AC 2007-907: ENHANCING CRITICAL THINKING SKILLS OF CIVIL ENGINEERING STUDENTS THROUGH SUPPLEMENTAL INSTRUCTION

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Enhancing Critical Thinking Skills of Civil Engineering Students Through Collaborative Learning Methods in Supplemental Instruction

Abstract

Supplemental instruction in civil engineering curriculum has been conducted at New Mexico State University since spring 2003. The SI session is designed to develop critical thinking skills of the students by applying collaborative learning methods. The SI session meets once per week to resolve student's questions in the topics of domestic water and wastewater treatment. Prior to meeting in the SI session, students submit questions on the engineering and design concepts discussed within the previous week of class. Active learning in the classroom and self-directed learning outside of class create opportunities for the students to identify questions which can be resolved in the SI session. Students follow a set of steps to develop proper questions and find solutions to their own questions by applying critical thinking skills. The course also requires the students to exercise critical thinking skills as it involves design oriented open-ended problem solving. The student improvement through the SI sessions has been monitored for three consecutive semesters. Comparisons have been made between the SI group and non-SI group students in terms of academic performance throughout the semester. Bloom's levels of learning have been considered to measure the student learning through critical thinking exercises. It has been observed that SI participants have performed better than others in monitoring work examples. Also the SI group earned better grades than the non-SI group in the class.

Introduction

"Fundamentals of Environmental Engineering" is a junior course taught in the Civil Engineering department at New Mexico State University. General course objectives are to learn and apply the engineering design process and develop and apply skills used by successful practicing professional engineers, including critical (reflective) thinking, communication, and documentation. This course teaches the fundamental civil-environmental engineering principles for design of conventional domestic water treatment and wastewater treatment systems. One of the primary learning objectives of the course is for students to be able to apply fundamental civil-environmental engineering principles and perform fundamental calculations for designing water treatment (physical-chemical treatment) and wastewater treatment (physical and biological treatment) systems. Design problems are used to demonstrate application of these principles and to create opportunities to comprehend and analyze conventional treatment alternatives. The depth to which the topics are covered is intended to develop comprehension of theories and concepts and analytical techniques required to successfully complete the design analysis and documentation for a facility preliminary engineering report as typically performed by a professional consulting engineering firm. The course builds on knowledge acquired in two pre-requisite courses, "Environmental Science" and "Introduction to Fluid Mechanics," and develops new skills which are specifically

applicable to the department's capstone design classes. The general objective of applying skills used by successful practicing professional engineers, critical (reflective) thinking, is addressed throughout the course and is the primary focus of the process of supplemental instruction (SI).

SI has been conducted for this class since Spring 2003. The purpose of the SI is to guide the student's development of critical thinking skills through:

- Identifying confusion or lack of understanding of course content and environmental engineering concepts,
- Asking clear and well thought-out questions, and
- Establishing a process for developing and evaluating answers to their own questions.

Engineers must have command of the skill of developing and articulating well defined problems and questions. Problem definition is a key factor in developing the most appropriate solution for a given set of conditions[1]. By working through identifying confusion and misunderstanding, formulating the right question, applying previous knowledge and experience (intuition) to the question, and identifying appropriate sources of information, the students apply a critical thinking process that will lead them to developing answers to their own questions.

The SI session is designed to develop this skill by applying collaborative learning methods. The SI session meets once per week to resolve student's questions in the topics of water and wastewater treatment. The students work in groups and strive to develop solutions to their questions using problem solving methods typically applied by practicing engineers. The facilitator for the SI session is a graduate teaching assistant (TA) majoring in environmental engineering. The TA typically serves as an SI facilitator for 3-4 consecutive semesters. The first semester, the TA is required to attend all class sessions to learn the content of the course and to identify areas of concern where students may have difficulty by observing student-to-student and student-to-instructor interactions that occur during class.

Prior to meeting in the SI session, students submit questions on the engineering and design concepts discussed within the previous week of class. Active learning in the classroom and self-directed learning outside of class create opportunities for the students to identify questions which can be resolved in the SI session. The first step of the SI assignment is to construct a question that is comprised of the following four parts:

- Clearly describe the confusion or lack of clarity on the topic of discussion during the past week.
- Why is this aspect of the topic confusing or unclear? Explain the specific details that are not clear.
- Describe the "engineering intuition" that you can apply to this concept that will assist you in developing logic or rational that will guide you to a description or answer clarifying the confusion? What knowledge and background from other

classes or practical experiences can you draw on to help yourself resolve this confusion?
- Use your textbook (or other appropriate sources) to find information that can be used to clarify your confusion. Cite a specific reference you have identified in the book (cite all of the following that apply: chapter and section numbers, paragraph, figure or table number, and page number), summarize or paraphrase your finding, and apply the information to clarify your confusion.

This approach allows for the student to conduct research on the topics of confusion and to improve their meta-cognitive skills and enhance critical thinking skills.

The facilitator uses the "Ask First and Tell Later" technique to engage students in participating in the topics of discussion. The collaborative learning techniques used in the SI sessions include group discussion, work in clusters, turn to a partner, and think-pair-share. Weekly questions are separated by topics and groups are assigned to work on one single question. Each group elects one leader and reporter. As the answers are reported to the class, other groups are also encouraged to contribute to the discussion of the topic. Through this approach, students learn to progress from self-learning, to small team-learning and class-learning.

The benefits of supplemental instruction are evaluated directly in student performance[6]. Final course grades have been compared between SI and non-SI students. Students who participate in the SI sessions perform better on quizzes, homework, and exams and ultimately received better grades in the class. Also, the progressive development in improving their critical, reflective thinking skills is measured by evaluating the quality of the questions asked and the methods or processes that are followed to develop solutions to their questions. At the beginning of the semester students do not follow the required steps to answer their questions; they simply leap to a solution without appropriate question development and research. By end of the semester they effectively implement the thinking steps and more effectively develop questions which are analyzed using a reflective process that is grounded in scientific and engineering principles. Bloom's levels of learning have also been considered in assessing student performance.

This paper will describe the SI process, provide examples of the work by the students and TA, and describe the results and outcomes that address developing and applying critical (reflective) thinking skills.

Supplemental Instruction in General

Supplemental instruction has a history of at least three decades in the United States. Many educators have realized the need for supplemental instruction to improve retention in higher education. Students who are not accustomed to working in a team or group environment and learn from and with others are least likely to continue higher education. Educators throughout the world have followed different methods or provided different incentives to the students to improve participation in supplemental instruction[2]. Initially supplemental instruction was intended for high risk students but later it assumed a wider

goal as intervention for high risk courses[3]. Supplemental instruction introduced in introductory engineering courses had significant affect on student performance[4,5]. Some educators also worked through supplemental instruction to improve grades of courses having poor performance such as math, physics, calculus, and chemistry[6]. Supplemental instruction expands the learning environment by adding more partners in the work and serves as a catalyst for better learning[7]. The supplemental instruction class in civil engineering at New Mexico State University is designed to help students improve critical thinking skills. SI, an innovative concept, when applied correctly, will improve the thinking skills of the students[8]. Students volunteer to attend the supplemental instruction to learn the concepts. Each semester offers approximately 12 SI sessions. Students who participate in the SI sessions are awarded with points for demonstrating critical thinking skills which will be included in the final grade. The maximum points that can be earned through participation in all SI sessions represent only 5% of the total possible points that can be earned for a grade. In order to qualify for these "bonus points" participants are required to attend a minimum of 8 of the 12 sessions. The points earned for each SI sessions are divided into two parts. Two-thirds of points are awarded for the question development and demonstration of the critical thinking process followed and one-third of the points are awarded for attending the SI session and participating in the discussion. Points are not awarded if both parts are not completed.

SI Session – Mix of Collaborative Learning Techniques

The actual method that students apply to learn critical thinking is a mix of approaches that follow a progressive pattern. Progression from individual learning, to small group learning and classroom level learning provides a good opportunity for discovering various aspects of a topic. The progression is illustrated in Figure 1. Each group is assigned one question for a 15-20 minute discussion period. As the groups review their questions the facilitator observes the discussion to ensure that the students are engaged in developing an appropriate response to their questions. When deemed appropriate, the facilitator may interject comments or questions that will guide the discussion toward a constructive outcome. Each group elects a leader, a note-taker and a reporter. Most of the time, the volunteers rotate freely without dominant repetition. The facilitator sometimes appoints the leader and reporter in order to give an opportunity to all the students to participate effectively in discussion. The reporter takes notes of the relevant outcomes while the leader leads the discussion by asking fellow members questions and also contributing to the discussion.

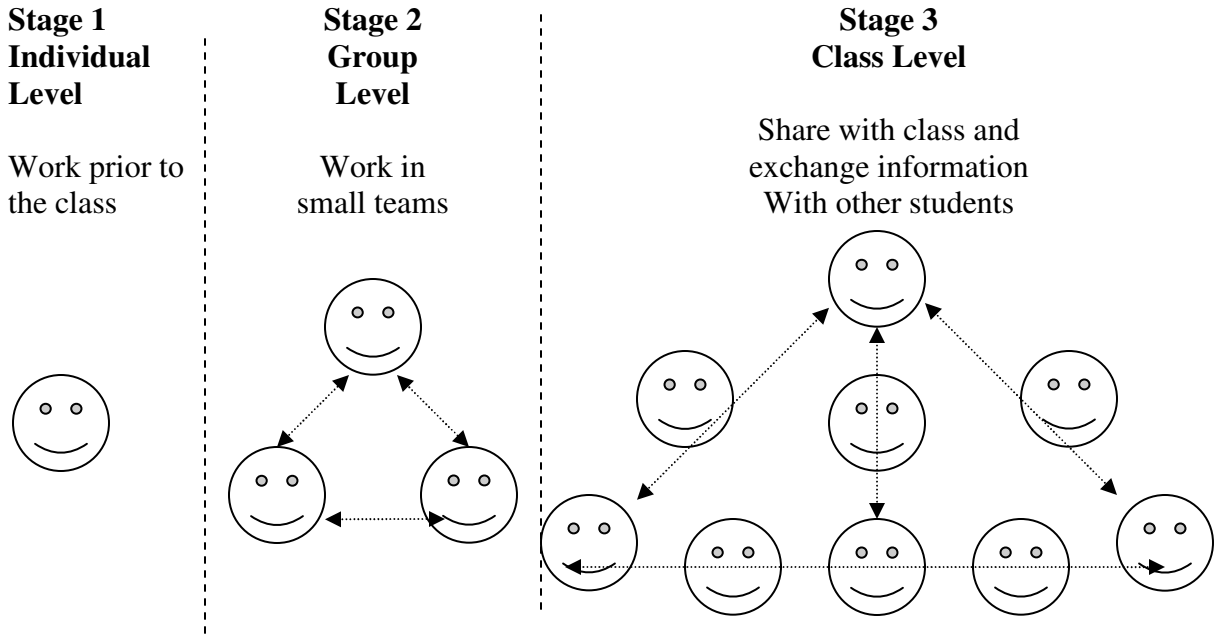

Figure 1. Stages of Participation in Supplemental Instruction

As the small group reports the outcomes to the class, students in different groups ask more questions and contribute additional information, thus making the discussion engaging and productive leading to students better understanding the concepts in greater depth and detail. Sometimes they are exposed to critique by other students in the class. While this critique promotes student interaction and collaborative learning, it also fosters a healthy interdependence, particularly evident when students learn by teaching others and when new perspectives and insights are shared within the group[9].

Critical Thinking, Essentially Good Thinking

Critical thinking is not evaluating something in a negative sense but critical thinking is a healthy or good thinking process. Critical thinking has to be exercised whenever a decision has to be made on a problem that has more than one solution. Critical thinking requires reliable information and evidence, so one can make a decision based on scientific principles. An individual experience, basic intuition and engineering reasoning are integral parts of a critical thinking process. Critical thinking involves asking well-thought out questions and evaluating a variety of solutions. A small amount of skepticism is required to improve the thinking process and to evaluate the evidence. Judgment has to be made after weighing the pros and cons in a sound manner. In the civil engineering profession, a successful engineer is expected to exercise the critical thinking process before making a decision as thousands of lives may be affected by a design whether it is a commercial building, a water treatment facility, a wastewater treatment facility or a transportation bridge. The safety of people, the environment and cost are the key factors considered for the design to achieve its goals.

For all engineering problems, there are fundamental questions that can be effectively addressed through application of the design process. The process begins with understanding the original problem, researching the problem, gathering information, developing a partial solution and completing the solution through successive cycles of actions as illustrated in Figure 2.

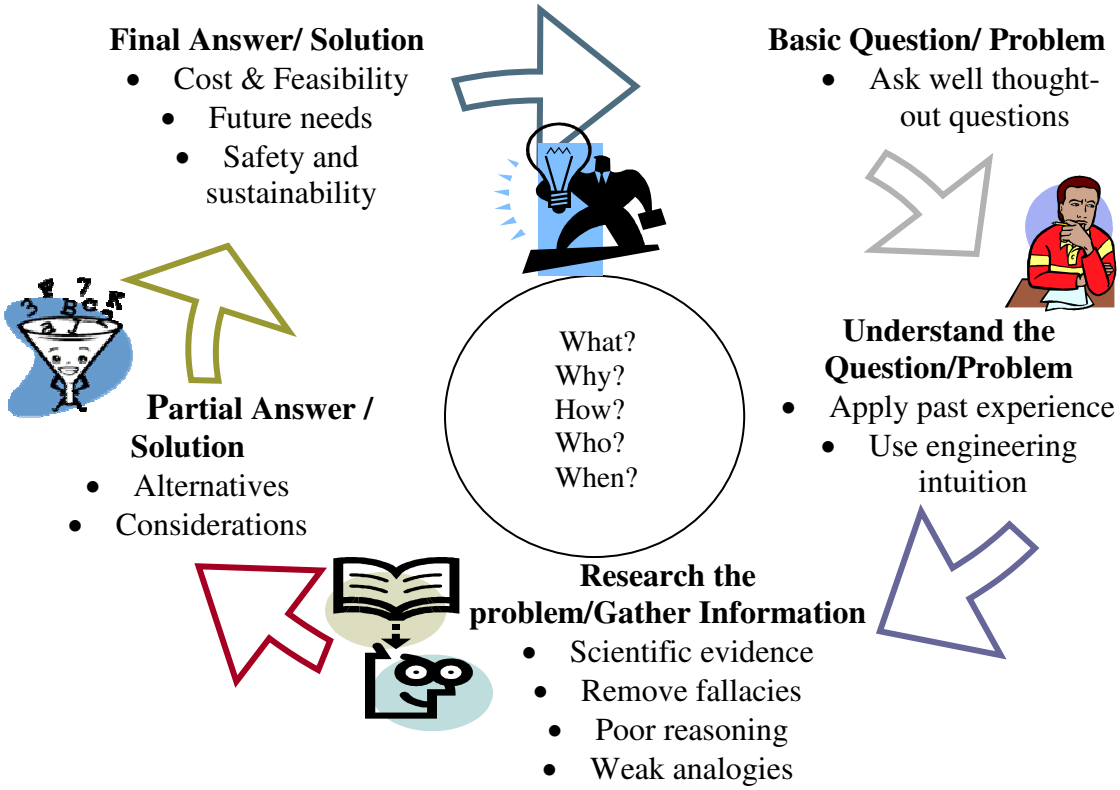

Figure 2. Typical Critical Thinking Process

A visual syllabus has been prepared for the SI session and is delivered to the class at the beginnings of each semester to enable students to understand the activity involved in the SI session. This visual aid is shown in Figure 3. Figure 3 also illustrates the topics covered in the course.

Facilitator as a Listener, Not a Teacher

The facilitator for the SI session assumes the role of organizing the working structure of the session and mainly becomes a listener of the student's ideas and opinions. The facilitator does not spoon feed the students to learn the concepts but works to extract ideas from the students. The student learning style in this environment is independent compared to a regular classroom environment[10]. The facilitator makes students comfortable in the session by negotiating, evaluating, discussing and confirming the student thinking process. The facilitator guides the student team by posing a theme

question which when answered addresses all queries of the team thus preventing the team from wandering without much result. The teams of students are given freedom to openly debate on the topics when required. The facilitator helps students to think independently, ask questions and find answers to their questions. By doing this, students learn to be independent while solving the engineering problems. The facilitator also acts as a counselor when required. Thus it makes more sense to call the SI session a discussion forum. The SI session is not intended to help students solve their home work problems. Student queries on the homework problems, assignments and projects are addressed by the TA or the instructor in separate office hours.

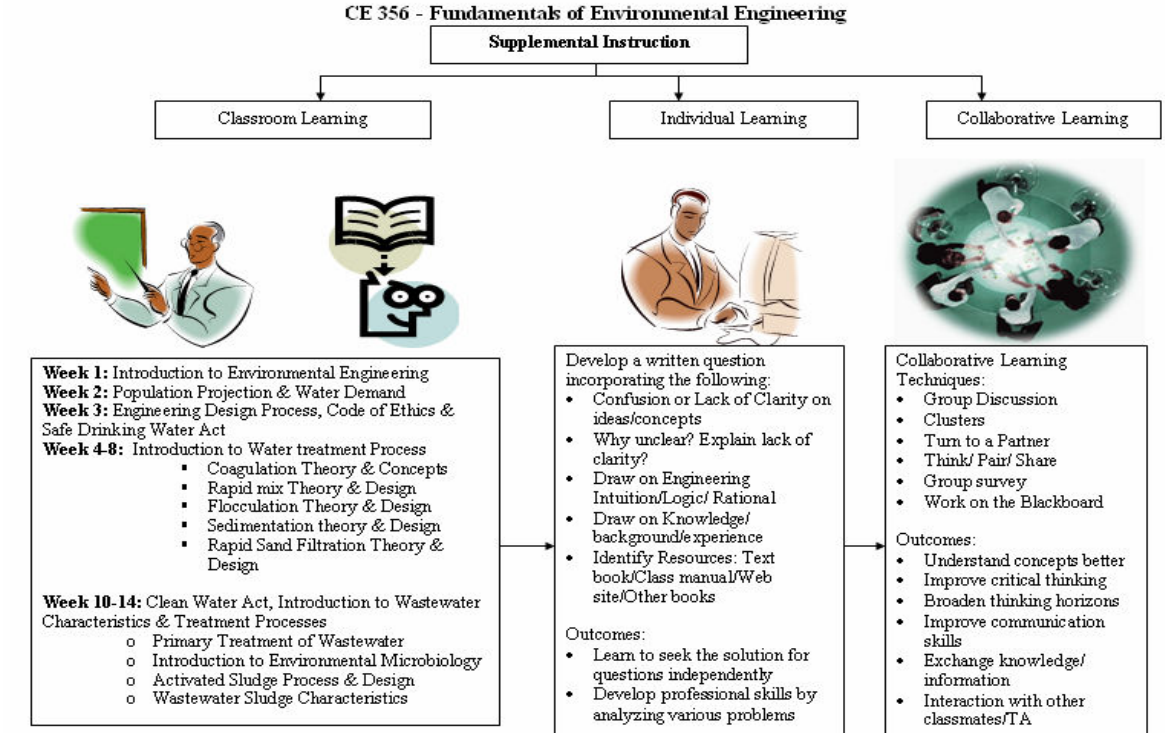

Figure 3. Visual Syllabus for Weekly Supplemental Instruction

Results

The work of the participants in the SI session as well as in the regular class has been monitored closely through three semesters. In this study, SI sessions in all three semesters have been facilitated by the same TA (graduate assistant, majoring in Environmental Engineering). Initially the TA used the "Ask First and Tell Later" technique in the SI session. In the latter semesters, with training on critical thinking exercises provided by the campus Teaching Academy and under the guidance of the course instructor, the TA has modified the format to small group and class level discussions. The TA has observed that the quality of questions asked by the students and the answers produced for the questions improved throughout the semester following the change in the SI format. The procedure or the set of steps that students follow helped them improve critical thinking. At the end the class they learned and performed at a

higher level and they were also able to arrive at a solution to the questions more readily. Early in the semester students do not follow the critical thinking process steps and therefore develop incomplete solutions. Some students, after following the critical thinking process, also required confirmation from the facilitator as they are not confident in their solution. The sense of confidence improves when they engage in a thorough discussion. At the beginning of the semester the students tend to ask questions which have a straight forward yes/no answer that does not require following the critical thinking process. After 2-3 SI sessions the quality of questions asked by the students improves in that solutions require greater depth analysis by conducting research, applying critique, justifying the answer provided by showing proper evidence and drawing conclusions based on scientific principles. On rare occasions the student work has involved the comments from the practicing engineers who are family members. This is an interesting example of the student expanding their network for learning the course concepts in greater depth.

As the course requires the students to exercise critical thinking which is a higher order thinking and learning, it becomes necessary to evaluate the student performance on the basis of bloom's levels of learning. As shown in Table 1, in most of the cases, the SI participants perform better or at the same level compared to the non-SI participants. Quizzes, the water treatment exam, wastewater treatment exam and preliminary engineering design report require the students perform and be evaluated at higher levels of Bloom's learning (Level 5: synthesis - propose, create, invent, design, improve: Level 6: evaluation - judge, select, critique, justify, optimize)[11].

Table 1. Bloom's Taxonomy as a Measure of Improvement

	Semester	Fall 05		Spring 06		Fall 06	
Assignment	Bloom's Learning Level	SI Group	Non-SI Group	SI Group	Non-SI Group	SI Group	Non-SI Group
Quizzes	5	75 %	68 %	97 %	78 %	81 %	71 %
Water Treatment Exam	5-6	89 %	81 %	75 %	64 %	72 %	64 %
Wastewater Treatment Exam	5-6	90 %	91 %	89 %	87 %	85 %	87 %
Preliminary Engineering Report	6	83 %	88 %	84 %	79 %	83 %	77 %

The benefits that students gain from the SI session is also evident by the grades they earn at the end of the semester. Student grades for the last three semesters with comparison between the SI and non-SI groups are presented in Table 2.

Table 2. Student Grade Comparison Between SI and non-SI Groups

Semester	SI Group		Non-SI Group		# of Students Who Improved Their Grade	Grade Improvement From B to A
	A -B	C-D	A-B	C-D		
Fall 2005	66 %	0 %	24 %	10 %	6	19 %
Spring 2006	59 %	0 %	12 %	29 %	3	17 %
Fall 2006	30 %	3 %	33 %	33 %	5	14 %

Students improved grades by participating in the SI sessions. It should be noted that the grade improvement from B to A is observed to be common and the percentage of grade improvement is acceptable which does not skew the overall grade of the class. Students who achieve a grade of A without attending the SI sessions, but who voluntarily attended and earned the bonus points, are not reported in the analysis because an actual grade improvement was not measured. The data primarily indicates that students who utilized the opportunity and are hard working by nature have progressed to a higher grade. Though this study evaluated the performance of the SI and non-SI groups based on monitoring work examples and grades, a pre and post SI assessment will be considered to evaluate the effectiveness of the SI sessions in improving a student's critical thinking skills.

Student Evaluations

The SI process is evaluated by the participating students at the end of each semester. The student evaluations are reviewed each semester to improve the SI session and to encourage more students to attend the session. A summary of the student participation is presented in Table 3. Student participation in the Fall 2006 semester decreased by 50% percent as compared to the trend observed in previous semesters. This change may have been influenced by factors such as peer influence, work-class schedule conflicts, personal life situations, or preference for an independent working style.

Table 3. Summary of Student Participation in the SI Process Fall 2005-Spring 2006

Semester	Fall 2005	Spring 2006	Fall 2006
No. of students in the class	29	17	36
No. of participants in the SI session	20	12	12
% of students participating in SI	66 %	66 %	33 %
Number of students who attended at least one SI session	22	12	28
Number of students who attended the minimum 8 SI sessions	11	4	2
Number of students who attended more than 8 SI sessions	9	8	10

Student responses for key survey questions are presented in Table 4.

Table 4. Summary of Student Evaluation of SI Fall 2005-Fall 2006

Semester	Fall 2005	Spring 2006	Fall 2006
SI Evaluation*	*E-G-A (%)	E-G-A (%)	E-G-A (%)
SI contributed to my learning of course material	6-35-35	17-58-25	8-23-54
SI contributed to developing the question of the week	0-18-59	17-58-17	15-39-23
Contribution of participating in the weekly SI discussion	12-41-47	17-67-17	15-39-46

* Percent of students rating SI E = Excellent, G = Good, and A = Average

The student evaluation analysis indicates that the greater majority of the SI participants feel it is a benefit and provides an opportunity to develop effective learning skills. Actual student comments on the SI experience are noted below:

- The group of students who attended the SI regularly expressed that the SI session did actually help them improve learning of the course material.
- The kind of exercises they practiced in the SI session has interested them and they actually learned when they asked questions and worked in small teams.
- Sharing with the class has improved their understanding of concepts.
- Some students said that they learned the most when they actually developed the question and conducted research for the answer.
- A few felt good because they were not only asking questions but were also able to help others who needed clarification on the concepts in the class.
- Some said that when they were working in small teams, did not have enough knowledge to make conclusion but it was helpful to share with the class to learn from others.
- Some of the students felt that it would have been better if the SI session would also discuss the homework problems.

Students who did not attend the SI session had the following comments:

- Most of the students have actually expressed interest in attending the SI sessions if they were scheduled at a different time that did not conflict with other classes or work hours. (The SI session meeting time set early in the morning, 7:30 am, did not draw students as they originally expressed.)
- Some students offered the opinion that, SI made mandatory or SI with actual credit awarded, would force them to attend the sessions.
- Some students were not convinced that the SI session would help them improve performance in the course.
- Some students commented that the SI session should cover the homework problems.

- Some students expressed that the class material was sufficient to understand the concepts and did not feel the necessity to attend the SI session.

Considering the feedback from the student evaluations, for future semesters the schedule for the SI session will be reviewed with the possibility of changing the time of offering from early morning to early evening to encourage more students to participate. For the immediate future participation in SI will continue to be voluntary.

Discussion

The SI session usually started with assigning small teams consisting of three members who have common queries on the topic taught in the week. Each session was conducted for 50 minutes. The teams were allowed to work for first 15-20 minutes of the session. Discussion begins when a confident or stronger student in the group takes initiative and assumes the role of a leader. The leader was usually one who asked questions of the team members and helped clear their misunderstanding. The leader also helped the group members research the textbook and other class materials to find answers to the confusing concepts. The leaders emerged naturally and they were usually the stronger students in the class. The group elected a note taker who is responsible to take note of the outcomes or conclusions from the discussion. The group also consists of a presenter who stands in front of the class to share the group questions and outcomes from discussion. Through this process, the group is exposed to critique by the class which promoted a healthy discussion as a class involving everyone. Few students felt uncomfortable and became defensive when they were asked critique-type questions. However, it depends on personal traits of students and some are easily prone to stress and are impatient toward skepticism. Another observation was that students stood in front of the class in pairs (presenter and note-taker or presenter and leader) when reporting the outcomes to the class. Perhaps, they felt comfortable to face the class when someone was by their side.

In most of the engineering courses, the learning environment in the class is formal and students are accustomed to sit and listen to the professors. Students sometimes feel comfortable to learn in that type of learning environment where not much formal engagement is required. It takes some time to bring them out of this practice and engage them in active discussions. Students were resistant in the beginning to ask the questions or to share the information with other group members and the class as well in the presence of the facilitator. This attitude is more prevalent in early sessions of SI. As the sessions continue, students realize the benefits from their discussions and more actively participate to improve their learning skills.

One of the key observations in the SI discussions was that some of the students who were not confident of the material or the concept chose to be quiet without participating much in the discussion whether it was a small group discussion or classroom discussion. This attitude was observed to be common among students who are not in the top 20 % of the class grade-wise. As the discussions carried through the semester these students would slowly become comfortable with other students in the discussion environment and contribute to the discussions and display the confidence by sharing their ideas to the

class. This is one of the goals of having weekly SI discussions. Most of the time, advanced students in the class lead the discussions and demonstrated the knowledge of the course material. Students who make average grades are intimidated by the presence of the other students and the facilitator and remained quite for the first 2-3 classes. Comparatively, students who make good grades are enthusiastic and strive to participate competitively in the SI discussions to learn the concepts.

After a few successful SI discussions, the student performance progresses in that the students needed less guidance in finding the theme or key question and developed the solutions in a shorter time by following the steps 1 to 4 in the critical thinking exercise. It took at least 4-6 sessions to observe this change in the students. These students also performed well in the design projects and open ended problem solving exercises of the class. A comparison made between the SI group and non-SI group better explains this difference (see Table 1). The students percentages earned in quizzes, water/wastewater treatment exams by SI participants are generally higher or the same as the non-SI participants. Initially, when answering one question students would get lost in the thinking process and result in asking more questions. Framing a theme question helps avoid this situation and proceed further in working through the critical thinking process.

New Mexico State University has a majority of Hispanic population and is therefore classified as a Hispanic Serving Institution. As shown in Table 5, the class usually consisted of 30 % Hispanic students. The SI sessions also consisted of a majority of minority students. The minority student participation may be higher due to the fact that they prefer to interact with others and prefer to work in teams supporting each other. Another factor could be the students have more encouragement or support from the family to excel in the studies.

Table 5. Summary of Hispanic Student Participation in SI

Semester	# Students Enrolled	# Hispanic Students Enrolled	# Hispanic Students Attending SI	Percent Hispanic Students Enrolled	Percent Hispanics Attending SI
Fall 05	29	13	8	45 %	62 %
Spring 06	17	3	3	18 %	100 %
Fall 06	36	13	5	36 %	38 %

Engineering is a highly male dominated discipline. This tradition is improving and many females are now enrolling in typical engineering curricula. In last three semesters CE 356 had male and female students in the composition illustrated in Table 6. Female students tend to be more socially oriented and therefore enjoy discussing ideas and concepts with others. Female participation in SI sessions shown in Table 6 supports the above characteristic. The TA has also observed that female student participants are more enthusiastic in the discussions as observed of the SI sessions compared to males.

Table 6. Female Student Participation in SI

Semester	No. of Students Enrolled	No. of Male Students	No. of Female Students	Male Students Attending SI	Female Students Attending SI	% Male Students in SI	% Female Students in SI
Fall 05	29	21	8	14	6	67	75
Spring 06	17	11	6	6	5	55	85
Fall 06	36	22	14	10	2	45	14

The working strategy of SI session is explained as follows. Students are dependant on the figure of authority to learn the basic concepts of the course which takes place in the regular classroom environment where students' participation in the class is formal and the involvement may be minimal due to the lecture mode as well as intimidation of open participation. This type of learning takes place in a dependent learning environment, students dependent on the instructor. When students attend the SI session, they work with peers in small teams interdependently and teach each other confusing concepts. This actively engaged, less intimidating environment helps the students improve their meta-cognitive skills. When students share with the class the outcomes from small team discussion, they are working interdependently with the peers and facilitator. While doing this, they exchange information with each other and confirm each other's opinions with the help of facilitator. This process expands the learning environment by adding new partners to the discussion and improving the critical thinking process at a class level. After a few successful cycles of critical thinking exercise, small team discussions and classroom exercises, students develop confidence in the work they do and improve their ability to answer their own questions independently by following the critical thinking steps.

Conclusions

Supplemental instruction helps students in many ways other than providing an opportunity to obtain better grades.

- Participation in SI session is voluntary. Students take responsibility for their own learning and attend the sessions which make them responsible future engineers.
- Students work in groups co-operatively and interdependently which is a usual scenario in the work environment of professional engineers.
- By applying critical thinking process cycle, students take control of their learning and learn to be independent at times when it is required.
- Students can apply these critical thinking skills in other classes which may help them learn concepts more thoroughly.
- When the students work individually in small teams and at the SI class level they produce more results which makes their learning complete.

- Supplemental instruction helps the TA facilitator to gain more knowledge of the course material as well as their discipline.
- The facilitator also develops constructive leadership skills and communication skills.
- Working with other students may provide the TA facilitator an opportunity to learn how to work with fellow engineers in the work environment.

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