CHANGING THE STATISTICS CURRICULUM FOR FUTURE AND CURRENT HIGH SCHOOL MATHEMATICS TEACHERS: A CASE STUDY

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Through a larger initiative involving mathematical sciences faculty from the three State of Iowa Board of Regents' institutions, faculty members from the Departments of Statistics and Mathematics at Iowa State University have started a collaboration in the area of statistics training for future and current mathematics teachers. In this paper, we begin by discussing the recent developments in high school mathematics education at both the state and national level that served as a focus for change in the statistics education of mathematics teachers in the state. We then describe our present efforts in changing curriculum in statistical content and pedagogy in the undergraduate and graduate programs at Iowa State for future and current mathematics teachers. Finally, we offer some direction for future work in these regards.

BACKGROUND

In May, 2006, a call was made by the Iowa State Legislature through the Iowa Department of Education for all high school students in the state to be better prepared in mathematics in order to successfully compete in the technology-rich, information-dense, global society. The Iowa Core Curriculum in high school mathematics stresses the importance of teaching for understanding in four main content strands of mathematics: algebra, geometry, statistics and probability, and quantitative literacy (Iowa Department of Education, 2006). Based on reports from several national committees, including *Principles and Standards for School Mathematics* from the National Council of Teachers of Mathematics (NCTM, 2000) and the *Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report* (Franklin, et al., 2007) for the Pre-K–12 classroom published by the American Statistical Association, the Iowa Core Curriculum calls for descriptive statistics, inferential statistics, and probability to be included in the mathematics curriculum for all students, not just students enrolled in an Advanced Placement Statistics course.

In addition to the call made at the state level, the American Competitiveness Initiative (United States Department of Education, 2006) established a nationwide goal to increase the number of teachers qualified to teach Advanced Placement (AP) mathematics courses. For the 2005-2006 academic year (the most recent year with available full score distributions), 9,833 AP exams were taken by 6,607 students in Iowa, with approximately 70% of these exams receiving a score of 3 or higher. Of these nearly 10,000 exams, only 223 AP Statistics exams were administered. By contrast, 1,180 Calculus AB or BC exams were taken by students in the state during the same academic year (College Board, 2006). Nationally, AP Statistics examinations constituted around 26% of all AP examinations in the mathematical sciences (Calculus AB and BC and Statistics) during the 2005-2006 academic year, while this same percentage in Iowa was only 16% (College Board, 2006).

In Iowa, many high schools enter into agreements with one of the 15 area community colleges in the state to offer dual-credit courses, such as calculus and statistics, in which students gain both high school credit and college credit by taking a college level course in high school. These dual credit courses can be offered in place of, or in addition to, AP courses. The instructors for these dual credit community college courses are frequently high school mathematics teachers. Since teachers in this role are essentially community college instructors, they must meet the same minimum requirements as all other instructors at the community college; a master's degree in any field with a minimum of 12 graduate credit hours earned in mathematics. While the number of students completing college introductory statistics courses through dual credit community college courses is not available, R. R. Smith, Chair of the Department of Mathematics, Des Moines Area Community College, reported that requests to teach dual-credit statistics courses in high schools in central Iowa have increased greatly in the last several years (personal communication, April 6, 2007).

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In reaction to the new Iowa Core Curriculum (Iowa Department of Education, 2006), the American Competitiveness Initiative (U.S. Department of Education, 2006), and other developments, a group of faculty members from the five mathematical sciences departments at the three Regent Universities in Iowa (Iowa State University, University of Iowa and University of Northern Iowa) started an initiative in June 2006 to affect change in mathematics and statistics education in the K-16 system. This initiative, the Iowa Initiative for College Mathematics and Statistics Education (IICMASE), focuses on several keys areas including the transition of students from high schools to community colleges to Regents' institutions, collecting data for program outcomes assessment, curriculum for future teachers, and professional development for current teachers.

THE SPECIAL CASE OF STATISTICS

From its early meetings, faculty involved in IICMASE expressed concern about the training of future and current high school mathematics teachers in statistics, especially given the focus on this area in the state's new Core Curriculum (Iowa Department of Education, 2006). As a part of the certification requirements for teaching secondary mathematics, future teachers are required to complete just one course in calculus-based probability and statistics. A current review of the statistics requirements for future mathematics teachers across the state found no institutions where students are required to complete a general introductory statistics course. In fact, at many institutions across the state, including Iowa State University, this requirement of one course in calculus-based probability and statistics translates into a course in probability and/or mathematical statistics. Future high school mathematics teachers consequently receive very little if any course work in statistical content or pedagogy as a part of their educational training.

The state of training in statistics for current mathematics teachers was not much better. With any master's degree and completion of 12 graduate credit hours in mathematics, high school mathematics teachers are qualified to teach dual credit mathematics courses through the community college. Teachers meeting the minimum requirements to teach mathematics at the community college could teach the introductory statistics course with little to no training in statistical content and pedagogy, either at the undergraduate or graduate level.

Two graduate programs designed specifically for current mathematics teachers are in existence in the state. The Master of School Mathematics (MSM) degree from the Department of Mathematics at Iowa State University and the Master of Arts in Mathematics (Secondary Emphasis) degree from the Department of Mathematics at the University of Northern Iowa are designed to extend the mathematical content and pedagogy knowledge of current high school teachers. Both programs require one course in probability and/or statistics. However, none of these courses is targeted to the special audience of current mathematics teachers. The required course work in statistics for these two programs seems of little value in actually preparing these teachers to teach the AP Statistics curriculum, the curriculum in the dual credit introductory statistics courses offered through the community colleges, or the new Iowa Core Curriculum.

In discussions between the IICMASE group and both the high school and community college divisions of the Iowa Department of Education, the current situation of preparedness to teach statistics at the high school and community college level in the state was described by representatives in the Iowa Department of Education as an "emergency." Of course, this "emergency" is not specific to Iowa and could be avoided if the curriculum for future mathematics teachers in statistics and probability matched the curriculum recommended by national committees of mathematics and statistics educators. As early as 1989, the National Committee of Teachers of Mathematics as a part of their document *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) called for data analysis and probability to be taught in the nation's schools. This call was repeated and expanded in 2000 as a part of the NCTM *Principles and Standards for School Mathematics* (NCTM, 2000). The Conference Board of Mathematical Sciences (CBMS) book, *The Mathematical Education of Teachers* (referred to below as the MET Report) (CBMS, 2001) and the report *Undergraduate Programs and Courses in the Mathematical Sciences: CUPM Curriculum Guide 2004* (Committee on the Undergraduate Program in Mathematics, 2004) by the Committee on the Undergraduate

Program in Mathematics of The Mathematical Association of America (referred to below as the CUPM Curriculum Guide) both re-enforced the need for statistical training in the preparation of secondary mathematics teachers. The CUPM Curriculum Guide states "(t)he emphasis on data analysis in the 2000 NCTM standards and the growth of Advanced Placement statistics courses in secondary school make a study of statistics necessary for those preparing for secondary school teaching in mathematics." (CUPM, 2004, p. 47). This report further states the importance of having all mathematics majors (including future secondary teachers) "study statistics or probability with an approach that is data-driven" (CUPM, 2004, p. 47) rather than the typical calculus-based approach. The MET Report goes further, by recommending that future high school mathematics teachers gain experience in (1) "Exploring data–using a variety of standard techniques for organizing and displaying data in order to detect patterns and departures from patterns"; (2) "Planning a study–using surveys to estimate population characteristics and designing experiments to test conjectured relationships among variables"; (3) "Anticipating patterns–using theory and simulation to study probability distributions and apply them as models of real phenomena"; (4) "Statistical inference–using probability models to draw conclusions from data and measure the uncertainty of those conclusions"; and (5) "Probability–understand basic concepts of probability such as conditional probability and independence. . ." (,CBMS, 2001, Chapter 9). In addition, the MET Report recommends future teachers gain experience in standard software packages for use in simulations, data analysis and statistical inference (,CBMS, 2001, Chapter 9).

At the same time, statistics and mathematics educators have been working on the development of outcomes and guidelines for teaching the introductory statistics course. As reported by Cobb (1992), the Guidelines of the American Statistical Association/Mathematical Association of America Joint Committee on Undergraduate Statistics called for the introductory statistics course to (1) emphasize statistical thinking, (2) include more data and concepts, less theory and fewer recipes, and (3) foster active learning (Cobb, 1992). Building upon this work, the *Guidelines for Assessment and Instruction in Statistics Education (GAISE) College Report* (Garfield, et al., 2005) by the American Statistical Association provides six recommendations for teaching the introductory statistics course and 23 student learning outcomes for all introductory statistics courses. The CUPM Curriculum Guide (CUPM, 2004) endorsed the guidelines as found in the Cobb (1992) report as a part of their recommendation for a data-driven approach to statistics and probability study for mathematics majors.

WORKING TOGETHER TOWARDS A SOLUTION

In light of these reports by the national committees of mathematics and statistics educators and the dire situation of preparedness in the State of Iowa to teach statistical content in the high schools and community colleges, the Departments of Mathematics and Statistics at Iowa State University decided to work together to get future and current high school mathematics teachers in the state of Iowa the type of statistical content and pedagogy needed to become effective teachers of statistics and probability. In the following sections, the curriculum changes in programs for future and current mathematics teachers are presented and the rationale for these changes are explained.

CURRICULUM FOR FUTURE HIGH SCHOOL MATHEMATICS TEACHERS

The Bachelor of Science degree in mathematics with certification to teach secondary mathematics is offered at Iowa State University as one of two degree options through the Department of Mathematics. Currently, students in this degree program are required to complete only the first course in the two-course calculus-based probability and mathematical statistics sequence for undergraduates. The first course includes a study of probability and probability distributions (discrete, continuous and multivariate) while the second course covers topics in statistical inference, estimation, linear model theory, and enumerative data. These two courses are currently being redesigned from the more traditional probability and mathematical statistics course sequence to one that places more focus on data analysis and investigations of concepts in probability, probability distributions, and statistical theory though real and simulated data. Both

courses rely on the statistical programming language R (R Development Core Team, 2008) to help students apply their knowledge of calculus and linear algebra to investigate the theoretical basis for probability and statistical concepts (Froelich & Larsen, 2008). Clearly, the first course on probability taught in this manner gives future teachers exposure to a modern statistical programming language and some of the content knowledge described in the MET Report (,CBMS, 2001, Chapter 9) (under anticipating patterns and probability), but little to no content from the other recommended areas.

In discussing changes to the curriculum for future mathematics teachers, the faculty in both departments agreed to follow the recommendations of the CUPM Curriculum Guide from 2004 and require these students to complete an introductory statistics course following the guidelines from the Cobb (1992) report and the *GAISE College Report* (Garfield et al., 2005). Completion of this course would give students in this program some content knowledge from the other three areas (exploring data, planning a study and statistical inference) from the MET Report (CBMS, 2001) and experience with a modern statistical software program (SAS Institute, Inc., 2007). More importantly, the content in the introductory statistics course is likely to comprise most of the statistical content future high school mathematics teachers would be required to teach. In order to teach a similar course in the future, these students should be expected to complete a similar course as a part of their educational training. The faculty selected a fairly new introductory statistics course created as a part of a separate NSF-funded effort by two faculty members in the Department of Statistics (Froelich, Stephenson, & Duckworth, 2008; Froelich & Stephenson, 2008). Developed for statistics majors and other students with strong mathematical skills (American College Test (ACT) Math score of 27 or higher or equivalent SAT Math score), this course was designed to encourage students to take ownership of course content and activities by making decisions about what data to collect, how to organize the data, and how to interpret results within the context of the problem and by discovering statistical concepts through guided activities.

While the introductory course as described above is a good start to the statistical content training of future mathematics teachers, faculty in both departments felt this one course did not provide enough content knowledge in statistics and in particular, did not provide students with a deep enough understanding of some areas from the MET Report (CBMS, 2001). Ideally, both departments would have preferred to require students to take additional courses in statistical methods (for example, a course in regression models and a course in the analysis and design of experiments). And, since the MET Report calls for the connections between different areas and applications of mathematics to be emphasized in the mathematics curriculum for future teachers, faculty in both departments would like to have these students complete the redesigned course in calculus-based mathematical statistics as well. However, requiring any of these additional courses for the degree would push the total credit hour requirement for this degree program to over 128 credit hours, compared to 120 hours for most other degrees at Iowa State University (ISU). Students entering ISU in this degree program and with a good background in mathematics should have no difficulties completing these additional courses in four years of study. However, graduation for any students transferring into this program later in their course of study could be delayed by additional required courses.

Given these concerns, a compromise was reached on the probability and statistics curriculum for this degree program. The introductory course and the calculus-based probability course will be required courses for the degree program. The calculus-based mathematical statistics course will be a part of the degree plan for the major but will be a highly recommended course at this point, rather than required. Faculty in the Department of Mathematics will also encourage students to complete the additional recommended courses in statistics (regression models and design and analysis of experiments) before graduation. Also, beginning in Spring 2010, the introductory statistics course described above will be a prerequisite for the calculus-based mathematical statistics course. In this manner, students will study the applications and principles of statistics before studying statistical theory and deeper connections to mathematics.

Finally, the first and third authors of this paper have begun the process of incorporating statistical pedagogy into the mathematics education courses for this program. During the Spring 2007 semester, the first author completed a two-week module on probability and statistics in a

new mathematics connections course, in which the mathematical content taught at the university level is connected to mathematical content taught at the high school level. We plan to continue the inclusion of a two-week module on probability and statistics in this course, with a shifting focus to statistical pedagogy as these students complete the new required statistics courses. A one-credit course investigating statistical pedagogy described in Rossman, Medina, and Chance (2006) will be used to guide the development of this module.

CURRICULUM FOR CURRENT HIGH SCHOOL MATHEMATICS TEACHERS

As described above, the Department of Mathematics at Iowa State University offers a Master's degree in School Mathematics (MSM) for current mathematics teachers. The goals of the MSM program are to enhance these teachers' knowledge of algebra, geometry, calculus, statistics and discrete mathematics, to provide effective strategies for creating a student-centered classroom emphasizing problem solving and to provide training in the use of computing technology in learning and teaching mathematics. The required courses for the MSM program are taught on a rotating basis every third summer and include both mathematical content and pedagogy courses. Current mathematics teachers completing this degree program possess the minimum qualifications to teach dual credit community college courses in the high schools.

The Department of Statistics has offered a special section of the course, Statistical Methods for Research Workers, for the MSM program every third summer. This course assumes a prerequisite of an introductory applied statistics course and covers methods of analyzing and interpreting experimental and survey data, such as simple and multiple regression and analysis of variance. As the name indicates, the emphasis of this course is on providing graduate students in fields outside statistics with tools and methodology sufficient to complete the statistical analysis required for their Master's degree projects.

Clearly, this course is not the most appropriate course for students in the MSM program. The prerequisite of an introductory statistics course does not match the academic backgrounds of most current mathematics teachers. While some of the course content is important for these teachers, there is no emphasis on providing or studying effective methods for creating a student-centered statistics classroom that emphasizes problem solving nor is there an emphasis on the integration of technology into the statistics classroom.

To more adequately prepare students in the MSM program to effectively teach introductory statistics and the AP Statistics curriculum, the Department of Statistics will offer a new six-credit course in Summer 2008 entitled Statistical Methods for Mathematics Teachers. This new required course for the MSM program will assume a prerequisite course in calculus-based probability and will cover the statistics material from the AP Statistics curriculum, similar to the Insights into Statistical Practice, Instruction and Reasoning (INSPIRE) program offered through University of California, Los Angeles (Gould & Peck, 2005), plus material just beyond the AP curriculum, such as multiple regression, design of experiments, analysis of variance and logistic regression. In addition to the content coverage, statistical pedagogy appropriate to teaching the concepts covered in the course will also be presented, with particular emphasis on pedagogy for the introductory statistics course. Students in the MSM program will also be exposed to current literature in statistics education, including the *GAISE Pre-K–12* and *College Reports* (Franklin et al., 2007; Garfield et al., 2005) through course work in their mathematical pedagogy courses. The design of the pedagogy course work will be modeled after a similar course described in Rossman, Medina, and Chance (2006).

CONCLUSIONS

Over the past almost two years, much planning and progress has been made to change the statistics education of future and current mathematics teachers through the collaboration between the Departments of Statistics and Mathematics at Iowa State University. In the coming years, we plan to monitor the effect of these changes by tracking the number and scores of AP Statistics examinations taken by students in the state and by tracking the enrollments in dual-credit and community college introductory statistics courses and the performance of these students in subsequent courses at ISU. While most of this work began as a pilot project at Iowa State University, we plan to extend this work to other institutions in the state with the ultimate

goal of changing the certification requirements in statistics and probability for future teachers and providing current teachers with training in statistical methods and pedagogy in order to make both more effective teachers of statistics in the high schools.

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