the AENG 200 course (Fig. 14). The largest increase in recognition of intrinsic value was also observed in the AENG 200 course (Fig. 14). This course was primarily designed as a hands-on class which included sketching, CAD, OpenVSP, and a bottle rocket design-build-fly component. Thus, the impact of the highly engaging, active-learning in these aerospace engineering courses was clearly seen.

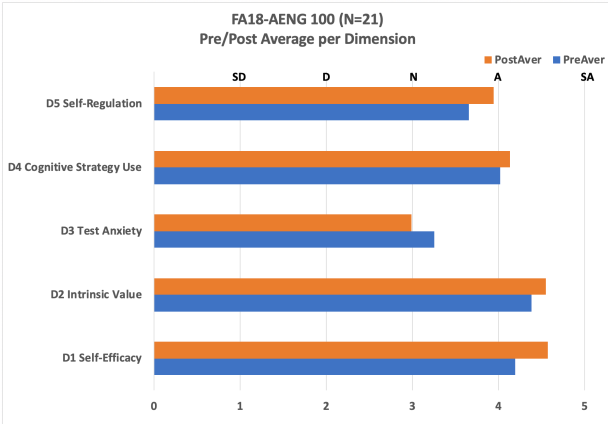


Figure 13. AENG 100 MSLQ Average Responses

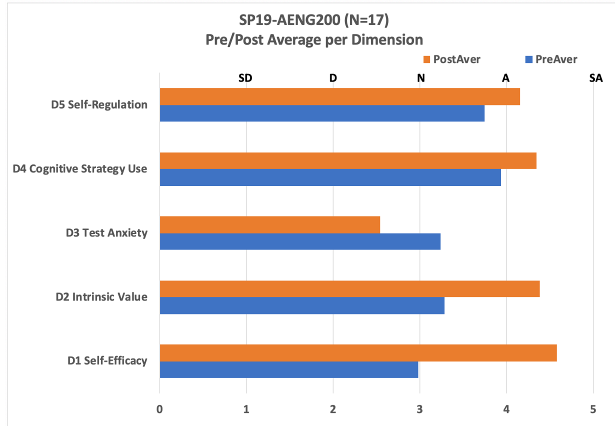


Figure 14. AENG 200 MSLQ Average Responses

Figure 15. AENG 242 MSLQ Average Responses

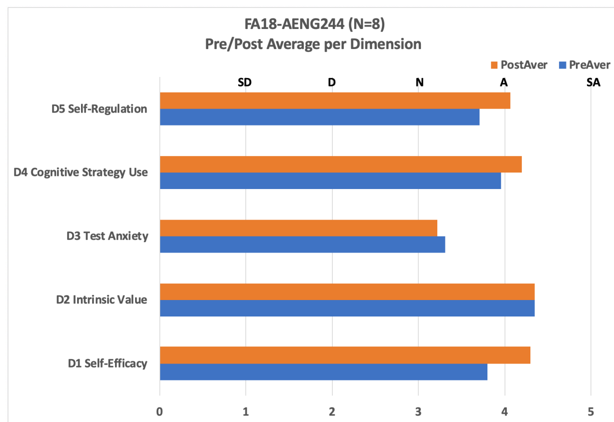


Figure 16. AENG 244 MSLQ Average Responses

Figures 9 to 16 show the pre and posttest averages per dimension for each intervention math and aerospace engineering course. Figure 17 shows changes in the average responses in the five dimensions. For instance, the test anxiety registered the highest improvement of the five dimensions in Math 107. Similarly, the self-efficacy improvement was the highest compared to all other dimension in AENG 200.

Figure 17. AENG 244 MSLQ Average Responses

Other than the academic performance and the MSLQ, the perceptions of the students about the methodology through a questionnaire at the end of the semester. Some typical responses are given below.

"What have you liked the best about the "flipped classroom"?

- gives me a chance to bring my grade up
- being able to learn from watching videos
- that i was able to understand the concepts
- practice worksheets; videos posted on Blackboard
- I liked the professor and her methods of teaching, I liked the amount of sources available to learn the material.
- The independence of the course work.
- It makes you work together with your classmates, thus encouraging social interaction and teamwork.
- The ability to get in touch with the concepts before we went in depth with them."

"What have you liked the least about the "flipped classroom"?

- Constant checks of study habits
- having to take quizzes before class lectures
- The blackboard quizzes
- The copious amount of work"

Conclusions and Future Work

The effectiveness of active-learning in engaging students was demonstrated based on the results of this research presented in this paper. These results indicated positive impact on student academic performance, self-efficacy, recognition of the intrinsic value of the course, test anxiety, use of cognitive strategies, and development of self-regulation. The course delivery methodology should be well designed to facilitate an active-learning environment. Several best practices were identified which were helpful in a successful implementation of the approach. These best practices include the structure of the course in the LMS which should be easy to navigate with clear information about the course. Every posted material should indicate a short description and expected learning outcomes from that material. The detailed course calendar with deadlines and expectations is found to be very helpful to guide students and keep them up with their work. The inclusion of short graded-quizzes on the pre-class learning materials proved to be effective in making students having some background before class meeting such that they are engaged in the learning process. The in-class activities must support group work, peer-instruction and close interaction with the instructor. The students provided positive feedback on the active-learning methodology through their responses to the "flipped classroom" questionnaire. This method helped the instructor identify students who were having difficulties from the beginning of the semester. The instructor can reach out to these students and provide additional support to help them succeed in the course.

The approach will continue to be assessed in the future delivery of the courses in which it has been implemented. The experiences of the methodology have been shared with faculty across the campus in the form of presentations and professional development workshops. Consequently, several faculty members have recognized the advantage of the methodology who along with the authors are designing additional courses to implement the methodology in other disciplines.

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