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Investigation of factors mediating the effectiveness of authentic projects in the teaching of elementary statistics

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ABSTRACT

Four instructors used authentic research projects and related curriculum materials when teaching elementary statistics in secondary and undergraduate settings. Projects were authentic in that students selected their own variables, defined their own research questions, and collected and analyzed their own data. Classes using these projects were considered treatment groups in the study. Student outcomes measured were content knowledge, perceived usefulness of statistics, and statistics self-efficacy. These outcomes were compared with those of students taught by the same instructors in prior terms without authentic projects (the control groups). Although all three outcomes increased for the treatment group in both settings, simple *t*-tests indicated that these gains were not statistically significant. Variables were identified as potential factors mediating the effects of treatment, and multivariate and univariate models were then used to examine treatment, setting, instructor effects, and student achievement level as variables jointly contributing to these three outcomes. Follow-up analyses suggested that some treatment effects were significant in more restricted contexts (e.g., in certain settings for certain types of students). The models also suggest multiple significant interactions among treatment, setting, individual instructor, and student achievement level, particularly on affective outcomes.

1. Rationale and review of the literature

Increasing recognition has been given over the last decade to the importance of statistical literacy. Statistics education has emerged as its own field, with the study of statistics highly relevant to both mathematics and science, yet distinct from each and providing a critical link between the two (Ben-Zvi & Garfield, 2008). The content of introductory statistics courses has also changed dramatically, both because more sophisticated concepts are covered and because technological tools have helped to shift the focus from the minutiae of statistical computations to the more fundamental meaning of the statistics constructs being used (Kirk, 2007). This shift in focus has played a role in distinguishing statistics education from the broader realm of mathematics education, in which statistics education finds many of its roots. Not only has early statistics education research been built upon or supported by prior work in mathematics education, but statistics education findings have often been presented in the more general context of mathematics education (Zieffler et al., 2008). For this reason, the present study is based on findings in both fields, and these findings are often interconnected.

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Researchers and educators have often suggested improvements to statistics teaching methods, especially those that focus on implementing the scientific method through authentic statistical experiences (Bryce, 2005). The consensus among many researchers is that statistics is taught most effectively with real data (Cobb & Moore, 1997). In particular, there is greater benefit to students' learning when they collect their own data rather than merely working with data already collected by others (Hogg, 1991). This finding parallels the suggestion by many researchers that statistics education should be student-centered (Roseth et al., 2008).

When best-practice pedagogies have been implemented in statistics courses, the results have been positive for achievement and for improved attitudes toward statistics. For instance, students who have participated in all aspects of statistical research – collecting data, performing analyses, and communicating results – have demonstrated benefits in exam performance and in students' evaluations of the course (Smith, 1998). This finding is consistent with research suggesting that apprentice learning, wherein students complete real-world mathematics in authentic settings, develops better conceptual understanding and better knowledge transfer to non-mathematical and non-school settings (Boaler, 1998). Research also suggests that statistics courses based on more constructivist models improve student attitudes toward statistics and that personal relevance is important for successful learning in statistics (Mvududu, 2003). One case study revealed that students learned more from a real-world project than from any other instructional component of a statistics course; the project also fostered an increase in student motivation (Yesilcay, 2000).

The American Statistical Association sponsored a project, the Guidelines for Assessment and Instruction in Statistics Education (GAISE), through which recommendations were developed for best practices in statistics teaching (Franklin & Garfield, 2006). These recommendations included the use of real data and the fostering of active learning. Also among the guidelines offered was the stipulation that "teachers of statistics should rely much less on lecturing, [and] much more on the alternatives such as projects" (Guidelines for Assessment and Instruction in Statistics Education [GAISE], 2005, p. 4). In agreement with this recommendation, Landrum and Smith (2007) suggest as a best practice "that students receive some 'hands-on' experience with a research project. An ideal situation would be to finish a complete project that included data collection and analysis" (p. 52). Nevertheless, although the use of projects has been increasingly recommended as a sound pedagogical practice in statistics, many instructors still do not incorporate projects into their statistics courses.

Research also suggests that instructors in statistics courses would do well to consider variables from the affective domain as an integral – not peripheral – part of the statistical learning process. This suggestion is supported by a meta-analysis of 113 mathematics education studies, which found a significant influence of attitude toward mathematics upon achievement in mathematics (Ma & Kishor, 1997). In a review of the literature surrounding motivation to learn mathematics, Middleton and Spanias (1999) report that careful design of instruction can strongly influence student motivation for mathematics achievement, which increases the likelihood that students will choose to take future mathematics courses. They maintain:

> Students must understand that the mathematics instruction they receive is *useful*, both in immediate terms and in preparing them to learn more in the fields of mathematics and in areas in which mathematics can be applied (e.g., physics, business, etc.). Use of ill-structured, real-life problem situations in which the use of mathematics facilitates uncovering important and interesting knowledge promotes this understanding" (p. 81, emphasis added).

This summation reflects many of the goals of the current research, including the goal to promote students' sense of the usefulness of statistics by experiencing real-world applications of statistics and its methods.

Finally, a wealth of evidence connects students' mathematics achievement with their self-beliefs in mathematics (e.g., Pajares & Schunk, 2001, 2002). Of particular interest in the current study is the construct of students' mathematics self-efficacy, or students' beliefs about their ability to carry out mathematical tasks (Pajares & Miller, 1994). Findings suggest that self-efficacy beliefs play a role in people's career choices, especially in mathematics and science related fields (e.g., Hackett, 1995; Zeldin & Pajares, 2000). Further, research suggests that mathematics self-efficacy may be as reliable as mental ability in predicting mathematics performance (Pajares & Kranzler, 1995). Well-established social-cognitive theory maintains that authentic mastery experiences exert the strongest influence on the development of one's self-efficacy beliefs (Bandura, 1997). Thus, one would expect authentic research experiences encountered in the study of statistics to have a positive impact on students' statistical self-beliefs, thereby also fostering higher achievement in statistics.

2. Purpose of the study

The present study was designed to examine the contribution of authentic projects to student outcomes in statistics courses. Projects used were student-defined and authentic in that students selected their own variables, crafted their own research questions, and collected and analyzed their own data sets. Students usually conducted these projects in groups of three or four. The student outcomes of interest were content knowledge, perceived usefulness of statistics, and self-efficacy for statistical tasks. Further, because the study was conducted with multiple instructors and a wide variety of students, the researchers aimed to examine potential variations in these outcomes associated with different instructors' implementations of the course and different students' overall achievement levels. Thus, the research questions guiding the present analysis were as follows: