A FOUR-PILLAR DESIGN TO IMPROVE THE QUALITY OF STATISTICAL REASONING AND THINKING IN HIGHER EDUCATION

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Abstract

In this paper an investigation of the connections and tensions among the four pillars of, content, pedagogy, technology, and assessment is presented from a standpoint of building a structure that is conducive to developing quantitative reasoning and analysis skills among university students, and, possibly, faculty members.

Purpose of Study

Traditional curricular materials and pedagogical strategies have not been effective in developing quantitative reasoning abilities of students. Much of the changes proposed by several research studies and various reform movements over the past decade have supported efforts to transform teaching practices to include an emphasis on students' development of conceptual understanding rather than a focus on mechanical calculations (Chance & Garfield, 2002).

Despite some very recent research studies investigating conceptual understanding of various topics among college students in statistics courses, there are still several unanswered questions regarding how we, as educators, can help students develop quantitative analysis skills at the post-secondary level (Budé, 2007; Slauson, 2008). The purpose of this paper is to propose a variety of learning experiences and environments to support students in developing quantitative analysis and reasoning skills.

Background and Theoretical Framework

The guiding theory for statistics education reform is based on a learning theory arising from earlier ideas and writings of Jean Piaget on cognitive development, and is referred to as constructivism (Garfield, 1995; von Glasersfeld, 1995; Wheatley, 1990). Constructivism views learning as an active process and learners as cognitively active human agents who construct their knowledge through interaction with the environment. The basic tenets of constructivism are in stark contrast with, and pose a strong challenge to the earlier conceptions of learners as passive beings whose empty minds are to be filled with information transmitted directly from and controlled by a central knower. According to Dewey (1933, p. 261), the mind of the student is "treated as if it were a cistern" into which information is filled with one set of pipelines and pumped out by way of another set of pipelines in the form of regurgitation on demand. In his analysis of the teacher-student relationship, Freire (1970, p. 72), varying the metaphor, used "the banking concept of education" as another metaphor for the traditional lecture-and-listen format, which is prevalent in our educational settings. This vivid metaphor also illustrates the above mentioned narrative character of teaching as a futile cycle of teacher, the depositor, making deposits which students, the depositories, who in turn receive, memorize, and repeat (Freire, 1970).

Several researchers indicated that in these traditional narrative-based settings students were not learning what statistics educators wanted them to learn (delMas & Liu, 2005; Gal, 2003; Konold, 1995). The efforts to improve the quality of statistics education extend beyond a mere criticism of this narrative character of teaching and learning. Statistics education research community embraces the idea that students construct knowledge by constantly negotiating and renegotiating new knowledge in relation to past experiences. To a large extent, this negotiation process is influenced by social, cultural, and historical backgrounds of students, as well as of those around the students (von Glasersfeld, 1995). It is through this complex network of rich interactions that students are able to propose or challenge new ideas, engage in dialogue about those ideas, and try to make sense of those ideas. Constructivism, along with the above outlined Vygotskian perspective, known as social constructivism, which takes into account social interactions and historical or cultural influences on learning, has become the guiding theory for our efforts to improve the quality of statistics education, and for much research in mathematics education, as well as science education (Hassad, 2008; Mvududu, 2005).

Despite the above described views, which guide the statistics education reform movement, there are many introductory statistics courses at the college level that continue to use the traditional lecture-and-listen format (Moore, 1997). In addition to using the lecture-and-listen format predominantly, many such courses also heavily rely on having students do assignments in textbooks or in computer labs, and take multiple choice or traditional tests emphasizing formulae, rote memorization skills and procedural knowledge, as opposed to conceptual knowledge of statistics (Garfield, 1995). Statistics education reform, guided by the views of constructivism and social constructivism, shifts the emphasis more toward conceptual knowledge, and focuses on helping students develop conceptual understanding of various statistics topics.

Some of the basic goals of quantitative skills are often stated or referred to by the statistics education researchers in terms of statistical literacy, statistical reasoning and statistical thinking (Zieffler, Garfield, Alt, Dupuis, Holleque, and Chang, 2008). Even though there has been an ongoing discussion among researchers on how to define these concepts unanimously, there continues to be a great deal of discordance regarding the definitions and the nature of these concepts which have several different competing models (delMas, 2002). As a result, the concepts and definitions of statistical literacy, statistical or quantitative reasoning and thinking remain unclear, overlap with one another, and often are used by many researchers interchangeably (Ben-Zvi & Garfield, 2004; delMas, 2002; Garfield & Chance, 2000). Motivated, in part, by the lack of clear and commonly used definitions of these terms as the outcomes of student learning, the recent research efforts have focused on conceptual understanding in quantitative analysis, in general, and statistics education, in particular (Budé, 2007; Slauson, 2008).

Hiebert & Lefevre (1986) view knowing-why as an indicator of conceptual understanding, as opposed to knowing how-to, which they consider to be an element of procedural understanding. Other researchers focus on the relational aspect of conceptual understanding (Dantonio & Beisenherz, 2001). In their view, conceptual thinking and understanding require the learner to create patterns or relationships among the different pieces of information gathered by the learner. A common thread emerging from the attempts made by several of the above cited researchers to define conceptual understanding is the formation of cognitive connections among the related components of a cognitive entity.

A Design to Improve Conceptual Understanding

The researchers have considered and proposed a multitude of changes in college and university level statistics course so that we, as statistics educators, can best help students learn. Much of these changes suggested by statistics education reform efforts have focused on the development of conceptual understanding of the underlying statistical ideas. These changes were made possible, in part, by recent trends in society toward quantitative literacy, and the abundance of advance technologies in computing and communicating. Based on a review of the literature focusing on the changes proposed to improve quantitative reasoning skills of students and faculty in higher education, I identified the following four broad and interconnected areas to consider: changes related to content, pedagogy, technology, and assessment.

Content Related Considerations

Statistical content is broadly viewed as what we, as educators, want students to learn in statistics. The traditional content, and approach to teaching statistics as a sequence of linearly and hierarchically ordered disjoint topics padded with a series of techniques lead students to view statistics as a collection of fragmented formulae and procedures taught in isolation without any interconnectedness established among the various topics. This fragmented view of statistics, created and promoted, in a large part, by the traditional content and approaches, tends to impress upon our students an image of statistics as a collection of specific, factual and behavioral objectives (Begg, 2004). In addition to their fragmentarily organized content, the traditional statistics courses have been also largely based on probabilistic inference (Moore, 1997). The content related changes, which were suggested by the joint curriculum committee of the American Statistical Association (ASA) and the Mathematical Association of America (MAA), advocated exploring and producing data, not just realistic, but real data arising from real problem settings. Interpretations of graphics, developing strategies for explorations of data, and informal inference need to be brought to the forefront of statistics education. The conceptual meanings of P-value, confidence, significance should be emphasized in college level statistics courses where the students may be at any level of mathematical sophistication or ability. There is a need for statistics educators to stress conceptual understanding rather than mere knowledge of procedures in teaching and learning of statistics. With the emphasis placed on conceptual understanding, there should be fewer procedures, recipes, calculations, and derivations (Turegun, 2009). It is more important for students to grasp the reasoning of statistical inference than the number of different inferential procedures they are taught. Numerous statistics courses contain a great deal of material with a collection of ideas which are presented disjointly by instructors, understood superficially and forgotten quickly by students. There is little value in knowing a set of procedures if students do not understand the important underlying concepts. For example, we, as faculty members and researchers, should consider how useful ideas of statistical inference could be taught from a conceptual point of view informally.

Identifying correctly, introducing early and revisiting often of the central ideas, building connections among different ideas, emphasizing common elements of analysis or interpretation, and minimizing time devoted to mathematical details were some of the points we need to take into consideration. In organizing our course content, the emphasis needs to be placed on students' conceptual understanding and practical use of statistical reasoning rather than memorization of statistical formulae and procedures. A decade earlier, Wheatley's (1991) mathematics education research resulted in similar recommendations. He advocated a more problem-centered content focus, and an emphasis on practical and contextual use of mathematics.

Pedagogy Related Considerations

Pedagogy can be broadly viewed as what we, as statistics educators, do to help students learn. Traditional pedagogic practices currently used in teaching statistics courses is, to a large extent, based on the lecture-and-listen model. In this model, students are conceived to be passively listening to lectures so that their empty minds can be filled with information transmitted directly from a central knower. We, as educators, need to remember that "we overvalue lectures" (Moore, 1997, p. 125). We also need to remember that, as teachers, we tend to "underestimate the difficulty students have in understanding basic concepts of probability and statistics" (Garfield, 1995, p. 31). The difficulty of subject matter combined with the passive and oppressive character of the traditional teaching and learning practices based on the traditional lecture-and-listen model has been one of the leading causes of frustration and dissatisfaction experienced by students and faculty with the statistics courses over the years. The widespread frustration and dissatisfaction with the course have led researchers to investigate alternative models, such as a move away from the traditional lecture-and-listen model toward activity-based courses which promote, and support active participation and interaction among all participants. Moore (1997) considered asking students to work in groups cooperatively, and having students communicate their findings orally and in writing to be necessary components of good pedagogy. He further stated that "the core of new pedagogy is genuinely active learning" (Moore, 1997, p. 130). Making changes from traditional lectures to active learning techniques pose considerable challenges to many statistics instructors. The traditional training of many statistics instructors could be one of the reasons which might make the change from a teacher-centered approach of lecture-and-listen format a difficult and challenging one for them. Another reason for the reluctance to make the change is identified as the ease with which statistics instructors can prepare a lecture. Contrary to preparing a lecture, designing a student-centered learning environment where students are engaged in the activities, group discussions and projects are generally more challenging and time and labor intensive practices for the faculty members. In an effort to alleviate such difficulties statistics educators might apply a cooperative approach to teaching and learning statistics. Based on the premise that statistics education ought to resemble the inherently cooperative nature of the practice of statistics, collaboration among statistics educators, as well as among students, may be considered to enhance and sustain the efforts of cooperative teaching and learning of statistics. The proper choice of curricular material and textbooks that emphasize and structure activities through which to illustrate concepts may also alleviate difficulties and challenges faced by the statistics instructors in making the pedagogical changes.

Although some traditionally oriented statistics instructors tend to believe that increasing interaction and active learning in our classrooms might cause them to "cover" less material, I believe this can be taken as an opportunity to focus on "big" ideas, to go deeper with those ideas, and use them as threads to weave a curriculum matrix for statistics courses (Turegun, 2009). When examined from a paradoxical perspective, teaching less may lead to learning more. Hence, less is more. Arguments in favor of active learning, which might be perceived by traditional statistics instructors as an implication for a decrease in the "material coverage", are actually attempts to increase learning by focusing on the "big" ideas of statistics.

Technology Related Considerations

Computers, graphing calculators, the Internet, statistical software packages, Web applets, and various apps are among the several forms of technology available to statistics educators in order to support the development of conceptual understanding and quantitative reasoning abilities of students. Several researchers have explored the use of these different forms of technology to improve teaching and learning of introductory statistics. For the most part, the decision regarding what form of technology to use might be dependent upon the issue of accessibility by students. Using computers or calculators merely to generate statistics, to follow algorithms or to produce graphs of data are very limited views of technology use in statistics education. These types of limited technology use do not tend to extend beyond the notion of, what I refer to as, "using technology for the sake of using technology." Technology use in that sense becomes a tool for doing statistics, not a tool for teaching and learning statistics.

Using technology to help students visualize concepts and understand abstract ideas is considered to be far more important than using technology solely to automate messy statistical computations. For example, simulating drawing samples from various populations and observing the distributions of statistic values computed from these samples are better ways of illustrating the Central Limit Theorem than providing a mathematical proof for it. Majority of the college and university faculty members, from various departments, such as mathematics, statistics, psychology, business, sociology, and economics, have been making changes in their courses over the past decade. The most common changes are in the form of increased use of technology. While there has been a considerable increase in the usage of technology, many instructors are still unaware of excellent Web resources, such as graphing calculators, Web applets, and apps. The use of graphing calculators has certain advantages, such as portability and suitability to active participation. However, several researchers expressed concerns regarding the use of graphing calculator technology (Moore, 1997). Limited amounts of data entry and small screens with static graphs are considered to be some of the weaknesses of graphing calculators. Although initial uses of technology focused on the computational power only, the uses of technology need to be shifting more toward the conceptual power to illustrate abstract statistical concepts. The applets have been gaining an increasing importance because of their effectiveness in illustrating various statistical concepts visually. For example, instead of using calculators to generate z-scores, it is possible to have students explore the empirical rule of 68-95-99.7 by using a Normal distribution Java applet. The website http://www.causeweb.org has an excellent collection of applets in order for students and faculty to illustrate various abstract concepts vividly.

Unfortunately, using a simulation or applet for the sole purpose of demonstration by instructor in front of a classroom with students being only passive learners does not ensure active learning, and can in fact lead to poor learning. Even though the concepts of randomness, confidence, and significance should be introduced to students through the use of simulations and applets, the importance of having students perform physical simulations first with hands-on manipulatives such as coins, dice and cards prior to the use of the calculator or computer was pointed out by Chance & Rossman (2006). Since the use of a computer simulation only for demonstration purposes is not sufficient for developing deep graphical understanding of concepts, having students perform physical simulations first with hands-on manipulatives is especially important.

Technology, in general, is viewed to serve content and pedagogy. The use of graphing calculators ties in with and encourages active participation. But, to a certain degree, technology has changed content and makes possible or allows new forms of pedagogy. Even though not all statistics teachers agree on what is simply a rule, automating anything that is simply a rule is considered good pedagogy (Moore, 1997). Yet, the of use technology in statistics education goes beyond the simple automation of rules. What makes the use of technology an effective learning tool, in addition to computing and producing static or dynamic graphs, is the capability of technology to illustrate various statistical concepts visually and make abstract concepts more concrete.

Assessment Related Considerations

The traditional method of assessing student learning consists of module tests, generally with multiple-choice questions, designed for ease of grading. The traditional exam questions place a strong emphasis on the procedural or computational aspects of statistics, and do not evaluate high-level cognitive and conceptual understanding of students (Zieffler, Garfield, Alt, Dupuis, Holleque, and Chang, 2008). These traditional testing methods tend to evaluate the rate of defects in the final product. The connection of the traditional testing methods to the actual statistical practice is an unexamined assumption. The efforts to improve assessment practices in statistics education should start with challenging and questioning this assumption. There is a need for appropriate assessment materials to evaluate students' statistical reasoning and conceptual understanding. We must search for new and innovative ways of assessing what our students know about statistics. Most statistics teachers tend to view assessment as separated from teaching, and as limited to testing, grading exams, quizzes and homework assignments. This traditional view of assessment and its related forms are considered to be too narrow and too specific to provide useful information about what students know and understand (Garfield & Chance, 2000). Even worse, several misconceptions about statistical topics, such as probability, may still persist, even though students are able to use appropriate terminology or formulae to answer questions correctly on a traditional test.

An emerging view of assessment, as an ongoing evaluation of students' learning over the course of the semester with constant gathering of information and providing feedback, can be very valuable in informing our teaching. In this emerging view of assessment, teaching and assessment no longer appear to be in a dichotomous relationship, but rather in a continuous cyclical relation of informing one another with the ultimate goal of improving student learning. As part of the considerations regarding assessment, instructors are encouraged to collect a variety of assessment information from sources other than individual student tests, the results of which traditionally were used to assign grades and rank students. Among some of the alternative forms of assessment are cooperative group activities, computer lab exercises, portfolios, projects/reports, presentations, essay questions, journal entries, and open-ended writing assignments. These alternative forms of assessment may be structured to provide some rich information in assessing the nature of student learning. Walking around the class to observe students as they work in small groups on an activity, and having students explain their answers are some of the ways to informally assess students' statistical reasoning. Being able to hear students express their understanding of what they have learned is important because it provides teachers with an ongoing, informal assessment of how well students are learning and understanding statistical ideas. Written reports on group activities are useful sources of information in assessing students' ability to solve a particular problem, apply a set of skills, demonstrate understanding of an important concept, or use statistical reasoning.

If our efforts focus on teaching our students what we, as statisticians or statistics educators, value most, then we must also assess what we value most. This is one of the important elements that we need to remember when designing assessment instruments. On a final note on assessment, I am in complete agreement with Ben-Zvi & Garfield (2004), and have become accustomed to regarding assessment as being a continual and recursive process, as opposed to being a sporadic and conclusive one; students as being active participants in this process, as opposed to being the objects of the assessment; and assessment outcomes as an opportunity for all students to achieve their potentials, as opposed to filtering and selecting students out of the opportunities to learn statistics.

Conclusions

In conclusion, the efforts outlined and proposed in this paper to improve the quality of statistical reasoning and thinking among students and faculty members in higher education can be gathered in the following four categories: considerations related to content, pedagogy, technology, and assessment. I regard these considerations in the four categories as the four pillars to raise the quality of statistics education. Considerations for content, pedagogy, technology, and assessment should not be evaluated as independent of one another or in a dichotomous relationship with each other. These four categories can be viewed as being the nodes of an organic web. We, as statistics educators, need to be cognizant of the connections, interactions, and tensions among these four pillars while pursuing our goals to improve the quality of statistics education in post-secondary level. Using these four pillars to build a holistic and flexible curriculum structure or matrix is one of the fundamental components in developing quantitative reasoning and analysis skills among university students, and, possibly, faculty members.

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