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ABSTRACT

Generally, the levels of participation and achievement of females in science do not match those of male learners. This report describes the formation and study of an all-female section of calculus-based physics for the purpose of providing an environment that might enhance the participation and achievement of females in the physical sciences so that the Illinois Mathematics and Science Academy could study the phenomenon of disproportionately low participation and achievement of females in an upper-level physics course. The study employed a pretest-posttest experimental-control group design and included three co-ed sections and one all-female section of first semester calculus-based physics. Findings included: (1) a different quality to the atmosphere, character, and climate of the all-female class; (2) greater performance-level growth on quizzes, homework, and class exams of students in the all-female class; (3) more females enrolled in and successfully completed calculus-based physics than before; (4) females in the all-female section demonstrated a significantly higher growth in self-confidence; and (5) for students who participated in the experimental section, prior facility in mathematics was less important for subsequent achievement success. (Contains 35 references.) (MKR)

Illinois Mathematics and Science Academy

Calculus-Based Physics Exploratory Study

Summary Report

IMSA

About IMSA

In 1985, the Illinois Mathematics and Science Academy was established as part of the state's comprehensive educational reform package "to serve the school system of the State as a catalyst and laboratory for the advancement of teaching" and "to offer a uniquely challenging education for students talented in the areas of mathematics and science" (Senate Bill 730).

IMSA is an educational laboratory for designing and testing innovative programs and methods to share with teachers, schools and students in Illinois. Included in the laboratory is a residential school program for 600+ Illinois students in grades 10-12.

The researchers for the Calculus-Based Physics Exploratory Study Summary Report are Dr. Raymond Dagenais, Edward Moyer, Dr. Diann Musial, Michael Sloan, Linda Torp and Dr. David Workman.

Illinois Mathematics and Science Academy
A Pioneering Educational Community

System for Partnership Initiatives

Calculus-Based Physics Exploratory Study Summary Report

Introduction

During the 1992-1993 academic year a number of elements (national level surveys and research reports, IMSA's professional development focus; a climate of reflective inquiry) focused attention on the participation and achievement of females in mathematics and science at a national level and, specifically, the participation and achievement of females in mathematics and science at the Illinois Mathematics and Science Academy. These elements served as the catalyst for the calculus-based physics exploratory study.

Even though equity in education was mandated by federal law in 1972 (Title IX of the Education Amendments), studies consistently showed that females were not receiving the same quality of education as males (Fennema, E., 1990; Kerr, B., 1985; Sadker, M. and Sadker, D., 1985, 1986, 1989a, 1989b; Tobin, K., Kahle, J. and Fraser, B., 1990). Responding to this concern, the American Association of University Women's (AAUW) Educational Foundation developed a research program to seek information. AAUW reasoned that girls and women must become better educated and more self-assured. AAUW sought to identify barriers to this agenda.

In 1991, AAUW released Shortchanging Girls, Shortchanging America. This report shared the results of a nationwide poll that assessed the attitudes, educational experiences, math and science interest, and career aspirations of girls and boys from nine to fifteen years old. Perhaps the most interesting and at the same time the most troubling findings centered on self-esteem. Both boys and girls experienced a loss of self-esteem in various areas as they progressed through our educational system. However, this loss is much more dramatic and has longer lasting implications for girls.

In 1992, AAUW released How Schools Shortchange Girls. This report synthesized the results of numerous research studies about girls and their educational experiences. The patterns of gender bias and entrenched inequity revealed were alarming, shattering the ideal of equal classroom treatment nationally.

A heightened national consciousness was mirrored by a heightened awareness and level of concern at IMSA. During the 1992-1993 academic year, one professional development strand focused on the work of Belenky, Clinchy, Goldberger, and Tarule. Their book, Women's Ways of Knowing: The Development of Self, Voice, and Mind, became the centerpiece of Academy dialogue and inquiry. Mary Belenky and Blythe Clinchy personally mentored some IMSA staff in efforts to inform their thinking and their pedagogy.

Belenky, et al. asserted that for well over twenty years women had been left out of the social science literature. The story of human development had essentially become man's story. They sought to uncover and to tell woman's story. Belenky, et al. studied the ways in which women come to know truth, what they know at varying stages, and the strength of their inner voice. They developed a schemata which described women's knowing from a position of silence, to received knowing, through a perspective of subjective knowing, to procedural knowing, and emerging with constructed knowing.

These efforts paralleled the examination of constructivism as a system of beliefs and a theory of learning that would ground the Academy's movement toward more integrative curricula. This climate of introspection and critique of the "as is" nurtured substantive dialogue throughout the institution. Informal optional evening sessions for Academy women (staff and students) expanded the discussion and provided a safe forum. A group of female literature students presented an evening of readings and interpretations that clarified both the hopes and frustrations of female IMSA students.

Sensitized by these events, members of the physics team voiced concerns about the level of enrollment of female students in upper level courses, most noticeably, calculus-based physics. The reservations harbored by some female students about taking and succeeding in calculus-based physics fueled the team's concerns. For example, an accomplished female IMSA graduate (and national Westinghouse Science Talent Search winner) described the ethos of the calculus-based physics classroom as a "shark tank" to one of the physics teachers. Females enrolled in fewer numbers than males and a significantly lower percentage of females completed the two semester calculus-based physics course sequence.

The synergistic power of these events and the feelings that they engendered coalesced during the summer of 1993. Members of the physics team proposed the formation of an all-female section of calculus-based physics for the purpose of providing an environment that might enhance the participation and achievement of females in the physical sciences and, at the same time, enable IMSA to study the phenomenon of disproportionate participation and achievement of females in the upper-level physics course, calculus-based physics.

Rationale

Empowering students to learn is an admirable goal. Achieving this goal presents a challenge which involves much more than the presentation of subject matter. Students bring with them differing background experiences, self-perceptions, and learning styles. Models of teaching and the ethos of the classroom are factors affecting successful learning which lie within the sphere of influence of instructors. The role that these factors play in meeting the needs of diverse learners is not clear. Generally, the levels of participation and achievement of females in science do not match those of male learners.

The possibility of an all-female calculus-based physics section represented a transition from the ideal of equal educational experiences to one grounded in a belief in equal educational outcomes. This shift allowed for differential treatment of a group of female learners to enable them to attain outcomes similar to the population of male learners.

The impact of the learning experience, combined with the ethos of the classroom, pedagogical choices, the choice of instructional materials, interactions -- whether they are student-teacher or student-student interactions -- and the expectations of instructors, students, and community, all contribute to equity. In an effort to explore these relationships, an exploratory study was designed to gather information relative to calculus-based physics.

Background

In order to firmly ground the design of the study and the development of research questions, individuals with a national reputation in the area of gender-based differentiated instruction were consulted. In addition, a thorough review of the relevant literature was conducted. The ideas generated by these renowned individuals as well as the results of the literature review are summarized below.

Contacts. Mary Maschino, librarian with Girls Incorporated National Resource Center, shared numerous relevant articles and facilitated the acquisition of studies conducted by Girls Incorporated designed to enhance the participation of females in science and mathematics.

Pam Miller, consultant with Graymill Consulting and GESA (Gender/Ethnic Expectations and Student Achievement) facilitator, confirmed what IMSA already knew, "Oftentimes girls experience academic difficulty in physics." Ms. Miller provided information about the relative achievement of females and males in single-sex settings.

Helen Miller of the Center for Research on Women at Wellesley College offered insights about the length of the proposed intervention. Ms. Miller emphasized that the period of study be no longer than one semester in length. She further suggested contact with Pat Campbell whom she believed to be the most knowledgeable about this subject.

Pat Campbell of Campbell-Kibler Associates cautioned that the tendency to want to "fix" the girls rather than deal with an institutional problem would do more harm than good. In her view, segregation was a band-aid approach to a much bigger problem. Is this intervention in response to the negative treatment of girls by boys? Is this in response to the differential treatment of girls in the classroom by both the teacher and the boys? Is this in response to genuine concerns regarding the achievement of girls in physics? She further cautioned that separate has never been equal.

Tasha Lebow of the Program for Educational Opportunity was very enthusiastic about the proposed course, citing the importance of providing additional support to women in science. She believed that single-sex opportunities may have some potential, but that there were obstacles to overcome.

Mary Pavone of the Women in Science Project of Dartmouth College shared information about their ongoing project. They have conducted a study concerning the attitudes of both women and men at Dartmouth toward the all-female science program. She shared the following:

- Male students at Dartmouth openly shared their opinion that this program is objectionable to them. Females in the program quickly learned of these attitudes and kept quiet about their involvement in the program.
- Females believed that they had an "unfair advantage" because of this program. This perceived "unfair advantage" diminished their achievements in this program. "I did well, but that was only because I was in the *Women in Science Program*."
- The overwhelming majority of adolescent males and females believe that "things" are more equitable than they really are. When in lower-level classes, they see a nearly balanced classroom makeup and this reinforces the notion that things are equitable in the sciences.

Literature Review. An extensive search of the literature also was conducted; pertinent resources were evaluated and collected; and all relevant resources were read and annotated. This information was shared with study participants and interested individuals. A complete bibliography can be found in the appendix.

In summary, articles and study findings suggest that in general:

- Physics teachers influence their students appreciation of and self-confidence in physics by providing particular kinds of learning experiences and information.
- Physics teachers do not provide females with positive role models in the field of science. There are fewer visual representations of females in science and in science leadership rather than in subordinate roles.
- Physics teachers provide different achievement expectations; different behavior expectations; and differential feedback to females about achievement and behavior.
- Teachers allow males to dominate (both verbally and with the use of equipment) in the physics classroom (target students).
- Teachers disengage or cut-off interactions with female students.
- Teachers engage male students in more in-depth interactions.

- The interaction ratio (male/female) is not dependent upon the teacher's gender.
- Choosers (both male and female) feel more confident and like physics more than non-choosers and hesitaters.
- Female students have fewer in-class interactions with the instructor.
- Females are asked lower-level questions while males are asked more higher-level questions.
- Females provide more on-task responses while males provide more off-task responses.
- Female students' performance on objective science tests is generally lower than males.
- Female students' performance on essay-type science tests is generally higher than males.
- Females do not take as many experimental risks as males.
- Females have lower self-confidence in physics than males.
- Females perform better in physics in single-sex schools because of higher expectations on the part of instructors and parents.
- Females are more polite and less obtrusive in the classroom.
- Females lack parental encouragement to persist in science.
- Females are more concerned with the teaching-learning process than are males.
- Females are more interested in personal experience as it relates to the topic at hand than are males.
- Females prefer learning environments in which the instructor is a participant in the learning process.
- Females enjoy collaborative classrooms; males enjoy competitive classrooms.
- Uses of calculus are associated with activities identified by society as male.
- Males focus on the importance of debate and argumentation.
- Males are more satisfied with an authoritarian educational setting.

Given the above comments and general findings, the *Science & Engineering Indicators Report (1991)* of the National Science Board is not surprising. The average science performance of females in three age groups (9, 13, 17) is lower than that of males, continuing a trend that has existed since the first assessment in 1970. The difference in science performance is greatest at the seventeen-year-old level. The difference in mathematics scores between males and females is slight overall at all levels; however, nine-year-old females out score males, while seventeen-year-old males out score females.

Design

These findings drawn from experts in the field and from the literature spurred several IMSA faculty and administrators to action. These faculty were determined to go beyond discussion and to attempt to make a difference in the classroom. Since it was apparent that the research contained many different insights, the faculty decided to conduct an exploratory study, one that contained some controls but also permitted the specific mix of classroom conditions to be somewhat flexible. This flexibility also was extended to the focus of research questions. Initial research questions were formulated but it was agreed that the precise focus of these questions and the manner in which questions would be answered would be left somewhat flexible and subject to limited change. It was further agreed that new research questions might emerge as the study proceeded.

The study employed a pre-posttest exploratory-control group design. Four sections of calculus-based physics were scheduled during the first semester of the 1993-94 academic year. Three of the sections were coed. The fourth section was all-female. Eligible students were given the opportunity to voluntarily enroll in the all-female calculus-based physics (mechanics) class during the fall semester of 1993. A male physics instructor with 20 years teaching experience taught the all-female section and one of the other coed sections. Two other experienced male physics instructors each taught one of the remaining coed sections. The coed sections were designated control sections and the all-female section was designated as the exploratory section.

Course content and academic expectations were the same for all four sections. Each of the three teachers for the coeducational sections agreed to approach teaching and learning in the same manner as they had in previous semesters of teaching calculus-based physics. However, the learning environment and the teacher-to-student interactions were different for the all-female exploratory section compared to that of the coed control sections.

The pedagogical approach for the exploratory section was developed by focusing on the insights from the literature review and the expert contacts. During the first several weeks of the 1993 fall semester, serious discussions led to the identification of a collaborative pedagogy focused on the educational needs of female students. In conjunction with these discussions, the instructor piloted several possibilities in the classroom. Through this process, the following characteristics of the learning environment were identified:

a) a single-sex environment;
b) flexible group seating based upon collaborative group needs and tasks;
c) in-class work dominated by exercises and problems that would be approached in a collaborative manner;
d) exclusion of activities that encouraged or required competition among class members;
e) development of small group learning communities that extended beyond class time;
f) ready access to information about contemporary female scientists coupled with pictures of female role models in the sciences and mathematics prominently displayed in the classroom.
g) course content introduced with a situation-based problem which raised questions that shaped the organizing frame for subsequent learning.
h) concrete, hands-on experiences to increase experiential background.

As noted above, these elements were to be left somewhat flexible, that is, the instructor was given permission to modify, emphasize, and even add others if warranted by the experience and supported by the prior literature study. In fact, this modification and emphasis did occur and two salient characteristics emerged that were deemed more critical than others to the development of a collaborative pedagogy in the exploratory all-female class. The first characteristic required a changed perception of the teachers' role in the classroom. This changed perception emphasizes the teacher as co-learner rather than expert provider of information and compels students to be the responsible agents for their own and others' learning. The second key element focuses on the those features that directly reduced competition and encouraged collaboration in the teaching and learning environment (characteristics b-e). These two features (the changed role of the teacher and the learners as well as the non-competitive collaborative environment) seemed to engender a totally different classroom ethos. The teacher as well as other observers were struck by this different ethos in the exploratory group; they repeatedly reported that there was a pronounced sense of caring for one another and seriousness about learning that became increasingly evident as the study evolved.

Research Questions

Four research questions were identified as important benchmarks for the study.

1. Is a single-sex (exploratory) section of calculus-based physics an effective strategy to enhance subsequent coeducational class achievement, self-confidence, and participation of female students?

2. Is there any apprehension on the part of female students at IMSA about taking calculus-based physics and is this apprehension related to factors that are within the sphere of influence of teachers, students, and administrators?

3. Are there factors other than differential classroom treatment that could account for differences in achievement and self-confidence between females and males in calculus-based physics during the 1993-94 academic year?

4. What was the character (difficulties, insights, and views of success) of the calculus-based physics experience?

Given the diversity of these questions, a wide variety of data was required. The data included test scores, written and verbal teacher reflections, observation data and survey data as well as interviews and focus group discussions.

Data Collection

In general, four types of data were collected. Information about the classroom environment and interpersonal interactions was gathered by means of classroom observations by a trained observer and accompanying journal reflections by the instructors. The second type of data included PSAT-V and PSAT-M scores which were collected by reviewing students' academic records. The third type of data was related to self-confidence and self-perception. A pre-experience and post-experience student survey was designed and administered to capture information related to students' perceptions of success, self-efficacy in science and mathematics, and insights into different later traits. The fourth type of information related to success and experience levels. Indicators of success and experience included in-class quizzes, tests, homework and discussions, prior levels of achievement in mathematics and calculus-based physics final examination scores.

Questionnaires: Using a collaborative process, the instructor of the all-female calculus-based physics course and two curriculum and research specialists designed questionnaires. Based upon the review of the relevant research on effective teaching of females and the teaching of physics, the following question clusters were identified for use with female physics students:

- perceptions of success in this learning experience.
- course taking motivation.
- perceived apprehensions about science and mathematics.
- perceived apprehensions about this course in particular.
- perceptions of the ethos of the learning environment.
- self-efficacy in learning situations.
- self-confidence.

Classroom Observations/Teacher Reflections: A total of 32 hours of observation over a total of 36 individual classroom visitations was completed by a trained and experienced observer (staff researcher) of classroom interactions and pedagogy. The observation record follows:

Classroom	Observations	Time
Control	11 classes	10 hours
Control	9 classes	8 hours
Control	5 classes	4 hours
Exploratory	11 classes	10 hours

The observation instrument employed was adapted from one developed by Evertson and Weade. It facilitated the capturing of both frequency data and anecdotal information. As a result of a review of the literature concerning single-sex schooling, calculus and physics instruction, and gender equity in the classroom, the following data points were identified as having potential value in this investigation.

Frequency Data:

- Male voices heard, both answering and posing questions.
- Female voices heard, both answering and posing questions.
- Level of questions (high/low) posed by the teacher.
- Method employed by students to gain the attention of the teacher (raising hands, calling out, etc,).

Mapping Patterns

- The interaction patterns between students during collaborative work.
- The interaction patterns between students and teacher during independent or collaborative work.

Anecdotal Information

- Comments/affirmations made by instructors to students.
- Depth of student/teacher interactions (i.e. question, response or question, response, probe, response, confirmatory paraphrasing, response).

Prior to observation by the trained observer each teacher was familiarized with the instrument and the procedures to be followed over the course of the investigation. The observer was present in each of the four classrooms on the first day of class to establish a pattern with both the teachers and the students. Following each of the first three class observations, the observer and the teachers reviewed the observation report for accuracy and clarity. This established the trustworthiness of the recorded information. It was also important for the teachers to be comfortable with the observation process and the type of data collected. The observer recorded objective data that reflected the "as is" situation in the classroom and direct quotes from the teacher and the students when appropriate. A conscious attempt was made to strictly avoid recording inferential and/or evaluative comments by the observer.

The teachers took possession of the observation report and used it as a tool to help them complete a personal reflection about the observed lesson. These reflections recounted the intended plan for the day's lesson, how that plan was operationalized, and the teacher's feelings about how the lesson went. When completed both the observation report and the teacher's reflection were returned to the observer. After these initial observations the observer and teachers interacted on an as needed basis only.

Summary of Classroom Observations

Coed Sections/Control Groups

There were three coed calculus-based physics mechanics classes that were regularly observed along with the exploratory all-female class. The three coed classes were taught according to the normal procedures employed by the experienced physics teachers.

Coed Class One (Control): The predominant model of teaching employed during the first control class was direct instruction. Knowledge was dispensed in lecture mode with few, if any, questions posed to the students or by the students. The teacher delivered knowledge and the students received it. The teacher operated from an expert position and an internal agenda that was determined by content coverage and correct answers to problems. Documented comments from the teacher to the students reflect this orientation.

- "In a minute we'll get to that."
- "We'll get to that."
- "Hang onto that."
- "If you don't understand, come talk to me."
- "Most everybody getting it?"

Teacher talk accounted for well over ninety percent of most class periods. Student-teacher interactions that did occur were not sustained. Students most frequently received one or two word affirmations regarding problem resolutions.

- "OK."
- "Right."
- "Exactly right."
- "No."

Over the course of the semester, the majority of the class could be characterized as silent learners. Few students volunteered responses, asked questions, or made comments. Only one of four females volunteered a response during the ten hours of classroom observation. Even among the male population in this section, most never spoke.

Teacher space as defined by the front portion of the area and student space as defined by the student desk area facing the front teacher area rarely were violated. Occasionally, but not consistently, during guided, independent, or group practice of problem resolutions the teacher entered the student space. More frequently, the teacher would respond to student inquiry from the boundary areas.

The expertise of the teacher in the area of calculus-based physics was evident, if not showcased, in this section. The subject matter content was delivered. Students, for the most part, assumed a passive/receptive role. Learning and understanding seemed to be approached as a private matter both from the perspective of the students and that of the teacher.

Frequency tallies of the number of male and female responses to the teacher recorded during classroom observations of this first class are listed below.

Coed Class One Student Responses:

Gender	Number	Response Total	Res. Tot. Percent	Avg. Responses/Person
Female	4	29*	16%*	7.3*
Male	18	149	84%	8.3

** It is important to note that of the four females in this section, only one posed questions or responded to questions during the ten hours of observations.*

Coed Class Two (Control): The intent of the second control group teacher was to support a classroom environment in which student engagement was high. A blend of direct instruction and cooperative learning was employed. Questioning by the teacher attempted to uncover student misconceptions and expose thinking behind problem solutions. The teacher continually brought up prior learning as a foundational reference or as a concept that needed further refinement or connection in the context of calculus-based physics.

- "Why do you think...?"
- "If..., what's...?"
- "Remember __ 's Law."
- "What's the old way?"
- "What does that say? Look beyond..."
- "This has implications for the next one we want to do."

Student/teacher interactions were characteristically sustained. Interaction patterns frequently reflected the following: teacher question, student response, teacher probe, student response, teacher confirmatory paraphrasing, student response. Student questions frequently elicited probes or reflective questions from the teacher (i.e. What do you think?). Teacher talk represented approximately seventy percent of class time.

Space in this classroom was shared. Students sat at round tables, most were positioned to face front when necessary. The teacher occupied teacher space at the front when employing direct instruction, but meandered among the student tables for the major portion of class time.

The frequency tallies of the number of male and female responses/questions to the teacher for the class are listed below.

Coed Class Two Student Responses:

Gender	Number	Response Total	Res. Tot. Percent	Avg. Responses/Person
Female	4	16	8%	4.0
Male	19	182	92%	9.6

Coed Class Three (Control): The predominant model of teaching employed during this class was direct instruction. Knowledge was dispensed as a result of problem resolution by the teacher. Many "tools" were derived and problems completed at the board. Questions frequently posed to students required supplying the next piece of needed information (the result of the preceding arithmetic or algebraic operation). At times specific students were invited to the board to complete the "tool" derivation or the problem resolution. The teacher would explain the student's work at the board. Questions from students centered on procedures utilized for problem resolution. The teacher displayed behaviors that reflected a high value for procedural knowledge. Teacher comments referred to "crunching" and "grinding through calculations."

- "We'll have to derive them."
- "What part of the velocity is in that direction?"
- "So here's... "

Teacher talk accounted for well over ninety percent of most class periods. Student-teacher interactions that did occur centered upon calculations and were not sustained. The teacher, at times, adopted a performance mode in the front of the classroom. Teacher space, as defined by the front portion of the area, and student space, as defined by the student desk area facing the front, were rarely violated. During student independent practice time, the teacher would respond to student inquiry from the boundary areas. The frequency tallies of the number of male and female responses to the teacher are listed below. Note that only five classroom observations were completed for this class.

Coed Class Three: Student Responses:

Gender	Number	Response Total	Res. Tot. Percent	Avg. Responses/Person
Female	3	5	17%	1.7
Male	15	25	83%	1.7

All-Female Section/Exploratory Group

Models of teaching employed during this class period were direct instruction, inquiry, concept attainment, and cooperative learning. The teacher identified misconceptions held by students early in units of study and supplemented students' experience base with direct hands-on experiences or demonstration.

The safety level established by the all-female learning environment was reinforced by the facilitative and interactive style of the teacher. In addition, the time spent on different concepts and problems was determined by student understanding more than the need for content coverage. Frequently individual students were affirmed in their learning or thought processes.

- "Eunice talked about something very interesting."
- "You've made some connections here."
- "Good explanation."
- "Marcia found a useful concept."
- "Most of you guys used defensible techniques."

Teacher talk accounted for approximately sixty percent (similar to control group two) of most class periods. Student-teacher interactions were sustained and frequently reflected the following pattern: teacher question, student response, teacher probe, student response, teacher confirmatory paraphrasing, student response. Students frequently asked questions of the instructor, probed instructor responses, or halted instruction to gain clarification.

- "Are we still working on these?"
- "Wait a minute!"
- "Can we talk in our groups?"

Student-to-student interactions were overwhelmingly task-oriented and intense. The behavior of the students in this section indicated that they had taken charge of their learning. If one working group became disruptive or infringed upon another group's learning a student or another group would redirect them with a pointed comment (i.e.,"Girls!"). Toward the end of the semester one table group that had occupied the back corner of the classroom decided to move to the front because "the back of the room was no place to learn."

Space in this classroom was shared. Students sat at round tables, most were positioned to face front when necessary. The teacher occupied teacher space at the front when employing direct instruction, but meandered among the student tables for the major portion of class time frequently stopping to interact with students or probe their thinking.

The frequency tallies of the number of female responses to the teacher for the all-female class are listed below.

All Female Class: Student Responses:

Gender	Number	Response total	Res. Tot. Percent	Avg. Responses/Person
Female	13	229	100%	17.6
Male	0	0	0%	0.0

Supporting Enrollment and Prior Performance Data

Enrollment data related to calculus-based physics from the 1991-92 school year through the 1993-94 school year were collected in order to provide information on the number of females taking the course during this time period. The information presented in the following table indicates that more females enrolled and persisted in a year of calculus-based physics during the 1993-1994 school year.

Calculus-Based Physics Enrollment Data
1991-92 through 1993-94

1991-92	Males	Females	Total
CBP-Mech	41	9	50
CBP-E&M	42	8	50

1992-93	Males	Females	Total
CBP-Mech	49	12	61
CBP-E&M	45	9	54

1993-94	Males	Females	Total
CBP-Mech	52	23	75
CBP-E&M	46	17	63

Preliminary Scholastic Achievement Test Mathematics (PSAT-M) scores were collected for each class to provide background information on female participants. The data are presented in the following table. Females in the exploratory group displayed a slightly lower (not statistically significant) PSAT-M score than females in the coed classes.

Female Mean PSAT-M Scores

Period	Number of Females	Mean PSAT-M Score
Control	10	72.0
Exploratory	13	68.8

The following table displays mean first and second semester final examination scores for both groups of females in calculus-based physics. These scores were collected to provide one type of success measure. Although females in the exploratory group scored slightly lower on the first final examination and slightly higher on the second semester final examination, the differences were not significantly different. Females in both the coed and exploratory groups scored similarly on final examinations in calculus-based physics. It was further found that although initial mathematics ability as displayed on the PSAT-M was a factor for predicting first semester achievement, its was not a significant predictor for second semester achievement. In other words, over time, differences in initial mathematics ability became less important.

Female Mean Final Exam Scores

Period	Number of Females	1st Sem Exam (150 Total Items)	Stand. Dev.
Control Groups	10	112.6	14.8
Exploratory Group	13	96.8	18.8

Period	Number of Females	2nd Sem Exam (150 Total Items)	Stand. Dev.
Control Groups	9	85.4	18.5
Exploratory Group	8	86.3	18.3

Findings

An analysis of the data yielded the following findings. These findings were formulated after careful analysis of the four different data types. Statistical analysis was used where numeric data were available. To properly interpret the open-ended comments and observation data, care was exercised to read and re-read, to discuss and debrief the participants, and to document those findings for which supporting evidence was clearly evident.

Finding:
There was a strikingly different quality to the atmosphere, character and climate of the all-female calculus-based physics class.

A genuine community of learners evolved in the all-female class; this community was characterized by a **profound sense of responsibility for learning** that extended beyond the individual to that of the entire class community. Students not only felt compelled to help others who asked for assistance but they also developed an advocate character. Students sought out others in a helping relationship.

There was a **different quality to the types of relationships** that evolved in the all-female physics class. The teacher and students interacted on a more personal level, one that extended beyond the business of physics per se. Students wanted to share past and current experiences, their feelings, and their frustrations and they did so freely. The teacher said he felt that he knew more about his students than ever before in his 20-year teaching career. There were different levels to these relationships that extended beyond individuals. He also reported that he felt related to groups as a whole and that this extended and deepened the overall quality of all interactions.

The teaching and learning atmosphere became more of an atmosphere of **co-learners.** Both teacher and students **felt safe to be honest about their learning** and personal needs. There was a sense of mutual trust that permitted students to express ignorance or confusion without fear of judgment. Teacher and student questions were valued and student-centered inquiry deemed to be more important than presenting information. Questions emerged more frequently. Classroom observations provided information on the frequency of student responses per student over the course of the 1st semester. Females in the first coed class averaged 7.3 responses per individual (It should be noted that all female responses in this class came from one of the four females in the class). Females in the second coed class averaged 4.0 responses per individual. Females in the third control class averaged 1.7 responses per individual. In comparison, females in the exploratory section averaged 17.6 responses per individual.

Students in the all-female class exercised greater control of classroom dynamics than students in the coed classes. The teacher of the exploratory class noted that he felt compelled to respond to the expressed needs of the students. He spoke of a changed locus of control, one which resided both in the students and in himself. This shared control enabled him to be more in tune with, drawn in by and responsive to student behaviors.

Finding:

Students in the all-female class displayed greater performance-level growth on quizzes, homework and class exams than did females in the coed sections taught by the same instructor.

The teacher of the all-female section employed the same quizzes, homework and class exams throughout the semester. Initially the females in the two classes performed about the same on in-class assignments. As the semester continued, there was greater growth evidenced by the performance of the all-female section. This performance was characterized by a growth in problem solving and problem analysis. Females asked better questions, formulated more independent responses and scored higher on exams. This higher performance level did not transfer to a common final examination administered to all students in a large-group coed setting. Females in the all-female section did not score significantly higher than other females in the coed section. It should be noted that the setting for this examination differed greatly from the all-female classroom ethos described above.

Finding:

More females enrolled in and successfully completed calculus-based physics than before.

This finding is based upon a review of the enrollment history of females in the calculus-based physics course over the past three years. The number of females taking a second semester of calculus-based physics increased from eight in 1991-92 and nine in 1992-93 to nineteen in 1993-94. This increase is attributed to the females having had the opportunity to participate in the exploratory section of calculus-based physics during the first semester of the 1993-94 school year. Additionally, an analysis of first and second semester calculus-based physics female final exam scores revealed that there was no significant difference in final exam mean scores between females who had participated in the exploratory section and females who had participated in the coed sections of first semester calculus-based physics. Using an analysis of covariance statistic, which factored out initial mathematics facility or power, effects related to differences in the exploratory and coed approaches were not significant.

Given that a larger number of females opted to take calculus-based physics during the 1st semester of the 1993-94 school year than either of the previous two years (due to the opportunity to participate in the exploratory section) and achieved at a comparable level to all other females, the all-female exploratory approach was an effective strategy to enhance subsequent coeducational class achievement and participation of female students.

Finding:

Females in the all-female calculus-based physics: mechanics section demonstrated a significantly higher growth in self-confidence when compared to females in the coed sections.

An analysis of covariance revealed a significant change in females' self-confidence. Females in the exploratory section of the calculus-based physics class demonstrated a significantly higher self confidence score on the post-survey than females who had participated in a coed section. No significant differences were found for these groups on the pre-survey.

Finding:

The predictive quality of PSAT-M scores for females continuing their studies of calculus-based physics lessened over the course of the year. For students who participated in the exploratory section, prior facility in mathematics is less important for subsequent achievement/ success.

For females, prior facility (or power) in mathematics accounts for the variance present in 1st semester achievement in calculus-based physics, but does not account for the variance associated with second semester achievement in calculus-based physics. Mean final second semester exam scores of both groups were not significantly different. This finding is supported by an examination of the PSAT-M covariate for first semester and second semester achievement. The PSAT-M was a significant covariate ($p=.01$) for first semester final exam scores but was not a significant covariate ($p=.16$) for second semester final exam scores. Female students performed better on the second semester examination than would been predicted by the PSAT-M.

Discussion and Interpretation

The purpose of this exploratory study was to gather information related to female participation in calculus-based physics at the Illinois Mathematics and Science Academy. Three coeducational classes and one exploratory group were established. The exploratory group differed from the coeducational classes in that the teaching approach used was deliberately facilitative in nature, allowing students to work together to a much greater extent than in the coed classes, and it was comprised entirely of female students. This combination offered a distinctly different experience for those students in the exploratory group as compared to the students in the coed sections. **The classroom ethos seemed to have the most dramatic effect on student learning. This ethos was mutually constructed over time by the learners and their teacher.** It can be said that the exploratory approach is an effective strategy to enhance subsequent coeducational class achievement and participation of female students in that the opportunity to enroll in the exploratory section appears to be related to an increase in the number of females who enrolled in the second semester of calculus-based physics. It also was found that the self-confidence of females in the exploratory section displayed a significant improvement compared to females in the coed sections over the course of the first semester. In addition, students in the exploratory section performed at a level on the second semester final exam which is not significantly different than that of females who were enrolled in the first semester coed sections.

It should be noted that not all students in the all-female section needed nor preferred a single-gender environment nor the classroom ethos of their section. A small number of students did not like one or both of these factors and did not consider their experiences to be successful. Comments from the written reflections of the teacher of the exploratory group provide evidence that two of the females in the exploratory class felt that they were not being sufficiently challenged. Similarly, some females in the coed sections liked the coed environment and/or the classroom ethos of their particular sections and considered their experiences to be successful.

One factor, other than differential classroom treatment, that has been shown to be related to achievement is the mathematical facility, as identified through PSAT-M scores, that female students bring with them to the study of calculus-based physics. Additional study may reveal other factors.

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