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Authentic Discovery Projects in Statistics

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Abstract

We report the activities and findings of a 3-year project, ―Authentic, Career-Specific, Discovery Learning Projects in Introductory Statistics,‖ funded by the National Science Foundation. The project scope includes: 1) development of teaching materials for using discovery learning projects to teach statistics; 2) training secondary teachers to use the materials developed; 3) evaluation of student outcomes, in both content knowledge and attitudes toward statistics; and 4) extending and refining teacher training.

With input from an interdisciplinary team of instructors, materials were developed to assist the teacher in facilitating collaborative discovery projects using linear regression techniques and comparison techniques with appropriate t-tests. Web-based student and instructor guides authored to facilitate these projects are now available online.

Five pilot instructors used the materials in their classes. Data collected from the instructors included qualitative data about teacher experiences and observations while employing the materials, as well as quantitative data about student performance and attitudes. These findings were used to inform a one-day teacher training workshop on effective use of statistics projects with the materials developed.

Preliminary data analysis suggests that students in classes using the discovery projects achieve higher content knowledge and stronger perceived usefulness of statistics than do their traditional class counterparts.

Authentic Discovery Projects in Statistics

Introduction

The teaching of statistics has received increasing attention over the last two decades in mathematics education research. 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). When best-practice pedagogies have been implemented in statistics courses, the results have been positive for achievement and for improved attitudes toward statistics. Research suggests 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). Findings also suggest 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).

These findings in the literature prompted a curriculum development effort supported by a grant from the National Science Foundation. The grant, titled –*Authentic, Career-Specific Discovery Learning Projects in Introductory Statistics,*‖ has funded development of instructional materials, creation of instruments to measure the effectiveness of these materials, ongoing quantitative and qualitative research about the success of these teaching methods, and instructor training workshops to share materials and findings. The instructional materials were designed to facilitate student projects as a learning tool. We will describe these projects and their use in the classroom, the materials developed to support the projects, and the training of instructors to use these materials to facilitate the projects. We will then describe pilot instructors' experiences and observations as they implemented the teaching methods and materials that were developed. Finally, we will share preliminary findings regarding the impact of these teaching methods on student comprehension and attitudes.

Research Timeline

Although data collection and analysis are ongoing, most activities of the study are complete at the time of this writing. A second phase is planned (pending funding) to extend the teaching methods to a greater variety of settings and to train instructors more effectively. The timeline for the first phase of the study is shown in Table 1.

Summer 2007	• Development of instruments to measure student outcomes
Fall 2007 – Spring 2008	• Exploratory study on effect of these teaching methods • Development of interdisciplinary constructs • Development of web-based and printed teaching materials • Validation and revision of instruments • Selection of five pilot instructors • Control group data collection from all pilot instructors

Summer 2008	• Training of pilot instructors
Fall 2008 – Spring 2009	• Four pilot instructors complete experimental sections using methods and materials developed • Treatment group data collection
Spring 2009	• Training workshops conducted for statistics instructors
Fall 2009	• Experimental section for fifth pilot instructor
Ongoing	• Data analysis and dissemination

Table 1. Research Timeline

Curriculum Development and Student Projects

The curriculum development effort was directed by three goals:

1) Increase students' knowledge and comprehension of statistics
2) Increase students' perceptions of the usefulness of statistics
3) Increase students' self-beliefs about their ability to use statistics

The instructional materials that were developed assist the teacher in facilitating two collaborative discovery projects for use with elementary statistics content taught in a secondary or undergraduate class setting. The first project uses linear regression techniques, and the second uses comparison techniques with appropriate t-tests. Both projects simulate the real-world effort of scientists to hypothesize, collect and analyze data, and draw conclusions. Students select their own research topic, craft their own research questions, design surveys, collect their own data, apply the appropriate statistical methods to analyze the data, and report their findings in writing. Students also share their research with their peers in formal class presentations.

Interdisciplinary Research Constructs

As part of the curriculum development, an interdisciplinary team of instructors met to develop worthwhile research constructs for students. Team members wrote clear definitions of research constructs and provided instruments or instructions for measuring the construct quantitatively. Students were allowed to use these constructs and instruments if they chose; they were also allowed to create their own. However, the research constructs developed by the interdisciplinary team gave students a springboard of ideas from which to start, as well as a good set of examples of how constructs may be defined operationally, measured, and quantified.

Among the disciplines that were represented on the team were psychology, sociology, criminal justice, ecology, physical therapy, nursing, and education. In the field of psychology, suggested research constructs included perceived stress, perfectionism, anxiety, attention deficit disorder, and obsessive compulsive disorder. Accompanying each of these constructs was a brief screening instrument that could be administered and scored easily for purposes of quantitative research. In the field of sociology, suggested constructs included attitudes toward various social issues (e.g., corporal punishment, homosexuality, racism), all of which could be quantified on a Likert type scale. In the field of criminal justice, suggested research constructs included attitudes toward various criminal justice issues (e.g., gun control, death penalty, legalization of marijuana, pornography), all of which, again could be measured on a Likert scale. These examples are just a few of the research constructs that were assembled by the interdisciplinary team. The constructs proved interesting and engaging to students as they worked to select research topics for their own projects.

Materials Developed

Online student and instructor guides were developed to facilitate these projects. These materials are currently available online at http://radar.ngcsu.edu/~rsinn/nsf.

The student guide includes three sections: 1) an overall project guide, which describes each project and the steps needed to complete it; 2) a technology guide, which directs students to use the features of Microsoft Excel to implement the project; and 3) a variables and constructs guide, which includes research ideas assembled by the interdisciplinary team, as well as guidelines on creating a viable research construct and a corresponding data collection instrument (e.g., a well crafted, unbiased survey).

The instructor guide includes four components: 1) project overviews with suggested timeline, project implementation details, and best practices; 2) links to appropriate student materials that correspond with different phases of the project; 3) student assignment sheets; and 4) a variety of evaluation rubrics that can be used to score the projects.

Teacher Training

Five pilot instructors (one secondary and four college) were selected to test and refine the materials before they were more broadly disseminated. These instructors were given preliminary training through a series of meetings, one-on-one work sessions, and mentoring by the project researchers and authors of the materials.

After the pilot phase, a one-day workshop for statistics instructors, entitled the ―Make It Real‖ Statistics Instruction Workshop, was hosted to disseminate the materials developed and to train teachers on effective use of these materials. All participants were high school teachers of Advanced Placement (AP) Statistics. Pilot instructors helped to deliver the training. Sessions conducted during the workshop included:

I – Designing Quality Variables and Constructs
II – Hands-on Survey Design Session
III – Project Organization, Phases, Assessment, and Rubrics
IV – Best Practices and Avoiding Pitfalls (Panel Discussion)
V – Technology Tools and Hands-On Data Analysis
VI – Team Presentations (Participants share their work product)
VII – Instructor Observations from First Implementations

Within 2 weeks of the workshop, a series of follow-up training sessions were conducted online to allow participants to discuss the material further, including details of their own plans for implementation. Instructors who so desired were eligible to earn one PLU (Professional Learning Unit) credit by participating in the workshop.

Instructor Experiences and Observations

As pilot instructors implemented these materials and teaching methods, they leveraged their own experiences to assemble a set of guidelines to help other instructors use such projects effectively. These guidelines were shared during the teacher training workshops. Some highlights of these guidelines address structuring and scaffolding the project, setting student expectations, and resolving potential issues with teams.

Structuring the Project

Projects are more successful when intermediate goals are set and students are required to submit defined deliverables along the way. For instance, students completing the regression project must first submit a list of several potential research ideas with specific variables, from which they will eventually select their final topic. After the topic is selected and approved, students must create a survey or other data collection instrument and submit this instrument to the instructor. The instructor often needs to help students refine the survey to set the stage for a more successful project. Once the survey is sufficiently refined and approved, students begin the data collection process, recording their data and beginning data analysis under some supervision. Sometimes an instructor will devote a day of class time for teams to engage in hands-on data analysis when the instructor is nearby for guidance. Finally, the team writes a report describing the research and the findings. This phase of the project is most successful if the students are given a template or outline of what should be included in the report. Some instructors also provide work samples from previous semesters for students to use as examples. By structuring the projects into these phases, instructors ensure that students stay on course and have a more successful experience overall.

Setting Student Expectations

Most instructors who have implemented these projects in the classroom will agree on the need to set student expectations early. Students often underestimate the effort and organization required to make their project a success. Many students also do not have a clear idea of exactly what they will do to analyze their data once the data have been collected; this part of the project is often a bit fuzzy in their minds (which is precisely why they need to do it for themselves.)

As one team of students elaborated on a post-project reflection:

> ‒The main thing that we have learned is that statistics take time. They cannot be conjured up by a few formulas in a few minutes. The time and effort that is put into a small research project such as this is significant. On a large scale, one can quickly understand the kind of commitment of money and time that is required just to obtain reasonable data.‖

Students will be much more successful if they know at the outset what to expect in terms of their own commitment of time and effort.

It is also a good idea to set student expectations regarding the findings of their data analyses. Students often expect to find strong correlations or highly significant statistical results, and upon obtaining some other outcome, they feel they must have done something wrong. In fact, researchers often obtain non-significant results; it is the appropriate interpretation of those results that is important. As another student noted:

> ―While our results did not meet our initial expectations, this is not an utter disappointment. Before this project, statistics looked simple enough for anyone to sit down and do, but now it is evident that it requires more creativity and critical thinking than initially expected. Overall, it was an edifying experience.‖

If students are prepared for the possibility of getting results they might find disappointing, they seem more likely to believe the project was worthwhile.

Resolving Team Issues

Some students dislike team projects. Many instructors allowed students the option to complete a modified version of at least one of the two projects by themselves. Even among students who do not outwardly object to team projects, poor team dynamics can lead to a great deal of frustration. Some of this frustration can be avoided by establishing explicit guidelines for communication and cooperation among team members. Some instructors also define each team member's role and responsibilities to hold individual team members accountable for the final product.

Instruments

Three instruments were developed to measure the impact of these materials and teaching methods. These were a content knowledge test, a survey measuring the student's perceived usefulness of statistics, and a survey measuring the student's self-beliefs in their ability to use and understand statistics.

Content Knowledge Test

The content knowledge test initially contained 21 multiple choice items designed to measure student content knowledge in three areas: linear regression, t-test design and usage, and statistical inference in the context of t-tests. These areas corresponded to the strands of statistics directly addressed by the student projects.

During instrument validation, three of the content items were removed. This modification strengthened the reliability of the instrument and reduced data collection time for subsequent groups. The remaining items loaded onto the three factors that were intended for the content test (linear regression, t-test usage, and t-test inference). For the revised 18-item instrument, a reliability score of 0.67 was obtained through KR-20 item analysis for homogeneity. Given the three distinct groups of questions in the instrument, this score was deemed acceptable.

Perceived Usefulness Survey

The perceived usefulness survey was designed to measure students' perceptions of the usefulness of statistics, including the extent to which they expect to use statistics in their subsequent lives and careers. The survey contained 12 Likert-style items, each scored on a 6-point scale with descriptions ranging from ―strongly disagree‖ to ―strongly agree‖. Five of the items were reverse scored. Cronbach's alpha coefficient for this instrument was 0.93, suggesting a high degree of internal reliability. Because all items related to the perceived usefulness of statistics in general, no sub-scales were identified for the survey.

Student Self-Beliefs Survey

The student self-beliefs survey was designed to measure students' beliefs about their ability to use and understand statistics. Similar to the content knowledge test, this instrument contained three sub-scales; these sub-scales addressed self-beliefs with respect to concepts in: a) general statistics, b) linear regression, and c) the use of t-tests. The survey contained 15 Likert-style items, each scored on a 6-point scale. Cronbach's alpha coefficient for this instrument was 0.95, suggesting a high degree of internal reliability.

Preliminary Findings

This study was characterized by a relatively small expected effect size, combined with a high degree of variability among students. Because these factors resulted in tests with relatively low statistical power, the researchers found a significance level of $\alpha = .1$ to be appropriate. Findings are described for the initial exploratory study and for data collected during the pilot of the materials with the pilot instructors mentioned above.

Exploratory Study

The initial exploratory study was conducted in conjunction with the development of these materials, using the discovery project-based learning techniques promoted by these materials. The exploratory study consisted of 10 sections of elementary statistics at the same college, of which 6 sections comprised a control group (with traditional instruction) and the other 4 sections comprised an experimental group (using the discovery projects as learning tools). All sections were for the same course and were taught using the same text. There is also no reason to believe that the students registered for these ten sections differed in any way that would confound the results. At the end of the course, willing students in all sections completed the 2 surveys and the content knowledge test. From the control group, 164 students out of 192 (85%) participated in the assessment; from the experimental group, 113 students out of 128 (88%) participated. The results from t-tests conducted in the exploratory study are given in Table 2.

Instrument	Control		Treatment		t	p	Cohen's effect size d
	Mean	SD	Mean	SD			
Content Knowledge	8.8700	3.2400	10.8200	3.3650	4.825	.0000	0.59
Perceived Usefulness	4.2398	1.0113	4.5154	0.8570	2.442	.0076	0.30
Self-Beliefs	4.6997	0.8755	4.8164	0.6411	1.259	.1047	0.15

Table 2. Means, standard deviations, and t-test results from exploratory study

The treatment group outperformed the control group on the content knowledge test; the difference between the two groups was significant ($p < .0001$), suggesting that students in classes using the discovery projects had a stronger grasp of the content at the end of the course than did their counterparts in the control group classes.

On the perceived usefulness survey, participants in the treatment group scored significantly higher than did participants in the control group ($p < .01$), suggesting that students in classes using the discovery projects perceived statistics to have more utility than did students in the other classes.

Although the treatment group scored higher on average than the control group on the statistics self-beliefs survey, the difference between the two groups was not significant. A possible confounding factor is that students who have conducted statistics projects for themselves gain a new respect for the complexities of statistics that may not exist in classes where students do not conduct projects.

Pilot of Developed Materials

The pilot instructors first used the fully developed materials in Fall 2008. To account for learning curve effects, schedule differences, and discrepancies between secondary and college teaching schedules, some pilot instructors completed their treatment groups earlier than others, as shown in the timeline given previously in Table 1. Therefore, results are only reported here for instructors who had completed their pilot sections at the time of this writing.

In a quasi-experimental design, each pilot instructor collected data from his/her own sections of a traditionally taught course during the semester or academic year prior to implementing the materials (control group). Then each pilot instructor taught the course using the materials for at least two semesters (experimental group). Pilot instructors' control and experimental results were compared using the data collected from the three instruments as described. Of the five pilot instructors, one is still conducting pilot sections and collecting treatment group data. Results are reported only for the remaining four pilot instructors. However, the data were analyzed not only by each instrument, but also for each sub-scale of the content knowledge and self-belief instruments. This analysis helped to illuminate the impact of the projects.

Because data collection and analyses are ongoing, results are incomplete. At this stage of data analysis, results have only been examined by individual instructors; therefore, the samples are relatively small, restricting the power of the statistical comparisons. When all data are collected, whole group comparisons are expected to yield more significance. As the data illustrate, results also varied by instructor. Results for each instrument and sub-scale by instructor are given in Table 3.

The overall mean content knowledge score increased for each instructor, though in most cases, the observed increases were too small to be significant. Two instructors also saw a slight decline in content knowledge for t-test inference concepts (also nonsignificant). However, one instructor achieved significant gains in content knowledge for linear regression concepts, for concepts relating to the usage of t-tests, and for overall statistics content knowledge.

All four instructors saw a gain in overall student self-confidence in statistics, though the gain was significant for only one instructor. Average student self-confidence in general statistics concepts increased in the experimental group for all four instructors, and the difference was significant for three of them. Two instructors also achieved significant gains in student self-confidence for linear regression concepts. Although student self-confidence in t-test concepts increased for all four instructors, none of the gains were large enough to be significant. The perceived usefulness score was higher for three instructors' experimental groups than for their control groups, though the difference was significant for only one of the pilot instructors.

Scale	**Instructor**	**Control**			**Treatment**			***t***
		N	**Mean**	**SD**	**N**	**Mean**	**SD**	
Content Knowledge – Entire Instrument	**A**	41	7.17	2.365	24	8.50	3.093	1.817**
	B	20	8.45	2.762	28	8.54	2.502	0.110
	C	33	5.33	1.708	44	5.93	2.546	1.233
	D	43	6.86	2.178	76	7.05	3.253	0.385
Content Knowledge – Linear Regression	**A**	41	2.12	1.029	24	2.58	1.472	1.354*
	B	20	2.10	1.119	28	2.29	1.384	0.513
	C	33	1.24	1.032	44	1.50	0.928	1.132
	D	43	2.42	1.180	76	2.45	1.628	0.111
Content Knowledge –	**A**	41	3.54	1.398	24	4.33	1.949	1.756*
	B	2	4.50	1.638	2	4.93	1.464	0.934

Design/Usage of t-Tests		0			8			
	C	33	2.91	1.284	44	3.05	1.656	0.407
	D	43	2.58	1.314	76	2.88	1.657	1.087
Content Knowledge – Inference on t-Tests	**A**	41	1.51	0.925	24	1.58	1.018	0.281
	B	20	1.85	1.137	28	1.32	0.819	-1.776
	C	33	1.18	0.917	44	1.39	0.920	0.967
	D	43	1.86	0.915	76	1.72	0.974	-0.765
Perceived Usefulness – Entire Instrument	**A**	41	50.59	10.361	24	54.88	9.014	1.751**
	B	20	49.35	9.016	28	46.75	12.183	-0.850
	C	32	51.41	9.339	44	53.30	10.064	0.843
	D	43	50.23	10.963	76	50.92	11.722	0.321
Self-Beliefs – Entire Instrument	**A**	32	62.97	15.073	24	66.38	9.221	1.044
	B	20	55.95	20.289	28	63.71	12.304	1.523*
	C	33	63.21	9.512	44	65.25	9.022	0.951
	D	43	56.23	12.569	76	59.39	14.398	1.250
Self-Beliefs – General Statistics Concepts	**A**	32	17.94	4.272	24	19.33	3.116	1.414*
	B	20	16.45	6.057	28	18.64	3.540	1.452*
	C	33	17.39	3.316	44	18.95	2.853	2.168**
	D	43	16.26	4.042				
Self-Beliefs		3	21.5					

A

2
0
5.2
92
2
1
8
.
7

7 16.8
6 0
4.505
0.680

2 22.7
4 1
3.520
1.024

2 23.0

– Linear Regression

B	0	5	6.995	8	4	4.393	2.420**
C	33	22.30	3.917	44	22.09	3.771	-0.239
D	4	19.3	4.825	7	21.6	5.346	

		3	5		6	6		2.411**
Self-Beliefs – t-Test Concepts	**A**	32	23.53	6.091	24	24.33	3.964	0.596
	B	220	20.75	7.684	228	22.04	6.009	0.624
	C	33	23.52	3.598	44	24.20	3.638	0.828
	D	43	20.63	5.451	76	20.93	5.594	0.292

Table 3. Means, standard deviations, and t-test results for 4 pilot instructors
$*p < .10$, $**p < .05$

Summary

The method of using discovery projects to foster deeper understanding of statistics has shown promise. Students taught with this method have shown better content knowledge, greater self-confidence, and greater respect for the usefulness of statistics than have their counterparts in traditionally taught statistics courses.

As with most teaching techniques, the method in which discovery projects are implemented will have a direct impact on the success of the projects. Instructors find it helpful to structure the project with intermediate goals, to set student expectations early and clearly, and to establish clear guidelines for working effectively as a team.

Revisions and enhancements are planned for the instructional materials developed as part of this study. Instructor training workshops were well received by secondary classroom teachers. A second phase of this research project is planned, in which online teacher training modules will be developed and tested. The discovery-based statistics projects and the associated instructional materials and teaching methods should prove increasingly beneficial as teachers gain training and experience with them.

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