The Mathematics Educator
2003, Vol. 7, No.2, 25 - 36

Using a Cognitive Taxonomy to Enhance Prospective Teachers' Mathematical Website Constructions

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Abstract: *A prior study of prospective teachers' mathematical website constructions demonstrated a trend for these prospective teachers to concentrate more on the design of the website than on its content. The present study used a taxonomy (1) to prepare guidelines for completing the construction project, and (2) to assess the cognitive level of the mathematical examples and exercises that the prospective teachers included on their websites. When compared with the constructions from the prior study, the teacher candidates in the current study showed a tendency to incorporate more examples and exercises at the procedural applications level of cognition.*

Introduction

The rapid development of information and communication technologies during the past few decades has led to many creative innovations in education. Particularly, the development of internet technology has required new expertise and an increased use of computers in instruction and learning. As a result, the Internet provides yet another avenue for teachers to enhance and develop instructional activities (Tsai, 2001).

As early as the 1950s, discussions of the future of school systems emphasized the opportunities provided by information and communication technology. Now in the new millennium, this technology continues to play a critical role in the design of school curricula. According to Sinko and Lehtinen (1999), "Education, learning and technology emerge in one way or another in all national and international documents whose attempts have been to outline the road to the information society" (p. 13).

A review of the literature dealing with technology in education revealed many reports of the profound changes inherent to the rapid construction of informational societies. For example, Means (2001) and Jervis and Steeg (1999) both reported evidence of the importance of internet technology as a valuable and necessary resource for pre-service teacher education. Charland (1998) particularly noted that prospective teachers consider the Internet as a valuable asset in their future teaching assignments.

Earlier, Cochran-Smith (1991) argued that designing educational experiences that enable prospective teachers to confront and reflect on their beliefs about teaching could lead to a deeper understanding of pedagogy. Now, teacher educators have taken this notion a step further and explored the potential of emerging technologies to support teachers in reflecting on their pedagogical belief systems and teaching experiences (Barnett, Keating, Harwood, & Saam, 2002).

Other research studies (Devlin-Scherer & Daly, 2001; Thomas, Clift, & Sugimoto, 1996) have explored how electronic networks support prospective teachers in becoming reflective practitioners by increasing teachers' knowledge of reform-oriented instructional practices. Still other studies have shown that electronic communication and networking tools can support collaborative discussions that result in pre-service teachers being able to articulate and reflect upon their beliefs and their evolving classroom practice. This articulation leads, in turn, to the development of a community of discourse about how to improve and reform teaching practices (Dutt-Donner & Powers, 2000; Schlagal, Trathen, & Blanton, 1996). Additional avenues such as tele-apprenticeships (Levin & Waugh, 1998; Thurston, Evangeline, & Levin, 1997) and Weblogs (Oravec, 2000) also show great potential in encouraging reflective communities of discourse.

In another study, Foote (1998) investigated the effects of student-generated, higher-order questions on learning. The students' questions differed in their levels of cognitive demand and these differences were consistent with constructivist perspectives of pre-service teachers' development. In a similar vein, Rivard (1994) found that creating cognitively advanced mathematical examples and exercises was a difficult but important skill that facilitated the development of advanced capacities for critical thought. The present article reports on a study that built on the work by Foote (1998) and Rivard (1994) within the context of the technological advances previously described and the widely known cognitive taxonomy of Benjamin Bloom.

The cognitive taxonomy used in the present study was *The Taxonomy of Educational Objectives: The Classification of Educational Goals* (Bloom, Englehart, Hill, Furst, & Krathwohl, 1956). This taxonomy provides carefully developed definitions of each of six major categories in the cognitive domain: knowledge, comprehension, application, analysis, synthesis, and evaluation. With the exception of the analysis level, each of these categories is broken into subcategories, and categories are ordered from simple to complex as well as from concrete to abstract. That is, the taxonomy represents a cumulative hierarchy with the mastery of each simpler category being considered a prerequisite to the mastery of the next complex one.

Specifically, in the study reported here, future teachers integrated a cognitive taxonomy into their development of mathematical examples and exercises for their own classroom websites. The comprehension cognitive level was adapted directly from Bloom's Taxonomy (Bloom, et. al., 1956), but the applications level was refined into three separate levels to represent better the complex nature of the examples and exercises that the future teachers incorporated into their websites. The resulting cognitive taxonomy thus included four levels: comprehension, procedural applications, conceptual applications, and problem-solving applications. The structure of the cognitive taxonomy with specific benchmarks and examples is listed in Table 1.

Table 1
Taxonomy Used in the Study

Comprehension: Requires the ability to understand and interpret facts and principles.
Example: Given a box-and-whisker plot, the student will be able to identify the lower and upper quartiles by observing the values from the plot.
Procedural Applications: Requires the correct use of methods or procedures.
Example: Given a box-and-whisker plot, the student will be able to find the minimum and maximum values of outliers.
Example: Given data, the student will be able to find the median.
Conceptual Applications: Requires the application of concepts or principles to non-routine situations.
Example: For the mean of 17, 10, 25, 28, and x to be 17, what is x?
Example: A student's median grade from 4 test scores is 82.5. If three of the test scores are 80, 95, and 85, what is the fourth score?
Problem-Solving Applications: Requires the application of methods, procedures, concepts, and principles to practical situations.
Example: Ann needs a mean of 90% for a grade of "A". If her final exam score is weighted twice her midterm exam score and she received 85% on the midterm, what must she score on the final exam to earn an "A"?

This taxonomy was used to show the breadth of the prospective teachers' questions and their utilization of higher order thinking skills across the spectrum of the taxonomy's categories. Higher-order questions were considered to be ones that required an increased level of cognitive understanding to respond to a question. That is, any question that required a student to think in an in-depth manner was considered to be at a higher level than a question in which a student simply relied on factual knowledge. For example, asking a student to recall the Pythagorean Theorem from memory would be classified as an item in the knowledge category. However, asking a student to solve a trigonometry problem in which the Pythagorean Theorem was utilized to obtain a numerical solution was an example of a higher-order thinking question.

In an earlier study (Carter & Ferrucci, 2000), prospective mathematics teachers were required to design their own websites dealing with statistical topics. An evaluation of these sites revealed that the pre-service teachers were more apt to concentrate on the design and the layout of their sites and less on mathematical content. In response to these findings, a mathematical website construction project was developed as part of the curriculum in a course for prospective mathematics teachers. This article reports on the project based on the experiences of two separate classes of prospective primary school teachers - 38 subjects from the previous study and 43 subjects from the current project. The prospective teachers were in their second year of study in a four-year program at a liberal arts college in the northeastern United States. Most of the future teachers were females in their early twenties, and all had completed two prerequisite mathematics courses in number systems and their applications.

Methodology

Four 70-minute computer sessions that focused exclusively on the technical creation of websites were incorporated into a required mathematics content course for the prospective teachers. The class sessions were designed to instruct the future teachers on how to construct, modify and upload websites as well as how to edit text and insert images, backgrounds, and links within web pages. Class sessions were held in a computer classroom and each pre-service teacher worked individually at a computer. Both classes of prospective teachers participated in the instructional computer activities.

Prior to the first computer session, each future teacher received an information sheet about URLs, an account number and a password. The purpose of the computer sessions was not only to instruct the future teachers on the use of the software but to help provide information on how to work with the Internet as well. Specific computer activities dealt with aspects helpful in creating websites: (1) searching the Internet to locate backgrounds and other mathematical images, (2) modifying text and backgrounds, (3) creating tables within a web page, and (4) creating links to other pages within a website and to other locations on the Internet.

At the completion of the fourth class session, the prospective teachers were given a description of the website project with an accompanying set of taxonomy-based guidelines. For the project, these future teachers were asked to create a website that could be used in their future classrooms. They were instructed to begin with an opening page that contained specific information such as their name as well as the school's name and grade level they hoped to teach. Other web pages were to include a list of upcoming classroom activities as well as a page of internet resource links. In addition, the website needed to contain web pages that provided instruction on the statistical concepts of mean, median, and inter-quartile range with specific examples, exercises and solutions. The future teachers were expected to create their own background, text, graphics, and links within the website they constructed. They were told that they were allowed to base the material in their website on information from school mathematics textbooks, but that the work on the project must be individual efforts. In addition, the prospective teachers were informed that it should take 10-15 hours to complete the project. To aid in the administration of the project, the future teachers were given already-uploaded, blank web pages and were instructed to replace them with their own pages about the mean, median, and inter-quartile range.

The guidelines given to the prospective teachers pertaining to the construction of their website specifically stated that they should include ample examples and exercises that involved problem solving and other higher-level cognitive processes. Prior to beginning the project, the future teachers participated in a class discussion of the guidelines that included the examples and descriptions from the taxonomy shown in Table 1. Particular attention in the discussion was given to the cognitive taxonomy and the development of higher-order tasks. During the discussion the prospective teachers practiced writing mathematical exercises that required the use of problem solving and other higher-order cognitive skills to solve the exercises.

Data Analysis

At the completion of the website projects, the mathematical content of each website was analyzed. The analysis centered on the cognitive levels from the taxonomy (Table 1) with respect to the future teachers' examples and exercises about the mean, median, and inter-quartile range.

A content analysis of the cognitive levels in the examples and exercises used by both classes (groups) in the construction of their websites was conducted. The two groups used as the basis for this report consisted of 38 pre-service teachers who used the original, unmodified guidelines (Carter & Ferrucci, 2000) and 43 pre-service teachers who were given the revised, taxonomy-based guidelines. Hereafter, the two groups will be referred to as "Group 1" and "Group 2". Every effort was made to ensure that the instructions and accompanying materials about the website projects were comparable for the two groups. As previously noted, both Group 1 and Group 2 students had opportunities during a class discussion period to practice writing exercises involving higher-level cognitive processes. The only difference between the two groups was that the guidelines for Group 2 were rewritten and included information that emphasized the need to prepare examples and exercises at higher cognitive levels on the website project.

A panel of two university-level mathematics educators and two graduate students were enlisted to analyze the cognitive levels of the examples and exercises used within the websites by the two groups. The panel reviewed and classified the items according to the taxonomy that was developed for the study. There were no unresolved differences among panel members with respect to cognitive-level classifications.

Results and Discussion

Figure 1 displays the average number of examples and exercises pertaining to the statistical topics of the mean, median and inter-quartile range that were created in the web sites of the prospective teachers from the two groups. An examination of the data indicates that the average number of examples and exercises on the mean, median, and inter-quartile range increased from Group 1 to Group 2. The number of examples and exercises for Group 1 was about three-fourths that of Group 2 for each of the three categories. These results indicate that the incorporation of the revised guidelines may have had a positive effect on the number of examples and exercises pertaining to the three statistical concepts.

The average number of examples and exercises pertaining to the mean by cognitive levels is exhibited in Figure 2. The four levels of cognition labeled Mean1, Mean2, Mean3 and Mean4 are the cognitive levels of comprehension, procedural applications, conceptual applications and problem-solving applications, respectively. In all cases except the Mean1 (comprehension) level, the average number of examples and exercises increased from Group 1 to Group 2. With respect to the data pertaining to the mean, there were no examples or exercises from either Group 1 or Group 2 at the comprehension level. This may be attributed to the fact that mere inspection of a graph or data can rarely identify

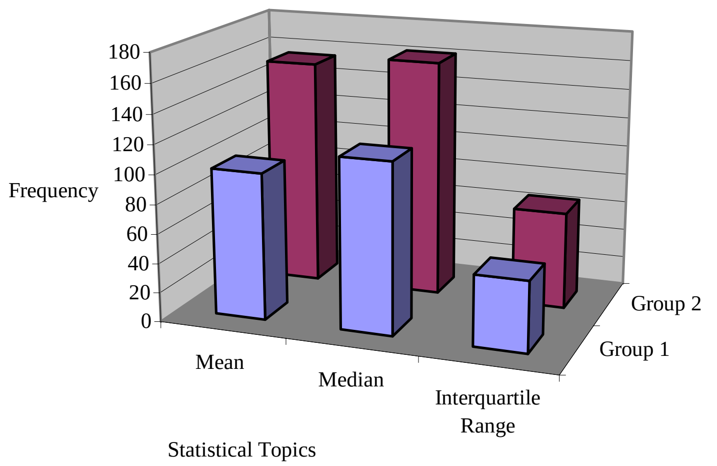

Figure 1. Number of Examples and Exercises on the Mean, Median, and Inter-Quartile Range Created by Groups 1 and 2

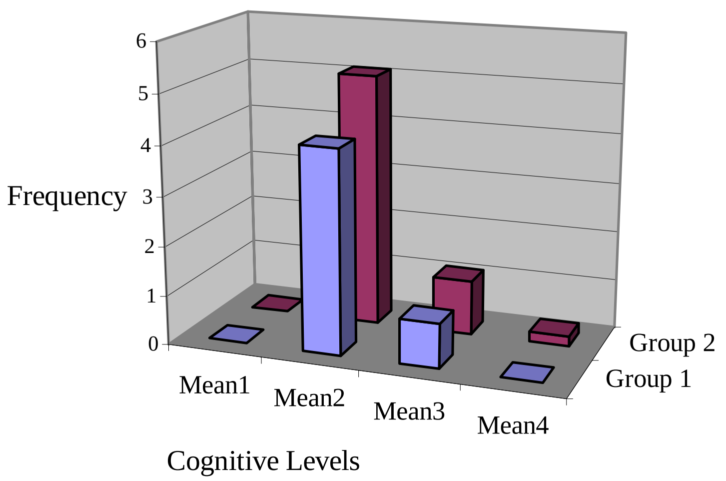

Figure 2. Number of Examples and Exercises on the Mean Created by Groups 1 and 2

the mean. However, there was a relatively small increase at the Mean3 (conceptual applications) level and another slight increase at the Mean4 (problem-solving applications) level. "If the mean score on a set of 20 scores is 75, what is the sum of the scores?" was an example of an item coded as Mean3. "If Jo's mean score was 85 and she had scores of 76 and 84 as well as two others that were identical, what were the two scores?" was an example of an item coded as Mean4.

Figure 3 displays the distributions of websites examples and exercises on the median by cognitive level for Group 1 and Group 2. The Median2 (procedural applications) level and the Median3 (conceptual applications) level show an increase in the average number of examples and exercises created by Group 2. However, the average number of examples and exercises at the comprehension and problem-solving applications levels was negligible for both groups. As was the case for the mean, the increase in the average number of examples and exercises at the procedural applications level was more pronounced. One prospective teacher included the following exercise within her website: "For the median of 17, 10, 25, 28, 5 and x to be 19, what is x?" This exercise was coded as Median3.

The distribution of examples and exercises pertaining to the inter-quartile range (denoted as IQR) by cognitive levels for the two groups is illustrated in Figure 4. For each of the three levels: IQR1 (comprehension), IQR2 (procedural applications), and IQR3 (conceptual applications), the average number of examples and exercises was greater for Group 2 with the largest increase occurring in the procedural applications cognitive level. An example of an exercise that was classified as IQR3 was one in which, given a data set, a student was asked to calculate the lower cutoff point for outliers. Essentially no examples and exercises were detected at the problem-solving applications level for either Group 1 or Group 2.

An examination of Figures 2, 3, and 4 indicate that there was at most a small difference between the average number of examples and exercises at the conceptual applications and problem-solving applications levels for all three statistical concepts. This result indicates that further research in this area could be undertaken to increase the number of higher-level cognitive examples and exercises included by future teachers in their websites.

In summary, the major increases in the average number of examples and exercises prepared by Groups 1 and 2 occurred at the procedural applications level for all three of the assigned statistical concepts. Notably, the average number of

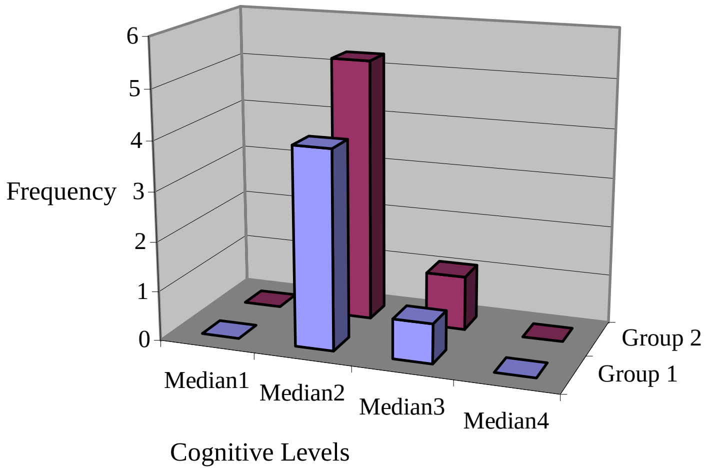

Figure 3. Number of Examples and Exercises on the Median
Created by Groups 1 and 2

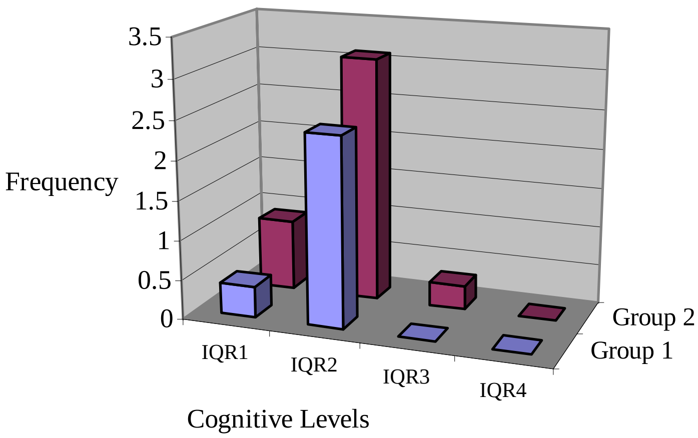

Figure 4. Number of Examples and Exercises on the Inter Quartile Range
Created by Groups 1 and 2

examples and exercises at the problem-solving applications level was barely discernable for each of the assigned statistics. Thus future research should aim to increase the number of higher-level cognitive examples and exercises in future teachers' website construction projects.

Concluding Remarks

Based on the findings of this study, there is evidence that website constructions can be an appropriate and reasonable part of the mathematics curriculum for prospective primary school teachers. An impetus for this study was an earlier finding that prospective teachers tend to concentrate more on the design of their websites and less on its mathematical content. Based on the findings of the current study, the employment of taxonomy-based guidelines appears to have increased the average number of examples and exercises at the procedural applications level for each of the three statistical concepts. The revised guidelines may have motivated the future teachers to focus less on design features and more on the mathematical applications.

According to Cyrus and Flora (2000), Heid (2000), and Clements and Nastasi (1993), ensuring that mathematics learning is not compromised whenever technology is employed is an important consideration in mathematics education. The use of the taxonomy seems to have somewhat increased the cognitive complexity of prospective teachers' internet constructions. Consequently, there is some evidence that the taxonomy ensured that mathematics learning was uncompromised or even enhanced.

Internet technology will continue to change the way educators teach and students learn. There is increasing evidence, including some from this study, that information technology on the web can be an effective tool in promoting student motivation and learning in mathematics. Moreover, prospective teachers are apt to be utilizing learning approaches that are significantly influenced by classroom experiences with both cognitive taxonomies and Internet technologies.

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