Surveying Mathematics Departments to Identify Characteristics of Successful Programs in College Calculus

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This report highlights the completion of the first step of a large national investigation of mainstream Calculus I that aims to identify the factors that contribute to student success in Calculus I. Calculus I is *the* critical course on the road to virtually all STEM majors. Even students who do well in it often find the experience so discouraging that it leads to a change of career plans. We have very little data on the preparation and aspirations of the students who enroll in this course or of the factors that contribute to success in calculus. This five-year NSF funded project begins to fill this gap in knowledge.

The report provides a brief overview of departmental and instructional factors that influence student persistence and success in college and university calculus. We also describe the processes of developing a suite of six survey instruments to assess the characteristics of calculus instruction at colleges and universities across the nation. Since the six surveys (department chair, calculus coordinator, instructor pre, instructor post, student pre, and student post) followed the same development process we will limit our discussion in this report to the student pre- and post-surveys. The survey development process began with the development of a taxonomy of critical attributes of successful calculus programs that have been reported in the literature. This was followed by cycles of item construction, clinical interviews with survey respondents and item refinement until survey items assessed the intended taxonomy variables and the survey question and answer formats were interpreted consistently with the designers' intent. The research that guided the item development, including the format choice and validation cycles will be described with findings that reveal items that are effective for gaining information about calculus instruction and its impact on students. Pre-course surveys have been administered to over 10,000 students across the nation and post-survey data will be available at the end of the fall, 2010 semester.

Brief Summary of the Literature

Over the last 25 years, various studies about student persistence in college in general and in STEM studies in particular have converged on a nearly common set of clearly identifiable factors that contribute to student persistence. Broadly, these factors pertain to (a) a strong sense of community and self-perception of identity with that community, (b) departmental or institutional supports for learning, and (c) instructional behaviors that meet students' intellectual needs, promote greater learning and develop student self-confidence. In the area of college calculus as well as secondary mathematics leading to calculus, research findings also highlight the effect of pedagogical issues that affect students' understanding of the key ideas of the course (e.g., limit, derivative). Numerous studies have also highlighted the importance of students' development of problem solving behaviors and habits of mathematical thinking that are consistent with ones held by acting mathematicians and scientists. Yet another vast area that has been shown to effect students' learning and mathematical self efficacy include the quality of interactive engagement within the

classroom and intellectual demand put on students in homework and within the classroom. (e.g., homework, explanations). Other areas that have been particularly influential in affecting student persistent include: i) student self-efficacy relative to mathematics, ii) student and teacher beliefs about the nature and methods of mathematics, and iii) student self-identity with the culture of mathematics.

Research findings reveal many more variables than are feasible to include on the CSPCC Survey. This resulted in our considering the extent to which research indicates that a particular variable is a powerful factor in learning calculus or in student persistence in calculus. Other criteria we took into account include: (1) How amenable is this factor to actual change or manipulation? (i.e. can the instructor or department do anything about it?); (2) How hard is it to answer the question? (respondent burden); and (3) How confident are we that students will give us a truthful answer? (expected reliability).

Our literature review (see bibliography) guided our choice of variables to include in our surveys. These variables have been articulated in the form of a taxonomy. The student post-survey variables characterize both the dependent and independent variables that we hypothesize (based on our review of the literature) are critical for student success and continued mathematics study.

Taxonomy Keyed to Student Post-Survey

What follows is a curtailed taxonomy that shows only the major dimensions. As noted below, most dimensions has several subcategories. The full taxonomy will be presented with the full report and related to the literature.

<u>Potential Dependent Variables</u>

A. Course grade and intention to take Calc II (with 4 subcategories)
B. Impact of Calc I course on student (with 4 subcategories)
C. Student self-perception of knowledge/skills in calculus

<u>Potential Independent Variables</u>

A. Student Beliefs and Affect (with 5 subcategories)
B. Perceived Behaviors and Values of the Calculus Instructor (with 4 subcategories)
C. The Role of Homework and Exams (with 4 subcategories)
D. The Role and Behavior of the Student in Learning (with 6 subcategories)
E. Supports for Students (with 2 subcategories)
F. Readiness for Calculus (Pre-survey) (with 3 subcategories)
G. Readiness for Calculus (Post-survey)

Format and Design of Survey

While the variables embedded in the CSPCC Survey questions relate to factors identified from the literature, the format and design of the questions are consistent with recommended practice in survey design (Colton & Covert, 2007; Fowler, 1995; Saris & Gallhofer, 2007). Depending on the information sought by each question, a specific question format was selected as deemed most appropriate (Likert, contrasting alternative, categorical, matrix configuration). Professional advice was also sought from Dr. Jillian Kinzie, Associate Director, Indiana University Center for Postsecondary Research and NSSE Institute, whose area of expertise is survey design. In addition,

we have been in periodic communication with Co-PIs Phil Sadler and Gerhard Sonnet regarding survey formatting and data processing plans. They have also reviewed drafts of the survey taxonomies and instruments, and have offered suggestions for survey question refinement.

Survey Development

The project team developed the following five surveys: i) course coordinator, ii) instructor pre- suvey, iii) instructor post-survey, iv) student pre-survey and v) instructor post-survey. The development process for each instrument involved cycles of: i) constructing items for each taxonomy item for each survey; ii) conducting clinical interviews with a talk-aloud protocol with subjects for each of the respective surveys (i.e., course coordinators, instructors and students); refining the item questions and answer choices based on analysis of clinical interview data.

Each survey included multiple question types, including likert, contrasting alternative, and categorical. The question format for each taxonomy variable was considered with the format choice relying on which format would provide the most valid and reliable data relative to that variable. As one example, the contrasting alternative format is more reliable in instances where likert scales are ambiguous because different survey respondents construct different images of what it means to select a value in the scale. They are also more valid in instances where the goal is to gain information about the relative degree to which students agree with two common alternatives to a particular statement. In the case of the contrasting alternative format a brief description is provided for each end of the survey scale so that the respondent is clear on what it means to select that answer choice. As one example, we devised a contrasting alternative item that provides two alternatives about what a score on a mathematics exam is measuring because these two choices were revealed during interviews to be the most common uses of exams.

Example *constrasting altetnative* item type that appears on both the student pre- and post-survey.

30. My score on my mathematics exam is a measure of how well

(a) I understand the covered material.	1	2	3	4	(b) I can do things the way the teacher wants.
	O	O	O	O	

The conference presentation and report will provide additional exemplars of survey items for each of the four surveys and some time will be allotted for participants to react to the taxonomy and sample items.

Significance

The potential significance of this five-year study is very strong and members of the RUME community will be interested in the progress and outcomes of this national project. Through the policies and publications of the Mathematical Association of America, the results of this project will effect calculus instruction and curricular development across the nation by providing knowledge of approaches to teaching calculus that are more successful, with particular attention paid to the differential effects of racial/ethic and gender variables. This report represents the first in a series of reports at the RUME conference detailing the progress and results of this important work.

Bibliography

American Mathematical Society (2009). Homework Software Survey Report. Providence, RI: American Mathematical Society.

Boaler, J. (1998). Open and closed mathematic: Student experiences and understandings. *Journal for Research in Mathematics Education*, *29*(1), 41-62.

Boaler, J., William, D., & Zevenbergen, R. (2000). The construction of identity in secondary mathematics education. Paper presented at the International Mathematics Education and Society Conference. Portugal.

Carlson, M., Buskirk, T., & Halloun, I. (1999). Assessing College Students' Views about Mathematics with the Views About Mathematics Survey. Unpublished manuscript.

Carlson, M., & Bloom, I. (2005). The cyclic nature of problem solving: An emergent multidimensional problem solving framework. *Educational Studies in Mathematics*, 58, 45-75.

Carlson, M., Bloom, I., & Glick, P. (2008). Promoting effective mathematical practices in students: Insights from problem solving research. In M. Carlson & C. Rasmussen (Eds.), *Making the connection: Research and practice in undergraduate mathematics, MAA Notes*, *Vol*. *73* (pp. 275-288). Washington, DC: Mathematical Association of America.

Colton, D., & Covert, R. W. (2007). *Designing and Constructing Instruments for Social Research and Evaluation* (Research Methods for the Social Sciences). San Francisco, CA: Jossey-Bass.

Datta, D. K. (1993). *Math Education at its Best: The Potsdam Model*. Framingham, MA: The Center for Teaching/Learning Mathematics.

Davis, R. B., & Vinner, S. (1986). The notion of limit: Some seemingly unavoidable misconception stages. *Journal of Mathematical Behavior*, *5*, 281-303.

DeBellis, V. A., & Goldin, G. A. (1999). *Aspects of affect: Mathematical intimacy, mathematical integrity*. Paper presented at the 23rd Annual Meeting of the International Group for the Psychology of Mathematics Education, Haifa, Israel.

DeFranco, T. C. (1996). A perspective on mathematical problem-solving expertise based on the performances of male PhD. mathematicians. In *Research in collegiate mathematics II* (Vol. 6, pp. 195-213). Providence, RI: American Mathematical Association.

Fowler, F. J. (1995). *Improving Survey Questions*: *Design and Evaluation*. *Applied Social Research Methods Series*, *Vol*. *38*. Thousand Oaks, CA: Sage Publications.

Galbraith, P. (2002). 'Life wasn't meant to be easy': Separating wheat from chaff in *technology aided learning. Electronic Proceedings of the Second International Conference on the Teaching of Mathematics* (*at the Undergraduate Level*). Hersonissos, Crete, Greece, July, 2002.

Geiger, V., & Galbraith, P. (1998). Developing a diagnostic framework for evaluating student approaches to applied mathematics problems. *International Journal of Mathematics, Education, Science and Technology*, *29*(4), 533-559.

Gersten, R., Ferrini-Mundy, J., Benbow, C., Clements, D. Loveless, T., Williams, V. et al. (2008). Report of the Task Group on Instructional Practices. Retrieved October 27, 2008, from http://www.ed.gov/about/bdscomm/list/mathpanel/report/instructional-practices.pdf

Goos, M., & Galbraith, P. (2000). Reshaping teacher and student roles in technology-enriched classrooms. *Mathematics Education Research Journal*, *12*(3), 303-320.

Hannula, M. S. (2006). Motivation in mathematics: Goals reflected in emotions. *Educational Studies in Mathematics*, *63*(2), 165-178

Hsu, E., Murphy, T. J., & Treisman, U. (2008). Supporting high achievement in introductory mathematics courses: What we have learned from 30 years of the Emerging Scholars Program. In M. Carlson & C. Rasmussen (Eds.), *Making the connection*: *Research and practice in undergraduate mathematics*, *MAA Notes*, *Vol 73* (pp. 205-220). Washington, DC: Mathematical Association of America.

Keynes, A., & Olson, A. (2001). Professional development for changing undergraduate mathematics instruction. In D. Holton (Ed.), *The teaching and learning of mathematics at university level*: *An ICMI study* (pp. 113-126). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Kokkelenberg, E. C., Dillon, M., & Christy, S. M. (2008). The effects of class size on student grades at a public university. *Economics of Education Review*, *27*, 221-233.

Lewis, J., & Tucker, A. (2009). Report of the AMS First-Year Task Force. *Notices of the AMS*, *56*(6), 754-760. Providence, RI: American Mathematical Society.

Martin, J. H., Hands, K. B., Lancaster, S. M., Trytten, D. A., & Murphy, T. J. (2008). Hard but not too hard: Challenging courses and engineering students. *College Teaching*, *56*(2), 107-113.

Mason, J., & Spence, M. (1999). Beyond mere knowledge of mathematics: The importance of knowing-to-act in the moment, *Educational Studies in Mathematics*, 38, 135-161.

Nickerson, S., & Bowers, J. (2008). Examining interaction patterns in college-level mathematics classes: A case study. In M. Carlson & C. Rasmussen (Eds.), *Making the connection*: *Research and practice in undergraduate mathematics*, *MAA Notes*, *Vol 73* (pp. 179-190). Washington, DC: Mathematical Association of America.

Pajares, F. & Miller, M.D. (1994). Role of self-efficacy and self-concept beliefs in mathematics problem solving: A path-analysis. *Journal of Educational Psychology*, *86*(2), 193-203.

Pierson, J. (2009). Responsiveness and intellectual Work: Characteristics of teachers' discourse that influence student learning. Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA.

Reed-Rhoads, T., Murphy, T. J., & Trytten, D. A. (October 2005). A study of gender parity: Department culture from the students' perspective. *Proceedings of the 2005 Frontiers in Education Conference* (pp. F2G1-F2G6). Indianapolis, IN.

Robst, J., Keil, J., & Russo, D. (1998). The effect of gender composition of faculty on student retention. *Economics of Education Review*, *17*(4), 429-439.

Sabharwal, M. (2005). Factors affecting persistence rates among Arizona State University freshmen and Implications for policymaking. *Perspectives in Public Affairs*, *2*, 21-33.

Saris, W. E., & Gallhofer, I. N. (2007). *Design, Evaluation, and Analysis of Questionnaires for Survey Research* (Wiley Series in Survey Methodology). Hoboken, NJ: Wiley.

Seymour, E. (1995). The loss of women from science, mathematics, and engineering undergraduate majors: An explanatory account. *Science Education*, *79*(4), 437-473.

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder, CO: Westview Press.

Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition and sense-making in mathematics. In D. A. Grouws (Ed.), *Handbook for research on mathematics teaching and learning* (pp. 334-370). New York: Macmillan Publishing Company.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(5), 4-14.

Solomon, Y. (2007). Not belonging? What makes a functional learner identity in undergraduate mathematics. *Studies in Higher Education*, *32*(1), 79-96.

Spangler, D. A. (1992). Assessing students' beliefs about mathematics. *Mathematics Educator*, *3*(1), 19-23.

Speer, N, Gutmann, T., & Murphy, T. J. (2005). Mathematics teaching assistant preparation and development. *College Teaching*, *53*(2), 75-80.

Speer, N., & Hald, O. (2008). How do mathematicians learn to teach? Implications from research on teachers and teaching for graduate student professional development. In M. Carlson & C. Rasmussen (Eds.), *Making the connection: Research and practice in undergraduate mathematics, MAA Notes*, *Vol. 73* (pp. 305-317). Washington, DC: Mathematical Association of America.

Spencer, A. (1995). On attracting and retaining mathematics majors – Don't cancel the human factor. *Notices of the American Mathematical Society*, *42*(8), 859-862.

Tai, R. H., Sadler, P. M., & Loehr, J. F. (2005). Factors influencing success in introductory college chemistry. *Journal of Research in Science Teaching*, *43*(9), 987-1012.

Tall, D. (1992). The transition to advanced mathematical thinking: Functions, infinity, and proof. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 495-511). New York: Macmillan.

Thompson, P. W., Castillo-Chavez, C., Culbertson, R. J., Flores, A., Greeley, R., Haag, S., Lawon, A. E., Rose, S. D., & Rutowski, R. L. (2007). Failing the future: Problems of persistence and retention in science, technology, engineering, and mathematics (STEM) majors at Arizona State University. Provost Office Report. Tempe, AZ: Arizona State University.

Thompson, A. G., Philipp, R. A., Thompson, P. W., & Boyd, B. A. (1994). Calculational and conceptual orientations in teaching mathematics. In A. Coxford (Ed.), *1994 Yearbook of the NCTM* (pp. 79-92). Reston, VA: National Council of Teachers of Mathematics.

Tinto, V. (1998). Colleges as communities: Taking research on student persistence seriously. *The Review of Higher Education*, *21*(2), 167-177.

Tucker, A. (1995). *Models That Work*: *Case Studies in Effective Undergraduate Mathematics Programs*: *An MAA Project Funded by the National Science Foundation*. *MAA Notes Number 38*. Washington, DC: Mathematical Association of America.

Weko, T., & Chen, X. (2009). Students who study science, technology, engineering, and mathematics (STEM) in postsecondary education. *Stats in Brief*. National Center for Education Statistics, Technical Report NCES 2009-161. Washington DC: U.S. Department of Education.

Wood, M., Luttrell, V., Callen, B., Allen, C., & Deeds, D. G. (2007). Assessing students' value for science and math literacy. In D. Deeds & B. Callen (Eds.), *Proceedings of the National STEM Assessment Conference* (pp. 314-325), October 2006 in Washington, DC, @Drury University.

Yackel, E., & Rasmussen, C. (2002). Beliefs and norms in the mathematics classroom. In G. C. Leder, E. Pehkonen, & G. Törner (Eds.), *Beliefs*: *A hidden variable in mathematics education?* (pp. 313-330). The Netherlands: Kluwer Academic Publishers.

Yimer, A., & Ellerton, N. F. (2006). Cognitive and metacognitive aspects of mathematical problem solving: An emerging model. *Conference Proceedings from MERGA 29* (pp. 575-582). Wahroonga, New South Wales, Australia: Mathematics Education Research Group of Australasia.