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EVALUATION OF THE SUPPLEMENTAL INSTRUCTION PROGRAM IN A FIRST YEAR CALCULUS COURSE

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Abstract
Supplemental Instruction (SI) is a voluntary program that incorporates collaborative learning in small, peer-led, group settings in order to integrate instruction in learning and reasoning skills with the content of the course with which SI is paired. This paper is the culmination of a three year study into the effect of SI implemented in a large first-year Calculus class for non-majors, a course with an abysmal pass/fail rate. The research addressed two related questions. Once ability / motivational, and gender differences were accounted for: did participation in SI improve student achievement, as measured by course letter grade; and, did participation in SI improve the pass/fail rate in the course? We statistically controlled for possible selection bias through the use of incoming grade point average, a combination of ability and motivation. Results of a 2 x 2 x 1 ANCOVA (SI by gender with prior GPA) and a sequential binary logistic regression indicate Supplemental Instruction is an effective method for boosting success rates in difficult undergraduate courses with concentrated mathematical content and is effective for both males and females.

Introduction

Decision to Implement Supplemental Instruction
Supplemental Instruction (SI) was initiated in response to a growing demand for academic assistance. In particular, requests for mathematics help through the Learning Skills Centre (LSC) one-to-one tutoring program began to exceed the capabilities of program staff. Students were unable to schedule appointments with mathematics tutors in a timely manner. The LSC lacked human resources and space to accommodate hiring additional tutors. As a result of these issues, the LSC staff looked to other options for providing mathematics assistance.

After collaboration with the Mathematics Program, a decision was made to pilot SI in the course, Math 152 (Calculus for Non-Majors), as a large number of students from this course drew heavily on tutoring services. By attempting small group, peer facilitated review sessions for this Calculus class, it was hoped that more students could be served with less expenditure in terms of cost and human resources. In addition there was a need for a new approach in providing mathematics support. Traditional tutorials had always been available for this course but were poorly attended by students except on occasion just prior to an exam. Frequently, the student at a tutorial session is merely a passive observer. Conversely, the SI program has been developed on sound pedagogical theories for learning. Students are active participants in the learning, they work collaboratively to solve problems, and the SI leader serves as the near-peer facilitator, guiding the students to a higher level of understanding.

Supplemental Instruction was introduced in the first two weeks of classes to provide proactive support. Three 50-minute sessions per week per leader were offered in efforts to provide accessibility for all students enrolled. All reasonable attempts to schedule SI sessions so that all students were able to attend at least one session per week, were made throughout the duration of SI at this institution. All students were informed of the support available through the SI program and of other mathematics assistance available to them at the university. Other assistance included one-to-one tutoring services offered through the LSC and instructor office hours. Tutorials were still available for the course initially. However, after three semesters, it became apparent that students were not attending the traditional tutorials even though excellent mathematics students were placed as tutorial assistants for Math152. They were attending SI. Tutorials were not offered in subsequent semesters. All services were, and continue to be, free. The SI Supervisor, a University of Missouri – Kansas City (UMKC) trained supervisor (the first author) monitored for approved SI practices throughout the duration of this research. Student attendance was monitored by the SI leaders.

The Nature of Supplemental Instruction

Many academic support programs have been developed to assist low achieving students in first-year courses at the post-secondary level. In contrast, Supplemental Instruction was developed to improve the learning of students in historically difficult courses. The SI program evolved in response to the academic needs of students enrolled in problematic courses in professional programs such as the School of Medicine, Dentistry, and Pharmacy at the UMKC. It has since been used extensively in a wide range of graduate, undergraduate, and professional school courses, and in a wide range of disciplines [1], [2].

The guiding principles of the SI program evolved as a result of collaborative learning theory and a need for improved practices. Martin [1] petitioned for a program that integrated reasoning and study skills with course content; not isolated from it. Consequently, the SI program developed with the following principles.

a) *Service is attached directly to a specific course*
b) *Service is proactive rather than reactive*
c) *Supplemental Instruction Leaders attend all classes for the targeted course*. Both the SI leader and the student are hearing the same lecture, creating an immediate point of reference for the students and SI Leader. Furthermore, the SI Leader is able to clarify what was said in the lecture and benefits from the review of material.

d) *Supplemental Instruction is not a remedial program.* Studies on affect and SI have pointed to the exact opposite. Internal motivation is an integral component of students who participate in the SI program [3].
e) *Supplemental Instruction programs are designed to provide a high-degree of student interaction and mutual support.*
f) *Supplemental Instruction leaders are trained.*

SI Leaders are trained to use proactive and participative activities in the sessions. For example, leaders are trained in questioning techniques based on Bloom's taxonomy comprised of six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation [4]. SI Leaders incorporate quizzes into the sessions that are not for marks, are often open book, and are generally completed in collaboration with other students. Quizzes provide students an opportunity to practice for tests, thus reducing the test anxiety that often accompanies mathematics tests. Other strategies include generating a table of contents, built on student input, to highlight key concepts, or having students generate potential test questions, compile a quiz based on these questions, administer the quiz, and discuss solutions.

Studies have shown that SI has improved student achievement, most notably in the decrease of D and F letter grades and increased GPA among students who attend SI [1] [5] [6] [7] [8] [9]. In 1981, and again in 1992, the U.S. Department of Education validated the Supplemental Instruction Program as an *Exemplary Educational Program*. The SI Program is one of only two programs that are officially recognized by the U.S. Department of Education as contributing to increasing student graduation rates [2].

Several of these studies are compilations of research over thousands of students and across decades. Three such studies are described in more detail. One recent study demonstrated that SI participants earned significantly improved final grades in all three of College Algebra, Calculus, and Statistics courses [6]. Their research contained data obtained from 45 different institutions in 177 mathematics courses for a total of 11,252 students. The scale for grades was: A = 4, B = 3, C = 2, D = 1, F = 0. Burmeister et al.[6] reported that SI participants earned higher mean final course grades: algebra (2.21 vs. 1.98); calculus (2.28 vs. 1.83); and statistics (2.49 vs. 2.32) and experienced lower rates of withdrawals. The authors identify some limitations in their research. For example, two questions they posed are: How closely did each of the institutions follow the SI model? Are the groups of SI participants similar from campus to campus? Unanswered questions about SI indicate a need for further analysis of the SI program.

The Center for Supplemental Instruction has been monitoring the effectiveness of SI since its inception in 1973. The Center compiles and analyzes data submitted by over 100 College and University SI programs annually. A review of the research used a quasi-experimental design to conduct a longitudinal analysis of SI effectiveness both in courses at UMKC and in course data submitted by other institutions [1]. Again, the scale for grades was: A = 4, B = 3, C = 2, D = 1, F = 0. In all analyses in this study, a student was categorized as a participant if they attended at least one SI session. The first analysis included data collected over a 19 year period, in 525 courses, for a total of 19,962 SI participants and 31,368 non-participants. Chi-square analyses demonstrated significant differences in A and B grades with a reported 54.4% of SI participants earning A and B grades in comparison to 42.9% of non-participants. Similarly, the Center reported significant decreases in D, F and W grades amongst SI participants (20.2% vs. 33.8%). The Center also established an overall significantly improved mean GPA value (2.70 vs. 2.43). The Center replicated the studies using the criteria of attendance at 5 or more sessions and concluded there is statistically significant improvement with these comparison measures that favor the SI participants. Similar results are reported by the Center for Supplemental Instruction [1] on data collected from other institutions. The national data was provided by 270 institutions between 1982 and 1996, composed of 4,945 courses offering SI to over 500,000 students. There were 815 courses in the Mathematics category with significant increases in A and B grades and significant decreases in D, F and W grades but a non-significant improvement in mean final course grades (2.17 vs. 2.11). A third study looked at the national data by course. There were a total of 143 Calculus courses supported by SI with significant increases in A and B grades, significant decreases in D, F, and W grades, and a significantly improved final grade (2.26 vs. 2.06). Similar results were obtained for College Algebra, Finite Mathematics and Statistics courses indicating SI is effective in Mathematics courses offered at a variety of institutions across America.

A Theoretical Framework for Supplemental Instruction

Current research [10] [11] [12] [13] [14] suggests students need to acquire adaptable problem-posing and -solving skills and to increase their ability to work collaboratively with others. Two major learning theories have evolved during the course of this last century and have influenced current conceptions of acquiring knowledge [15]. The first of the emerging theories, Piaget's theory of "constructivism", challenged the idea that knowledge is passively acquired. The second theory, sometimes referred to as "social constructivism" [15] is a Vygotskyian philosophy that argued learning occurs through social interaction in meaningful contexts with the aid of practices such as scaffolding [16] Scaffolding is the various types of support that teachers/near peers need to provide in the process of supporting students as they learn to think. Scaffolding can be accomplished through directions, suggestions, and meaning making [4] [17]. Consequently, educators need to create learning environments where conversation occurs freely and scaffolding is provided although not necessarily by a teacher. Through communication, ideas are reflected upon, refined, and remembered [13] [16] [18] [19] [20]. The creation of mathematical knowledge is thus improved by making meaning through processes of social interaction and language [14] [15] [17] [19] [20] [21] [22] [23]. Gee [19] endorses the use of scaffolding and enculturation through supported interactions with people who have already mastered the discourse. Linn and Kessel [17] assert that scaffolding is a method to increase student success in mathematics and it is most effective if it involves tasks within the learner's zone of proximal growth [4]. The zone of proximal growth, another Vygotskyian concept, is the state of the individual's current potential for further intellectual development. Vygotsky believed that through the use of scaffolding, the individual may rise to further understanding. This may be accomplished through modeling, feedback, and dialogue [18].

Current theories on improving mathematical knowing, built on models proposed by both Piaget and Vygotsky [15] [19] indicate that the SI program guidelines are established on a solid theoretical foundation. The SI leader, through facilitation, interaction, scaffolding, and explanation promotes learning in a socially non-threatening environment where students can “safely” make mistakes, and open discussion is a means for clarifying concepts

Method

Research Questions

There are two related questions that are the basis for this study. First, does Supplemental Instruction improve the final course grades of students enrolled in Calculus for Non-Majors when effects of gender and ability/ motivation factors have been removed? The second question: does Supplemental Instruction improve the success rates of students enrolled in Calculus for Non-Majors when effects of gender and ability/ motivation factors have been removed?”

Participants

Final grades and SI attendance were collected from 2002 to 2004 resulting in data for 869 students enrolled in 9 sections of the course. Of these, 269 students were classified as SI participants (attended 5 or more SI sessions) forming the first group, the remaining 600 non-participants formed a second group. Data was obtained for a further 390 students enrolled in Math 152 from the year prior to SI implementation, forming a third pre-treatment group. For the purposes of analysis, the final grades (the dependent variable) were converted to numerical values and used to compile the statistics that follow. Note that this scale is in a different metric than the UNBC letter grade scale. Also note that the authors decided to give a Withdraw (W) a lower score than a Fail (F) as they believe that the common case of a student withdrawing from a course was an assessment by the student as to the probable lack of positive outcome in the course.

Measures and Procedures

The students’ final letter grades in Math 152 were taken as the measure of achievement in the course. The letter grades were converted as follows.

Table 1: Final Math 152 Grades Numerical Conversion

Letter Grade	Scale	Letter Grade	Scale
A+	12	C+	6
A	11	C	5
A-	10	C-	4
B+	9	D	3
B	8	F	2
B-	7	W	1

A prior grade point average (GPA) was created from the students’ available records. In the majority of cases, students enrolling in Math 152 had an incoming GPA based on coursework at UNBC. For students not having a UNBC GPA, if they were a transfer student from another college or university, their transfer GPA was automatically converted to the same metric as UNBC GPA upon admission and this value was used. If students had neither a UNBC GPA nor a transfer GPA then their Grade 12 grade was converted to a value comparable to a UNBC GPA. The genders of the students were available as part of the university student records. After examination of the frequency of attendance data we decided that attendance of less than 5 of the available SI sessions would be considered non-attendance. This cut point fit well with natural breaks in the data and with our belief that a student could not possibly be expected to display benefits of SI with lower numbers of sessions. We also classified students who took Math 152 prior to the implementation of SI as Pre-SI as a first attempt to assess the effects of possible selection bias and as an indicator of whether or not any grade inflation or other changes in grading practices had taken place in the Pre-SI to SI time period.

Results

Descriptive statistics were calculated for each of the three groups, Pre-SI, SI, and Non-SI and are presented in the following table.

Table 2: Summary Statistics for the SI Groups

Treatment	N	Mean grade	Letter Grade	SD
Pre-SI (no opportunity)	390	4.9	(C-/C)	3.4
Non-SI (attended < 5 times)	600	5.4	(C)	3.7
SI (participant)	269	6.9	(C+/B-)	3.5

The lower mean, 4.9, of the Pre-SI group, a mixture of Non-SI and SI individuals had there been the opportunity to participate, suggested either random variation in achievement, or possibly changing standards, or even grade inflation. However, when a one factor ANOVA test was applied, and evidence of statistically different means were found ($F = 26.779$, $p < .0005$), post hoc testing revealed that the only differences were between the SI group and the other two groups. The Non-Participants did not differ from the Pre-SI group. This suggests that ability / motivation differences between the pre-SI and non-SI groups and minimal grade inflation from one year to the next are only due to chance variation. Of greater interest is the suggestion that the SI participants are exhibiting higher levels of achievement than those who had not attended.

While an increase in letter grade is a desirable result, pass or failure in the course may be the more crucial issue for some students. The raw data are presented in Table 3.

Table 3: Proportions of Success or Failure by Supplemental Instruction Group

Group	Count	Failure	Success
Pre - SI	Observed	205	185
	Expected	174	216
	% of group	52.6 %	47.4 %
Non-participants	Observed	283	317
	Expected	268	332
	% of group	47.2 %	52.8 %
SI Participants	Observed	74	195

	Expected	120	150
	% of group	27.5 %	72.5 %

A two-way contingency table was used to evaluate relationship between final grades and the three groups: pre-SI, SI participant, and Non-Participant. Categories used were success/failure with DFW grades in failure group, the rest in success. D grades were included in the failure category since a D grade often prohibits students taking post-requisite courses. The Pearson Chi-square test result was statistically significant (χ^2_2 = 43.4, $p < .0005$). The success rate of the SI group, 72.5%, is a stark contrast to the success rate of approximately 50% for either of the Non-SI or Pre-SI groups.

Preliminary results appear to indicate that SI participants earn statistically improved final grades, SI participants earn practically improved final grades (Cohen's d = 0.58 or about 1.75 letter grades higher), SI participants succeed at higher rates (72.5 vs. 50 %). Furthermore, there is a lack of evidence to support differentiation between pre-treatment and non-participant groups. These groups were combined for following analyses. However, the effect of self-selection into SI based on achievement cannot yet be ruled out, that is, students that have displayed more motivation to do well or demonstrated more ability to achieve may have opted to take SI sessions in greater proportions than their lower achieving counterparts. These preliminary analyses did not address factors such as each student's natural academic ability, a common flaw in the SI research. This study addresses the contributing factors that impact final course grade, aspects such as ability and motivation, and also gender, to answer the question as to whether the program is effective after these factors are taken into account.

SI Effects Corrected for Prior Academic Achievement

The next two analyses, an analysis of covariance (ANCOVA) and a binary logistic regression, were performed to correct for the differing prior achievement between groups that might have resulted due to student self-selection into groups. A 2 x 2 x 1 (SI by gender by Prior GPA) ANCOVA was performed to assess the difference in final grades between SI participants and non-participants after adjusting for ability through use of incoming GPA as a covariate. The following two tables summarize the results.

Table 4: Mean Final Grades (By Gender and SI treatment)

SI (2 category)	Gender	Number	Mean grade	SD
Non-SI	M	509	4.8 (C-)	3.4
	F	481	5.6 (C)	3.7
	Overall	990	5.2 (C)	3.6
SI	M	135	6.6 (C+)	3.5
	F	134	7.2 (B-)	3.6
	Overall	269	6.9 (C+/B-)	3.6

Table 5: Summary of ANCOVA Results

Source	MS	F	p
Incoming GPA	3186.8	316.9	.000
SI treatment	520.1	51.7	.000

Gender	74.9	7.5	.006
SI*Gender interaction	10.1	1.0	.316
Residual	10.1		

The ANCOVA results (Table 5) are interpreted as follows. The incoming GPA is a statistically significant predictor of success in Math 152 ($p < .0005$). This was expected. The SI/gender interaction is non-significant ($p > .05$), that is, there is no differing effect of the treatment for males and females. This result is desirable; one would not want a program that was effective for one gender and not for the other. There were significant differences in performance even after correcting for incoming GPA! Participation in SI improved grades even after ability/motivation, and gender were accounted for. Further analysis indicated that the SI treatment was of practical significance as well, Cohen's d = 0.49, approximately half a standard deviation, or about 1.8 letter grades higher. This is considered a medium size treatment effect. In contrast gender was statistically significant but a Cohen's d value of 0.19 represents a small effect size, or less than one letter grade difference between males and females.

Correction of Success (Pass/Fail) Rates for Prior GPA
Binary logistic regression was performed to determine if SI participation contributed significantly to prediction of success or failure after the effects of incoming GPA and gender were accounted for. The results are displayed in Table 6. The first mathematical model tests whether Incoming GPA and gender statistically predict outcomes of success or failure better than no model at all. The chance of getting this value or larger ($\chi^2_2 =$ 182.931) are less than 5 times in 10 000 ($p < .0005$). Therefore we accept the idea that Incoming GPA and gender are predictors of success/failure in Math 152 for the population of students who take this course. The SI treatment was then added to the model and as we might expect these three predictors as a group are successful at predicting success. Note that the chi-square value increases with the added predictor.

Table 6: Sequential Logistic Regression Results

Model	Chi-Square	df	p	-2 log likelihood
Model 1 GPA, gender	182.931	2	.000	1547.910
Model 2 GPA, gender, SI	224.120	3	.000	1506.721

The difference in chi-square values between the two models ($\chi^2_1 = 41.189$, $p < .0005$) confirms that SI participation is a significant contributor to prediction of success in the course, Math 152, Calculus for Non-Majors, after both gender differences and incoming GPA were accounted for. The effects of each the three predictors were examined in more detail. These results are presented in Table 7.

Table 7: Variables in the Prediction Model

Variable	B	S.E.	Wald	df	Sig.	Exp(B)
SI	.992	.160	38.333	1	.000	2.696
GPA	1.103	.092	144.089	1	.000	3.014
Gender	.146	.125	1.365	1	.243	1.157
Constant	-4.157	.364	130.205	1	.000	.016

The Wald test results verify that SI treatment was a significant predictor of success ($p < .0005$) as was Incoming GPA ($p < .0005$). However gender was not significant ($p = .243$) when the effects of incoming GPA were taken into account. This sequential model demonstrated that SI participation had an effect on success in the Calculus class after the issues of possible selection bias were accounted for. Prior GPA, an achievement measure, is not only a measure of ability but is very likely to be influenced by motivation as well. As with the ANCOVA, there is a measure of the importance or practicality of these predictors. The quantity e^B, EXP (B) in Table 7, represents the ratio change in the odds of success for a one-unit change in predictor. For example: the odds of a person succeeding are 2.696 times greater as a result of SI participation while one unit of Incoming GPA (approximately 3 letter grades) had only a slightly greater effect. Gender, if it were statistically significant, was seen to be of no predictive value as the odds ratio is approximately 1. This mathematical model accurately predicts a student outcome 68% of the time.

Conclusion

The program of Supplemental Instruction as delivered at this university can be credited with a two letter grade increase for students participating in the program. Neither the incoming GPA, nor the gender of the student can be used to explain the increase. This was a substantial increase in outcome, in particular since the average grade of non-participants was a C and the average grade of SI participants was a B-. Male and female students benefited equally from SI participation. When we focus our concern on successful completion of the Math 152 course, here again, the results are clear. After controlling for incoming GPA and gender, it was obvious success rates for SI participants are considerably higher than for non-participants (73% vs. 50%). The results demonstrate that even with a correction for demonstrated student ability/motivation that Supplemental Instruction is effective whether measured by letter grade improvement or Pass/Fail rates.

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