ROLES OF TECHNOLOGY IN STUDENT LEARNING OF UNIVERSITY LEVEL BIOSTATISTICS

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ABSTRACT

This study explored threshold concepts and areas of troublesome knowledge among students enrolled in a basic biostatistics course at the university level. The main area of troublesome knowledge among students was targeted by using technology to improve student learning. A total of 102 undergraduate students who responded to structured questionnaires were included in this study. The results suggest that threshold concepts regarding "statistics" and "random sample" need to be better understood. "Confidence interval" and "hypothesis testing" were the two most frequent troublesome areas among the participants.The pedagogical role of technology in teaching and learning statistics, and the mechanisms whereby technology may improve student learning were discussed.

Keywords: *Statistics education research; Technology; Threshold concepts; Troublesome knowledge; Biostatistics*

1. THRESHOLD CONCEPTS

The notion of threshold concepts has renewed interest in examining what is important for students to learn, and the challenges they may encounter while learning (Meyer & Land, 2003, 2005, 2006). It presents a transformed way of understanding, interpreting, or viewing something, without which the learner cannot progress. Threshold concepts may represent, or lead to troublesome knowledge, which is conceptually difficult, counterintuitive or 'alien' (Perkins, 1999). It increasingly appears that a threshold concept may on its own constitute, or in its application, lead to such troublesome knowledge (Davies, 2006). When students do not understand a threshold concept, it may be due to the concept representing "troublesome knowledge" for students. This may lead them to approach the course by learning numerous techniques, and attempting to pass the course by remembering how these techniques work. Therefore, exploring threshold concepts may clarify troublesome knowledge that is difficult or challenging for students to learn when studying introductory statistics (Bulmer, O'Brien,

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& Price, 2007). Teaching efforts aimed at plausible threshold concepts and troublesome knowledge may lead to successful student participation and learning, especially with the aid of advanced technology. The thresholds perspective also emphasizes the importance of disciplinary contexts. Typical examples might be 'The Testable Hypothesis' in biology, 'Gravity' in physics, or 'Depreciation' in accounting (Meyer, Land, & Baillie, 2010).

1.1. POTENTIAL THRESHOLD CONCEPTS IN STATISTICS

Statistics is an important subject in many fields, such as jobs, study programs, and everyday situations. Attention to the development of statistical literacy and the enhancement of statistics education at all levels has recently increased (Ben-Zvi & Garfield, 2008). The study of statistics provides students with tools and ideas to use in order to react intelligently to quantitative information in the world around them (Garfield & Ben-Zvi, 2007). Statistical thinking offers non-intuitive mental tools for trimming a large mass of information by selecting and organizing information that is relevant to a particular context (Ben-Zvi, 2000). Students need to engage in meaningful learning in order to interrelate and structure their statistical knowledge.

Historically, many students have viewed the discipline and methods of statistics as difficult and unpleasant to learn (Garfield & Ben-Zvi, 2007). Students often view statistics as a branch of mathematics because it uses mathematical formulas, so they look at statistics through a mathematical lens. Upon completion of introductory statistics courses, the majority of students do not understand the basic logic of classical statistics, such as the concepts of repeated samples and sampling distributions. They know how to carry out procedures such as computing a sample variance, running a regression analysis, and testing a hypothesis, but they do not have a feeling for the 'big picture' (Meyer & Land, 2003). In a study involving 465 students learning introductory statistics at a university, probability received the highest number of votes among conceptual areas students found to be simple while also receiving the third highest number of votes as a difficult conceptual area (Dunne, Low, & Ardington, 2003). Another study based on a large, multi-institution sample of college students in the United States showed a small overall increase in conceptual understanding of statistical terms after completion of an introductory statistics course (delMas, Garfield, Ooms, & Chance, 2007). These findings indicate that there may be several threshold concepts (e.g., repeated sampling, sampling distributions, regression analysis, hypothesis testing) that students find troublesome and inhibit their development of a deep understanding of statistics.

1.2. THE ROLE OF TECHNOLOGY IN TEACHING STATISTICS

Due to the influence of modern technology, learning and teaching statistics at university is constantly changing (Ramesh, 2011). The technology revolution has had a greater impact on teaching statistics than on many other disciplines, as it has changed the nature of statisticians' work, and has, therefore, been changing what and how we teach (Chance, Ben-Zvi, Garfield, & Medina, 2007). Today's statistics classes may be taught in a classroom with a computer monitor projected on a screen, or may take place in a laboratory with students working at their own computers (Chance, Ben-Zvi, Garfield, & Medina, 2007). Technology covers information technology (IT) and information systems (IS), which are commonly used as a synonym for computers and computer networks, but they also encompass other information distribution technologies such as television and telephones (Koh & Maguire, 2009). These technologies fall into at least one of the following categories: 1) Statistical packages (tools) include software for computing statistics and constructing visual representations of data; 2) Microworlds consist of software programs used to demonstrate statistical concepts and methods, including exploratory visualizations and simulations; 3) Tutorials include programs developed to teach or tutor students; 4) Various resources that support teaching statistics such as an online course or electronic journal; and 5) Teacher meta-tools (processes, activities, or mindsets) that are used to create an interface and educational goals (Ben-Zvi, 2000; Chance, Ben-Zvi, Garfield, & Medina, 2007; Pratt, Davies & Connor, 2011).

Pedagogically, technological tools designed for statistics learning have been developed to support students in many ways. First, technology enables students' active knowledge construction, by "doing" and "seeing" statistics. Second, technology provides opportunities for students to reflect on observed phenomena. Third, technology may develop students' metacognitive capabilities – that is, their knowledge about their own thought processes, self-regulation, and control. Fourth, technology supports the renewal of statistics instruction and curriculum on the basis of strong synergies among content, pedagogy, and technology (Chance, Ben-Zvi, Garfield, & Medina, 2007). Finally, technology may assess learning with more accurate grading (Garfield & Ben-Zvi, 2009). Further, technology allows one to deal with the quantitative complexity inherent to statistics, easily access methods of data analysis, and explore the roles played by chance and probability models. Integrating simulation into teaching can have positive benefits by allowing students to experiment with data and statistical distributions (Engel, Sedlmeier, & Worn, 2008; Garfield & Ben-Zvi, 2009).

However, professional statistical software is often very complex, and may not be suitable for all students. When statisticians do statistics, they get involved with far deeper concepts and carry out activities that require a wider range of cognitive skills compared with just applying statistical techniques. It has been argued that pedagogical developments have not kept pace with those in software design, in that the opportunity to use computers to engage students in the full statistical inquiry cycle is not being exploited (Pratt, Davies, & Connor, 2011). Therefore, an assessment of different statistical software packages that are used in a statistical course is required for adjusting to the level of the statistical course. Currently, several statistical software packages such as SPSS (Statistical Package for the Social Sciences), SAS (Statistical Analysis System) and Stata have been commonly used in statistical courses. These packages have different interfaces and languages in application, and some of them (such as R and SAS) are more sophisticated than the others and require deeper statistical knowledge. Currently, no studies have reported which statistical software is best for learning and teaching statistics at university level, especially at medical universities.

Although technology has significantly changed statistics education, and studies on the teaching and learning of statistics has grown dramatically (Zieffler, Garfield, Alt, Dupuis, Holleque, & Chang, 2008), research on the role of technology in statistics education through identifying threshold concepts and troublesome knowledge has been sparse. In the present study, among students enrolled in a basic biostatistics course at university level, we aimed: 1) to identify students' threshold concepts and troublesome areas when learning statistics; 2) to explore whether technology that supports visualization and simulation can help students to overcome some of the most frequent difficulties; 3) to describe which type of technology is the most commonly used when encountering problems; and 4) to investigate which statistical software package is the most preferred program for students' learning and practice during the course.

2. METHODS

2.1. PARTICIPANTS

The initial population included 109 undergraduate students who were taking an introductory course in biostatistics. Of the 109 students, 84 were third-year undergraduates in public health, which is a five-year program leading to a bachelor's degree in public health, and 25 were second-year undergraduates in the International Bachelor's Program in Science of Nursing, which is a three-year study program leading to a Bachelor's of Science in Nursing. All students in four sections of the course were invited to participate in the present study. Informed consent was received from all of the participants. A brief introduction on common statistical software such as SPSS, Stata, SAS and R was made in the beginning of the course by showing the interface of the software, accessing data, listing variables and exploring data. Students could choose one of the programs to use during the course after a short guided practice.

2.2. COURSE DESCRIPTION

The course was an introduction to basic biostatistics principles and their role in medical research. Concepts presented in the course were hypothesis testing, type I error, type II error, estimate, measurement of dispersion, regression analysis, making inferences, and how to present results. After the course, students should be able to present basic summaries of data, perform analyses, and display an enhanced ability to recognize, understand and critically view the statistics encountered in medical articles. The course covered these statistical methods: chi-squared test, *t*-test, regression analysis, and non-parametric methods. The textbook for the course was Campbell, Machin, and Walters (2007). Access to a computer, the Internet, and a statistical program (SPSS, Stata, SAS or R) was required.

2.3. DATA COLLECTION AND STATISTICAL ANALYSIS

Data were collected through a structured questionnaire that included two parts. The first part was posted online, and emailed to all students before the course started, and the second part was posted online, and emailed to students at the end of the course. Students were requested to return the questionnaire by email, online or personal delivery. In addition to demographics, students were asked to provide the following information before (questions 1 and 2) and after (questions 3-7) the course: 1) their impression about statistics before the course was started; 2) explanation in their own words of the term *random sample*; 3) the most difficult or tricky aspect of the course; 4) if they were teaching this concept to a friend, what they would do to help with the difficult or tricky part; 5) what is most commonly used when they have questions while completing homework: I. Internet search; II. Email to teacher or classmates; III. Telephone call or message; IV. Library; or V. Other; 6) what they thought about the role of technology during the course; and 7) what software they used and which program they preferred: I. Stata; II. SAS; III. SPSS; IV. R; or V. Other.

In this study, “confidence intervals” was the most frequently cited area of difficulty, and present in 19 (18.6%) of the students. These 19 students (16 of whom which were in the public health program) indicating confidence intervals as a difficult area were invited to participate in a workshop after the course. The workshop included demonstrations of confidence intervals using Stata with different sample sizes and intervals (90%, 95% and 99%) to show how the width of the CI (confidence interval) changes with the size of the sample drawn. These students were requested to answer a question on the relationship between the size of the sample, the confidence level and the width of a confidence interval before and after the workshop.

Differences in responses by gender were compared using chi-squared tests for categorical variables and *t*-tests for continuous variables. Logistic regression analysis was performed to estimate odds ratios (ORs) and 95% CIs for the relationship of age, education and subjects of study to gender, and the association of the threshold concepts on “Statistics” and “Random sample” with the two most frequent troublesome areas identified by the participants. SPSS Statistics 20.0 was used for all analysis. All tests were two-tailed and used a significance level of $\alpha = 0.05$.

3. RESULTS

Among the 109 students, six dropped out due to lack of access to a computer or the Internet, and one refused to participate in the study, leaving 102 participants (94%) for the current analysis. The participants’ were ages 19–36 (mean 22.3) years and 66 (64.7%) were female. Table 1 presents the characteristics of the participants.

Table 1. Participant characteristics by gender (N=102)

Characteristic	Female (*n*=66)	Male (*n*=36)
Age (mean ± SD)	21.2 ± 2.3	22.6 ± 2.5
Education, years (mean ± SD)	14.9 ± 3.4	15.2 ± 2.8
Study subjects (*n*, %)		
Public health	54 (81.8%)	26 (72.2%)
Nursing science	12 (18.2%)	10 (27.8%)

Logistic regression analysis showed that male students were more likely to be older (OR 1.02, 95% CI 1.01-1.05), and less likely to study public health (OR 0.88, 95% CI 0.64-0.97) than female students. There was not a statistically significant difference in terms of education (OR 1.04, 95% CI 0.96-1.21).

3.1. THRESHOLD CONCEPTS AND TROUBLESOME AREAS

Figure 1 shows the students' impression about statistics before the course started. Almost half of the students considered statistics to consist primarily of calculation and numbers. Many students seemed unable to write a coherent sentence, or a logically-constructed sequence of statements about what is meant by the term "random sample." Five categories that participants' responses fell into for definitions of "random sample" are shown in Table 2.

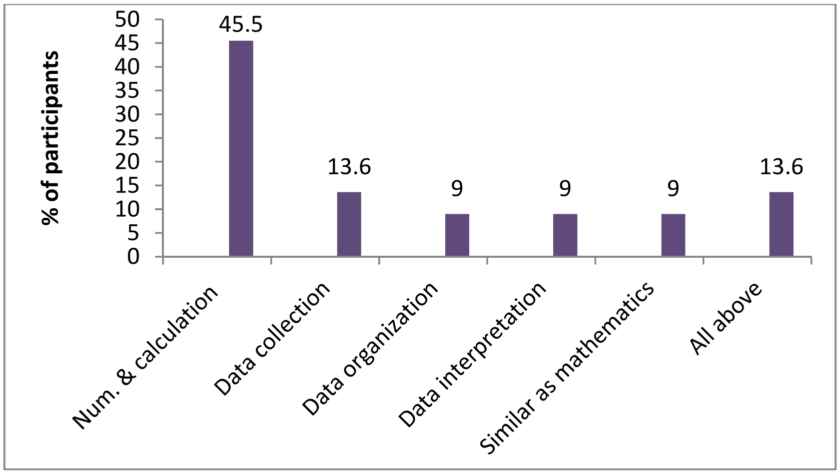

Figure 1. Students' pre-course impressions of biostatistics.

Table 2. Students' description about random sample (N=102)

Students' description	*N*	%
A group of a population taken in any way possible	24	23.5
As some type of variable picked out at random and used as a basis to estimate the whole population	19	18.6
A selection of items with no formula used only done by a person	14	13.7
Randomly chosen figures from a huge choice	13	12.8
Selected without prior research	14	13.7
Other	18	17.6
Total	102	100.0

Figure 2 shows ten concepts dominating students' responses to what they found to be "Difficult" in the course. Most students deemed confidence intervals, hypothesis testing, and regression as difficult areas. Almost half (45.1%) of the students mentioned difficulties in understanding the formulas or in completing the calculations associated with statistical techniques.

Regarding the question about what they would do if they taught the difficult concepts to a friend, two major categories of the students' responses were to provide "Examples" (24.2%), or "Explanation" (23.6%). In the "Examples" category, students mentioned providing a number of examples to help the friend understand the concepts. In contrast, in the "Explanation" category, students said they would provide clear, precise and simple explanations. Two other categories that received a number of responses from students were: "Practice" (8.8%) and "Text/Web/Lectures" (8.1%). "Practice" included responses that mentioned telling their friend to do lots of practice. Responses in the "Text/Web/Lectures" category centered on instructing their friend to read the textbook, look at specific websites, or go to relevant lectures.

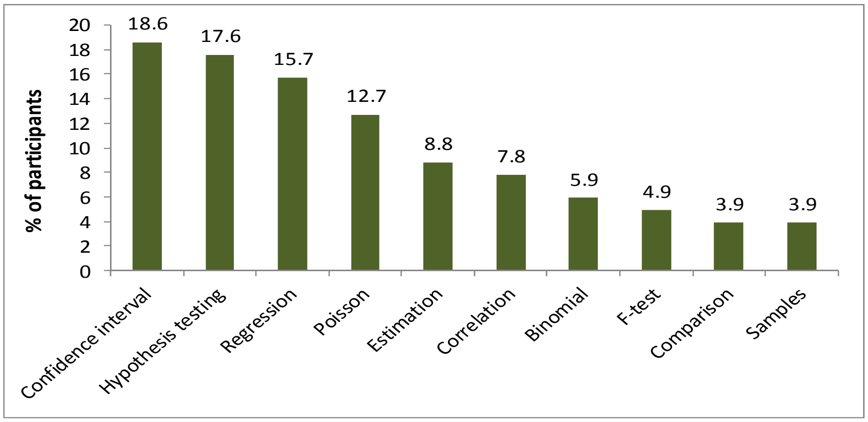

Figure 2. Areas most frequently noted by students as difficult.

Table 3 presents the relation of concepts of "number and calculation" for "statistics" and of "a group of a population taken in any way possible" for "random sample" in relation to the most frequent troublesome areas, "confidence interval" and "hypothesis testing". The two inaccurate concepts for "statistics" and "random sample" were significantly associated with the two troublesome areas.

Table 3. Odds ratio and 95% confidence interval of the relation of threshold concepts on "statistics" to the troublesome areas (confidence interval and hypothesis testing)

Threshold concepts	*Confidence interval* OR (95% CI)	*Hypothesis testing* OR (95% CI)
"Number and calculation" for "statistics"	2.13 (1.06-4.26)	1.99 (1.22-4.78)
"A group of a population taken in any way possible" for "random sample"	1.79 (1.33-4.57)	1.46 (1.11-4.44)

Among the 16 students who participated in the post-course workshop on confidence intervals, the question on the relationship between the size of the sample, the confidence level and the width of a confidence interval was correctly answered by 4 (25%) and 15 (93.5%) students before and after the workshop, respectively.

3.2. FREQUENCIES OF TECHNOLOGY USE

The most commonly used tool to answer questions and problems raised during the course and homework was the Internet (Figure 3). Further, online searching or email to friends were inversely associated with the two most frequent troublesome areas with ORs of 0.77 (95% CI 0.23-0.94), and 0.89 (95% CI 0.21-0.96).

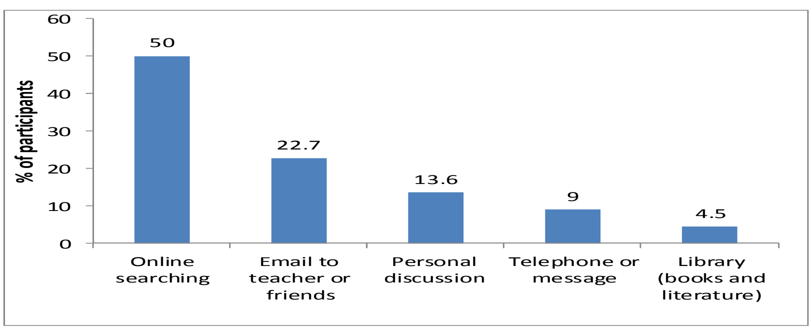

Figure 3. First choice for solving problems in introductory biostatistics course (N=102).

Among the four statistical software programs, Stata (45%) was preferred the most among the participants. However, there was a significant gender difference in the preferred software ($\chi^2 = 21.29$, 3 *df*, $p < 0.01$; see Table 4). Male students were more likely to prefer Stata, while female students preferred to use SPSS, followed by Stata.

Table 4. Participants' statistical software preferences

Preferred software	Female (*n*=66) (%)	Male (*n*=36) (%)	Total (*N*=102) (%)
SPSS	32 (48.5)	8 (22.2)	40 (39.2)
Stata	26 (39.4)	20 (55.6)	46 (45.0)
SAS	6 (9.0)	5 (13.8)	11 (10.8)
R	2 (3.0)	3 (8.3)	5 (4.9)

In addition, computers, software and online resources were considered important and helpful technology by 85 (83.3%) of the participants. Of the participants, six (27%) who had previously taken online courses on statistics or software use had a mean score of 14.1 (maximum possible score: 15) and performed better ($p < 0.01$) than the rest of the students (mean score of 12.1) on the course final examination.

4. DISCUSSION

In this study of undergraduate students taking an introductory biostatistics course who responded to a structured online questionnaire, we found that 1) threshold concepts for "statistics" and "random sample" need to be better understood, and "confidence intervals" and "hypothesis testing" are areas of troublesome knowledge. The threshold concepts are significantly associated with the troublesome areas; 2) technology such as statistical software-based simulation and visualization may help students overcome the difficulty of confidence intervals; 3) technology is commonly used among students to solve problems during the course, and 4) the statistical software Stata was the most preferred program among the students. Our findings suggest that teaching efforts aimed at helping students understand plausible threshold concepts and troublesome knowledge with the aid of technology in a basic biostatistics course may lead to successful teaching and learning.

4.1. LIMITATIONS

The main strength of this study is the inclusion of university students who had similar educational backgrounds in the subjects of public health or nursing science. However, some limitations should be noted. First, because the study population was not a random sample of all students who are taking the course, the study sample might not be representative of the source population. Cautions are needed when generalizing our findings to other students, especially to those students who are from a different discipline. Second, in our study, there was no control group consisting of students who were taking the course without using any technology. Thus, the absolute effect of technology on learning outcomes among the participants could not be determined. As technology has been widely used among students, it is difficult to recruit students who do not use any technology. Third, there is no objective assessment to define troublesome knowledge, which was based merely on self-reported complaints and the examination after the course in this study. Finally, this is a cross-sectional study, and the results from the current study are exploratory. Longitudinal studies with repeated measurements to evaluate the impact of technology on student learning statistics are needed.

4.2. THRESHOLD CONCEPTS AND TROUBLESOME KNOWLEDGE

By definition, a threshold concept is integrative, and subsumes some previous knowledge. A threshold concept is also transformative, and may lead to a different perspective within a discipline

(Meyer & Land, 2003, 2005). A threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something (Meyer & Land 2003). An essential element of the threshold nature of a concept is defined mainly by a student's subjective experience in acquiring it rather than simply by an objective analytical process. If the notion of threshold is as robust as it appears, then there is a prospect for facilitating student learning by specifying and delineating the constructs that constitute thresholds, and tailoring teaching efforts to incorporate explicit strategies to assist students across them.

Past experience may lead teachers in statistics at the tertiary level to surmise that threshold concepts in basic statistics will include the notion of randomness. Some specific concepts (such as confidence intervals, hypothesis testing and regression) could be considered to be conceptually difficult aspects of biostatistics at the introductory level since each of these concepts could themselves be considered a 'threshold' and transformative for students' learning. In this study based on a small sample, the main difficulties were in knowing confidence interval, hypothesis testing and regression. Given the centrality of such concepts within sequences of learning and curricular structures, their difficulty for students assumes significant pedagogical importance. What might account for the variation in student facility to cope with these learning thresholds? How might we assist our students to gain understanding of such difficulties? This study prompted pedagogical reflection. In the first instance, the findings are immensely valuable to better design the introductory biostatistics courses for undergraduate students by providing an empirical basis and feedback approaches to support student learning with technology (ASA, 2010).

When considering how to assist students' learning of these concepts, the student-nominated approaches provide an interesting feedback pattern for the improvement of teaching. In this study, many students seemed unable to write a coherent sentence, or a logically constructed sequence of points. The terms "statistics" and "random sample" were not well understood. "Confidence intervals," "hypothesis testing," and "regression" were areas of troublesome knowledge among the participants. However, technology has the potential to help students learn through visualization of these concepts and automation of calculations. Indeed, technology was commonly used among the students. In addition, students who demonstrated difficulty in understanding confidence intervals showed a large improvement in their understanding after participation in a technology-based post-course workshop on the topic.

4.3. POTENTIAL FOR TECHNOLOGY TO IMPROVE STUDENT LEARNING

A cognitive technology has been described by Pea (1987) as "any medium that helps to transcend the limitations of the mind" (p. 93). This approach is based on a specific conception of human cognition (Dascal & Dror, 2005; Dörfler, 1993; Pea, 1992). This conception of cognition leads to specific ways of using technology in statistics education, and a view on how the technology lends itself to support cognitive and sociocultural activities (Cobb, 1998; Dunlosky, 2013). The perspective on conception is comprised of two metaphors: the amplifier metaphor and the reorganization metaphor.

Amplifier metaphor In environments that are not based on technological tools, representations produced and used during classroom activities are limited in number. Graphs or tables are often presented to students or constructed according to prescriptive instructions (Kaput, 1992). Representations are then often the same for students learning in the same class. Instruction often concentrates simply on translation skills between representations, and mastery of these skills tends to become the central goal of teaching. The use of multi-representational technological tools turns many of the manipulations of representations into automatic operations.

Reorganization metaphor An appropriate usage of technological tools has the potential to bring about structural changes in cognitive and sociocultural activities, rather than just to amplify human capabilities. A powerful tool brings about the reorganization of physical or mental work in at least the following ways: 1) Shifting the activity to a higher cognitive level (Hattie, 2009; Hershkowitz & Schwarz, 1999); 2) Changing the objects of the activity-- not only the structure and form of the activity, but also its content; 3) Focusing the activity on transforming and analyzing representations distinguishes between an action notation system, which involves calculations and transformations (e.g., the algebraic representation of a function), and a display notation system, where the activity of the user is generally confined to interpretation, such as graphical and tabular representations of a function (Dunlosky, 2013); 4) Supporting a situated cognition mode of thinking and problem solving (Keengwe, 2008). Technological tools can assist students to bridge statistics and 'real' life by opening access to the modeling of concrete situations and real data (Martin, 2003).

4.4. CHALLENGES AND RECOMMENDATIONS FOR USING TECHNOLOGY

Technology has led to numerous changes in content, pedagogy, and course format in statistical education (Chance, Ben-Zvi, Garfield, & Medina, 2007). Many problems that were previously intractable in analysis now have approximate solutions. The use of technology allows many assumptions that are needed for modeling to be relaxed. These changes in statistical practice have a direct impact on the content that should be taught, even in introductory material. Technology has also changed the way people use statistics, the speed and efficiency with which researchers produce statistics. We have seen the power of technology as described above to change the way people teach and students learn statistics. However, challenges have been raised and some issues should be considered in terms of choosing appropriate tools, critical evaluation of software, and curriculum design.

Choosing appropriate tools How can teachers and curriculum developers of introductory biostatistics courses navigate within the rich universe of existing software? Priorities for software supporting introductory biostatistics education are: 1) Tools for student learning and use can be integrated into an introductory course; 2) Data resources; 3) Microworlds; 4) Further resources (Internet, electronic books, and multimedia resources); and 5) Tutorial shells. In addition, teachers' meta-tool functions should be included at all levels to allow adaptations for a specific course. In the present study, the Internet and data resources, but not microworlds and tutorial shells were frequently used among the students.

Critical evaluation of software Biehler (1997) stressed the need for the biostatistics education community to develop a perspective, guidelines, and specification of ideal requirements to evaluate existing software critically and to produce better software in the future. Although the need was pointed out more than 20 years ago, it still requires further consideration (Pratt, Davies, & Connor, 2011). What we need, ideally, is an integrated system of coordinated tools for educational purposes that are adaptable, extensible, and simple. Among the students in our study, Stata and SPSS were the most preferred statistical software programs in the introductory course, and could be recommended as basic tools for teaching and learning basic biostatistics at the university level. For teachers, traditional professional knowledge is not sufficient to address the complexities in the teaching–learning situation created by the technological revolution. We need more experimental research and theoretical analysis to identify the differences between traditional teaching and computer-based teaching, to explore how teachers can prepare themselves to teach in new instructional environments, and to develop appropriate professional support systems.

Curriculum Design If technology is used simply to carry out procedures, students' difficulties with threshold concepts and troublesome areas are likely to persist. This implies that learning activities have to be transformed so that students can develop their usage of tools in line with the reorganization metaphor. This goal necessitates new kinds of tasks, supported by powerful tools that permit activities on higher cognitive levels, such as a statistics curriculum that takes advantage of the technology and stresses conceptual understanding, mathematical modeling, problem solving, real-world applications, and new methods of analyzing data.

For the undergraduate students attending the introductory biostatistics course, the threshold concepts "statistics" and "random sample" need to be better understood, and "confidence intervals," "hypothesis testing" and "regression" seem to be areas of troublesome knowledge. Technology can help students' learning through simulation and visualization as well as automations of calculations targeting the troublesome areas (such as confidence interval). At the university level, technology is commonly used among students, and Stata and SPSS seem to be the preferred statistical software packages for the basic course. Considerations such as selection of software and curriculum design should also be taken into account to deal with the use of technology in learning and teaching biostatistics at the university level.

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REFERENCES

American Statistical Association (2010). *Guidelines for assessment and instruction in statistics education: College report*.
[Online: http://www.amstat.org/education/gaise/GAISECollege.htm]

Ben-Zvi, D., & Garfield, J. (2008). Introducing the emerging discipline of statistics education. *School Science and Mathematics, 108*(8), 355–361.

Ben-Zvi, D. (2000). Toward understanding the role of technological tool in statistical learning. *Mathematical Thinking and learning*, *2*(1 & 2), 127–155.

Biehler, R. (1997). Software for learning and for doing statistics. *International Statistical Review*, *65*(2), 167–189.

Bulmer, M., O'Brien, M. & Price, S. (2007). Troublesome concepts in statistics: A student perspective on what they are and how to learn. In I. Johnston & M. Peat (Eds.), *Proceedings of the assessment in science teaching and learning symposium*. UniServe science, Sydney University (pp. 9–15).
[Online: http://science.uniserve.edu.au/pubs/procs/2007/06.pdf]

Campbell, M. J., Machin, D., & Walters, S. J. (2007). *Medical statistics: A Textbook for the health sciences* (4th ed.). Chichester, England: John Wiley and Sons.

Chance, B., Ben-Zvi, D., Garfield, J., & Medina, E. (2007). The role of technology in improving student learning of statistics. *Technology Innovations in Statistics Education Journal*, *1*(1), 1–23.

Cobb, P. (1998). Analyzing the mathematical learning of the classroom community: The case of statistical data analysis. In A. Olivier & K. Newstead (Eds.), *Proceedings of the 22nd Annual Conference of the International Group for the Psychology of Mathematics Education* (Vol. 1, pp. 33–48). Stellenbosch, South Africa: University of Stellenbosch.

Dascal, M., & Dror, I. E. (2005). The impact of cognitive technologies: Towards a pragmatic approach. *Pragmatics & Cognition*, *13*(3), 451–457.

Davies, P. (2006). Threshold concepts: How can we recognise them? In J. H. F. Meyer & R. Land (Eds.), *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge*. London: Routledge.

delMas, R. C., Garfield, J., Ooms, A., & Chance, B. (2007). Assessing students' conceptual understanding after a first course in statistics. *Statistics Education Research Journal*, *6*(2), 28–58.
[Online: http://iase-web.org/documents/SERJ/SERJ6(2)_delMas.pdf]

Dunlosky, J., Katherine, A. R., Marsh, E. J., Nathan, M. J., & Daniel, T. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest*, *14*(1), 4–58.

Dunne, T., Low, T., & Ardington, C. (2003). Exploring threshold concepts in basic statistics, using the Internet. *The International Association for Statistical Education (IASE) satellite conference on assessing student learning in statistics*.
[Online: http://iase-web.org/documents/papers/sat2003/Dunne.pdf]

Dörfler, W. (1993). Computer use and views of the mind. In C. Keitel & K. Ruthven (Eds.), *Learning from computers: Mathematics education and technology* (pp. 159–186). Berlin, Germany: Springer.

Engel, J., Sedlmeier, P., & Worn, C. (2008). Modeling scatterplot data and the signal-noise metaphor: Towards statistical literacy for pre-service teachers. In C. Batanero, G. Burrill, C. Reading, & A. Rossman (Eds.), *Joint ICMI/IASE study: Teaching statistics in school mathematics. Challenges for teaching and teacher education*. Monterrey, Mexico: International Commission on Mathematical Instruction and International Association for Statistical Education.

Garfield, J., & Ben-Zvi, D. (2007). How students learn statistics revisited: A current review of research on teaching and learning statistics. *International Statistical Review*, *75*(3), 372–396.

Garfield, J., & Ben-Zvi, D. (2009). Helping students develop statistical reasoning: Implementing a Statistical Reasoning Learning Environment. *Teaching Statistics*, *31*(3), 72–77.

Hattie, J. A. C. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. London, England: Routledge.

Hershkowitz, R., & Schwarz, B. B. (1999). Reflective processes in a mathematics classroom with a rich learning environment. *Cognition and Instruction*, *17*(1), 65–91.

Kaput, J. (1992). Technology and mathematics education. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 515–556). New York: Macmillan Publishing.

Koh, S. C. L., & Maguire, S. (2009). *E-technology: E-business, intranet, extranet, internet. Information and Communication Technologies Management in Turbulent Business Environments*. (pp. 266–284). New York: Information Science Reference.

Lane, D. M., & Peres, S. C. (2006). Interactive simulations in the teaching of statistics: promise and pitfalls. In A. Rossman & B. Chance (Eds.), *Proceedings of the Seventh International Conference on Teaching Statistics* [CD-ROM]. Voorburg, The Netherlands: International Statistical Institute.

Martin, M. A. (2003). "It's like... you know": The Use of Analogies and Heuristics in Teaching Introductory Statistical Methods. *Journal of Statistics Education*, *11*(2).
[Online: www.amstat.org/publications/jse/v11n2/martin.html]

Meyer, J. H. F., & Land, R. (2003). Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practicing within the disciplines. In C. Rust (Ed), *Improving student learning-ten years on* (pp. 1–15). Oxford: OCSLD.

Meyer, J. H. F., & Land, R. (2005). Threshold concepts and troublesome knowledge: Epistemological considerations and a conceptual framework for teaching and learning. *Higher Education*, *49*(3), 373–388.

Meyer, J. H. F., & Land, R. (Eds.) (2006). *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge*. London: Routledge.

Meyer, J. H. F., Land, R., & Baillie, C. (2010). Threshold concepts and transformational learning. In M. A. Peters (Ed.), *Educational futures: Rethinking theory and practice*, Volume 42 (pp. 4–5). Rotterdam: Sense Publishers.

Pea, R. D. (1987). Cognitive technologies for mathematics education. In A. H. Schoenfeld (Ed.), *Cognitive science and mathematics education* (pp. 89–122). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Pea, R. D. (1992). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87). New York: Cambridge University Press.

Perkins, D. (1999). The many faces of constructivism. *Educational Leadership*, *57*(3), 6–11.

Pratt, D., Davies, N., & Connor, D. (2011). The role of technology in teaching and learning statistics. In C. Batanero, G. Burrill, & C. Reading (Eds.), *Teaching statistics in school mathematics-challenges for teaching and teacher education* (pp. 97–107). New York: Springer.

Ramesh, N. (2011). Use of technology to enhance teaching and learning in mathematics and statistics. *MSOR Connections, 11*(1), 34–36.
[Online: http://journals.heacademy.ac.uk/doi/full/10.11120/msor.2011.11010034]

Zieffler, A., Garfield, J., Alt, S., Dupuis, D., Holleque, K., & Chang, B. (2008). What does research suggest about the teaching and learning of introductory statistics at the college level? A review of the literature. *Journal of Statistics Education*, *16*(2), 1–25.
[Online: http://www.amstat.org/publications/jse/v16n2/zieffler.pdf]

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