Important Lessons in Engineering Education Learned from Seven Years of Experience in Undergraduate Academic Support Programs

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Abstract - A deep understanding of how and why students struggle in core courses in science and math when they enter engineering programs helps us respond to demands for academic support services. The success in applying student centered instructional approaches, in particular, the Supplementary Instruction (SI) Program in the College of Engineering, teaches us important lessons in engineering education: to teach is to engage, and, to engage is to connect. Peer-led SI sessions integrate features of subject- and problem-based learning to foster a supportive learning community. SI has not only facilitated the learning of course material but also promoted a spirit of inquiry and a culture of joyful learning. The learning outcomes show that SI has made a positive impact on students’ learning, which in turn has helped to increase engineering retention. Future plans to incorporate technology and advance SI are presented.

Index Terms – Academic support, Active learning, Student engagement, Supplementary instruction

INTRODUCTION

Calculus, physics, and engineering mechanics are topics that sometimes frighten beginning engineering students, even those who have passed selective admission standards to enter engineering. In light of statistics showing an increasing number of engineering students who give up engineering because of struggles in introductory courses, engineering programs nationwide have reacted differently. One common realization is a consensus among engineering educators that the quality of engineering teaching needs to be improved, and that traditional lectures, even with stellar instructors, fail to motivate students to meet learning challenges. One response of the College of Engineering at University of Wisconsin-Madison, which is part of a strategic plan to produce greater diversity in engineering for the new century, has been comprehensive academic support services, specifically the Supplementary Instruction (SI) Program.

In this paper, we report how and why SI and other academic support services have made a significant impact on teaching and learning in our college of engineering, which in turn has positively improved engineering student retention for the past seven years. The paper describes our observations of students’ responses to traditionally subject-based teaching and their struggles in these courses. It shows that attrition in engineering enrollment has related to students’ disappointing performance as well as feelings of isolation, particularly during the first stage of their engineering education. The paper demonstrates that academic support programs such as SI are able to respond to students’ needs effectively. It describes our findings that engineering undergraduate facilitators play a critical role in the success of SI, which signifies pedagogies of student-centered collaborative learning. Plans to further promote active and engaged learning in engineering education are discussed.

BACKGROUND INFORMATION

The Supplementary Instruction Program has proven to be a successful program developed at various institutions for different disciplines [1]. Common practices in SI, such as targeting at-risk courses, utilizing peer mentors and small study groups, etc., provide unique opportunities to address important issues in education. To maximize its potential, however, it is important to implement SI with proper resources and considerable team effort, including careful identification of courses, close collaborations with course instructors, applications of new teaching techniques and technologies, and most importantly, a focus on engaging students in learning.

The SI program developed in the College of Engineering at UW-Madison seven years ago was based on our understanding of how and why students struggle in the core courses for engineering education. Students entering college encounter many learning challenges that arise from their background, strengths and weaknesses, interests, motivation and ambitions, and varied preferred learning approaches [2]. In the face of academic challenges, one concern shared by most students, but sometimes more acutely felt by entering students, is the sense of alienation. In such cases, students’ frustrations related to academic readiness and learning preferences can be aggravated by feelings of isolation. Many transfer students also face difficulties in adapting to a new learning climate in
engineering, which is always challenging, but sometimes may not be inclusive. One of the important goals of SI is to provide a supportive environment fostering a learning community.

The courses that SI has targeted are traditionally difficult ones containing dense material content delivered at a fast pace. These courses lacked campus-level academic support when SI was first initiated in engineering. In spring 2001, SI started with sessions for three courses, Calculus (III), and calculus based introductory-level Physics (I) and (II). Prior to this, an SI session for Statics had been piloted. The success of the session led to the addition of a recitation section to the course, which was not offered before. In fall 2005, SI for Statics was resumed to meet students’ demand for academic support because of changes in engineering curricula. In fall 2007, SI sessions for Calculus (III) were replaced with SI for introductory dynamics courses, after needs and resources in engineering were carefully assessed.

Figure 1 shows entering engineering (EGR) student performance in Physics (I) & (II) (spring 2001–fall 2007), Calculus (III) (spring 2001–spring 2007), and Statics (fall 2005–fall 2007). Students are required to complete either Physics (I) or Statics before they are admitted to the degree-granting engineering department, and complete Calculus (III) and Physics (II) as part of their degree requirement. EGR is the classification assigned to all new students from high school, who have not yet been admitted to a department. More than 25%-30% EGR students struggled in these courses, and some gave up engineering professions as a direct consequence of their struggle. Those who dropped the course were not included in this figure.

Figure 2 suggests that academic performance indeed affects attrition in engineering enrollment. It shows engineering retention during the period of spring 2001–fall 2007. The data tracked the group who were classified as “EGR” while taking these three courses. It illustrates that struggling and failing in the core courses led to decreased probability of earning an engineering degree. For example, EGR students who scored “D” and “F” are likely to leave engineering, or withdraw from the university altogether.

SI sessions meet twice a week for an hour every meeting. Students spend the majority of their time working on problems within a smaller group of three or four students. The groups are informal, which creates a welcoming atmosphere that invites questions and encourages collaborative learning. Worksheets with problems that highlight the important concepts of the course material are provided by SI facilitators. These SI facilitators are undergraduate engineering students who also attend all lectures. The main role that the facilitator plays is to facilitate problem-solving, and to lead group discussions. The facilitator also gives a mini lecture at the beginning of the session. Students in SI are required to meet the attendance requirement of no more than five unexcused absences per term.

Some may wonder why SI is successful, because it appears to be just another recitation-type section that is typically offered with big lectures. Engineering may be unique in that it combines so many aspects of learning, understanding, and creativity in its educational process [3]. These practices, however, can also do disservices if we fail to engage students in their learning. In these conventional
lecture-based courses, students are told what they need to learn, but never get a chance to apply the content that they are told to learn. When complex concepts are delivered at a fast pace, it is not surprising that students with different preparations and learning preferences quickly lose interests and become discouraged from facing learning challenges. Even highly motivated and self-driven students are not satisfied with their experiences in these lectures, despite their excellent grades in the courses. They simply believe that real learning has never taken place. Dissatisfaction in the first stage of engineering education takes away confidence and motivation in learning, and worse, causes attrition in engineering enrollment. One student who got a “D” in Calculus (III) told us that he is “on (academic) probations and stuck in engineering.” He needed “to transfer to (the College of) Letters and Science.” His feelings are shared by those who are frustrated with their academic performance.

Problem-solving within the context of small groups that SI applies is extremely effective in engaging students. We believe SI provides several components necessary to promote active learning, which is also indicated by students’ feedback through surveys, conducted every semester. Students’ comments are included in Table I.

First, SI integrates features of subject- with problem-based learning, which is important in these intro-level courses. In SI, students are given instructions and are told what to learn. However, they are also given opportunities to test and apply what they learn by working on problems with their peers. These exercises are carried out in an interactive context, which effectively engages students in learning. Secondly, SI embraces different learning styles and learning preferences. Problem-solving with guidance within a small group allows individuals to approach learning using their preferred styles at their own pace. Students appreciate the opportunity not only to watch how problems are solved step by step, but also to develop their own logic and strategies. Sharing learning insight with their peers leads to lively discussions with question and answer from peers. Interactions between instructors and students as well as among students in SI enable cognitive elaborations, helping students formulate problems and plan solving steps with different perspectives. Students learn to value diversity in learning, and also learn to gradually adapt to various teaching styles in big lectures. Thirdly, SI provides a learning community, not only to promote collaborative learning, but also to take away feelings of isolation. Knowing there are students who are in a similar position helps students ease pressures and doubts that they may not belong to engineering. Seeing peers who have gone through the same path and excelled through hard work and dedication encourages students to face learning challenges. When students start to enjoy the subject they are required to take, and are inspired to do well, real learning will surely take place. Students have told us that is what is happening in SI.

### HOW DOES SI WORK?

Here, we describe a few truly remarkable examples to illustrate how SI provides an interactive learning environment that engages students in learning, and why students feel connected, and are motivated to learn actively.

- **Example (I)- Analogies in learning “RLC circuit”**
  
  In Physics (II), functions of a resistor, capacitor, and inductor in RLC circuit with an AC power supply are not straightforward to students. To avoid memorizing the material, one of facilitators led a session asking students to make analogies that mimic roles of these elements. An example using flowing water in a closed loop was created. Narrow portions of the pipe line represent resistors. A spring board works as the capacitor, which stores and releases water passing through. It functions better with high frequencies. A spin wheel in the system is the inductor. It spins when flow rate change is low, and stops otherwise. Another example used checking account and credit card to contrast the frequency dependence of capacitive and inductive reactance, respectively. Students had so much fun in sessions like this, and told us, “Your teaching tactics paid off.”

- **Example (II)-Visual images assisting learning in calculus with two or three variables**

  In Calculus (III), the most challenging part perhaps is to imagine a 3-D picture in students’ head. Lectures and recitation sessions usually show a static 2-D image. One of our facilitators just learned how to use Maple and Captivate. He wasted no time in applying his knowledge to make video clips displaying images with spatial and dynamic range to make teaching and learning easier and more entertaining. One student commented that he always “just learned how to solve problems, but never understood material conceptually, and (SI) helped me learn the concept.”

There have been numerous fruitful discussions in SI sessions, which involve interesting questions that students bring in. Some of these questions are related to their daily experiences, others are from TV shows. Facilitators welcome these questions, and are able to turn discussions into ones that strengthen conceptual understanding. Students’ comments presented around three benchmarks perhaps are the best answer to the question of how does SI work.

- **Confidence and motivation**
  
  “Sometimes I think I really don’t belong here because I don’t feel smart enough. I am smart enough and I can do everything I work hard for.”
  “SI taught me that I can learn the material.”
  “Learning along the right track brings me interest and confidence of learning.”
  “In the end, it is mostly intuitive, so getting past the stigma of “physics is supposed to be hard” is one of the hardest topics.”
“Everything can be learned, even if a person’s background isn’t very strong in that particular topic. SI proves that.”
“I’ve enjoyed it, academically I had a bit of a rough start, but I’m doing better now and this SI class is part of the reason.”
“The facilitator did a good job of reducing and mitigating my sense of intimidation at the materials.”
“I have been in three SI courses so far and they have all helped me greatly in succeeding in the class.”

- **Connection with a supportive learning community**
  “SI is invaluable. To have multiple people working together, bouncing ideas off of each other, is wonderful. I cannot say enough good things about SI.”
  “It was a good way to get a more in depth look into the material with someone your age that can explain it thoroughly.”
  “SI mainly helped me to find a group of other hard-working students to study with, do homework with, and stay motivated.”
  “SI takes off the edge in a big lecture like this (Physics (I)), and makes learning a possibility.”
  “Everyone involved is great--facilitator and students!”

- **Active and collaborative learning**
  “(I) just feel like I am doing everything in my power to learn the material.”
  “Concepts are explained in an understandable way.”
  “Every session seems to clarify my understanding.”
  “This is the first time I see problems are solved step by step.”
  “I am not memorizing. I am actually learning!!”
  “SI helps you understand concepts, rather than just telling you how to do problems.”
  “SI has given me several new strategies for understanding math/science. I think that the things I’ve learned this year will help me in future classes.”
  “I feel comfortable and not intimidated to ask questions in small groups.”
  “The facilitator is instrumental in explaining material. The sessions are informative.”
  “Regardless of my grades, I have learned so much in SI this semester.”
  “Somewhat, supplementary session was the most effective in terms of learning the actual thought process for physics.”
  “I have become a more thoughtful and critical thinker.”

**IS SI EFFECTIVE?**

The learning outcomes of SI students, which include student’ course performance and their level of motivation and confidence in learning have been used to examine the effectiveness of the program. In general, SI students have earned a higher or slightly higher average course grade as compared with all EGR students in the class, and fewer SI students have had grades lower than “C”, which, we speculate, is critical in retention.

In Figure 3, we compare course performance of SI students with that of all EGR students in the periods of spring 2001-fall 2007. (For statics, fall 2005-fall 2007). SI students outperformed all EGR students in terms of getting fewer failing grades (“D” and lower), which we believe is significant in increasing engineering retention.
In Figure 4, we compare retention rate of EGR students who had SI experiences with those without SI. We sampled EGR students who enrolled in Physics (I) from Spring 2001 to Spring 2004. We found that the group that did not have SI experiences had a higher probability of leaving engineering. The group size for EGR without SI is 826, and 112 for SI. We suspect that struggling academically is one of the main obstacles that drive EGR students away. Further researches will be needed so that more effective plans can be laid out.

![Figure 4: EGR Engineering Retention](image)

**FIGURE 4**

**EGR ENGINEERING RETENTION**

For many students, however, the significant impact on learning that SI has made goes beyond a good course grade, or retention in engineering. SI has not only effectively facilitated the learning of course material, but has also fostered a spirit of inquiry and a culture of joyful learning. It provides an inclusive learning community that connects a diverse student population.

### TABLE I

**APPROVAL RATING**

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<th>Not sure</th>
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<tr>
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<td>9.3</td>
<td>9.1</td>
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<tr>
<td>2</td>
<td>222</td>
<td>9.1</td>
<td>9.3</td>
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<td>9.3</td>
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**TABLE II**

**IMPACT ON LEARNING OUTCOMES**

<table>
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<tr>
<th>Impact on learning outcomes</th>
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<th>No</th>
<th>Not sure</th>
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<tbody>
<tr>
<td>SI has helped improve my course performance</td>
<td>716</td>
<td>95.5%</td>
<td>1.5%</td>
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</tr>
<tr>
<td>SI has helped me become more confident in learning subjects</td>
<td>500</td>
<td>85.6%</td>
<td>10.0%</td>
<td>4.2%</td>
</tr>
<tr>
<td>I will recommend SI to friends</td>
<td>222</td>
<td>97%</td>
<td>1.5%</td>
<td>1.5%</td>
</tr>
<tr>
<td>I will enroll in SI if it is offered for another course</td>
<td>222</td>
<td>97%</td>
<td>2%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Table I shows approval ratings of some activities in SI. Students’ feedback regarding group discussions and problem-solving practices is remarkably positive. The rating scale is from 1-10 with 10 being the highest. Table II illustrates that students welcome SI and other academic programs and appreciate the support to succeed. It clearly suggests that SI makes a positive impact on course performance and learning confidence.

### Why is SI effective?

The student-centered, peer-led instructional approach provided by SI is the key to the effectiveness of SI. In general, SI students show a higher attendance in lectures and discussions. They have learned to adapt to different teaching styles, and thus feel more comfortable and confident in the face of academic challenges. The success of SI signifies the importance of pedagogies of engaging students in learning. It exemplifies good teaching practices that encourage student-instructor contact, cooperation among students, and active learning in engineering education [6].

Guidelines for practices in SI are based on our understanding of how and why students struggle in these core courses. We understand that the planning effort will reap better returns in terms of learning outcomes if more emphasis is placed on a broader institutional context in which learning takes place [6]. In order to connect to students, we have made efforts to know our students better. We have conducted several surveys during the semester to keep an open dialogue between SI and students. For example, students are asked to do post-exam evaluations and rank difficulties that they encounter during the exam and its preparation. An overwhelming number of students point toward their lack of analytical skill for the first midterm exam, i.e. “don’t know how to approach and start a problem” for every SI session. Later in the semester, challenges shift to include difficulties in “conceptual understanding” and “equation applications.” The feedback helps us prepare worksheet problems that focus on enhancing skills in inquiry and critical thinking.

Undergraduate student teachers play a critical role in connecting and engaging students in learning. Because they are carefully selected and trained, SI facilitators have an outstanding academic record. They enjoy learning, like to help others learn, work hard, and have leadership and good communication skills. What differentiates SI facilitators from other student teachers who are assigned to the job, however, is the strong desire to make a difference in engineering education. Some of our facilitators are destined to be engineering professors of the future and consider the job a perfect training opportunity. Instead of being “assigned to teach,” they want to teach and regard teaching as a rewarding profession that requires the highest level of knowledge, talent, and skill [7]. SI facilitators think big and plan big. They may not be experts in the subject, but strive to achieve expert status as instructors. They are eager to do things in unconventional ways, and are extremely creative in applying their talents and skills to devise new methods in helping students. Over the past seven years, 51 students
have worked for the program. Some of them believe in learning intuition, while others are well organized and prefer learning using a logical sequence. Every one of them takes ownership of his/her students’ learning, and brings in unique ways of teaching and learning. As a team, they have helped shape the program, and have built a culture of taking challenges and meeting high expectations.

**ACADEMIC SUPPORT IN ENGINEERING: A GOOD INVESTMENT**

Throughout the seven-year journey of implementing academic support for engineering undergraduates, resource issues have arisen regularly. The question of why put resources into SI when it is hard for the college to meet its teaching assistant budget is a good one. It is also logical to ask why the lessons from SI cannot be incorporated into the structure of the courses supported.

Those are difficult questions, to which these answers may apply. The fact that students see SI sessions as designed to help them rather than conquer them (as they see most course components) is important. The fact that the students who take part in SI voluntarily choose to participate in the learning community that is SI is another. The question “Do I need to do this?” never comes up with SI students. Finally, it is possible that peer learning has inherent value that instructions from faculty and graduate students can’t have, no matter how it is done. Facilitators know much about difficulties presented to first-time learners because they have been in learner’s shoes recently. Students in SI feel it is easier to relate to SI facilitators who present course material in an understandable way with enthusiasm. It is obvious that students trust their peer instructors who show genuine interests in helping them succeed. Whatever the answers, any observer can tell the difference between the inquisitive, engaged demeanor of students in SI sessions, and their behavior in regular lectures and discussion sections.

The resources needed for a successful academic support program go beyond the paid student help. Supervision and training from an experienced adult instructor is crucial. That same director must work well with faculty, and work diligently to gain credibility. Even a single incorrect approach or answer given out in an SI session early in our seven year history could have done serious damage to our future.

Finally, the success of SI in our experience is also due to extensive support from the instructors and advisors. Course instructors lent help when SI needed to open new sessions to accommodate increasing enrollments. A few students referred by advisers are usually in great need of academic and peer support. SI facilitators are also informed if students need additional attention. In turn, advisors are provided with feedback from SI, so that they can schedule proactive advising to prevent students from failing.

**FUTURE PLAN**

Our experiences in academic support services have taught us that it is important to appreciate and embrace students’ different learning preferences. While there is no one-size-fits-all academic or academic support program that tailors individuals’ learning needs, programs like SI are effective in improving students’ experiences in engineering education. Engineering is a profession that requires greater diversity. Engineering education therefore needs to place greater emphasis on pedagogies to promote active learning, and in delivery systems to reach out to students’ different learning styles, preparation and motivation. We plan to incorporate technology to strengthen peer-led instruction in SI [8], permitting learners to use visual aids, apply analogies, and patch-up deficiencies. We expect the improvement of SI will further students’ skills in critical thinking and problem-solving.

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**REFERENCES**


