Enhancing student's understanding in the cellular and molecular laboratory course with the use of base computer modules

Acrecentar la comprensión de los estudiantes en el laboratorio de biología celular y molecular a través del uso de módulos computacionales

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Abstract

In our traditional science laboratory course, students perform an experiment, record the data, and postpone the analysis and verification of outcomes for a later date when they are away from the laboratory. This has the disadvantage of separating the measurement and data input from the analysis process. The goal of the Natural Sciences Department at the University of Puerto Rico-Aguadilla is to improve the laboratory course on Cellular and Molecular Biology through the development of computer-based modules to be integrated into an online manual. A recent project was undertaken through a Technology for Teaching Grant from the Hewlett Packard Company to encourage the transformation of learning and teaching through technology. A set of ten computer-based modules were developed. Each of them might include animations, computer simulations, video clips, focus and inquiry questions and links to related information. Students were assessed by taking quick online pre- and post-tests to demonstrate preparedness and knowledge obtained after completion of the laboratory exercises. Pre and post-test scores suggest that students' understanding of laboratory techniques and their applicability to research and industrial work, as well as indicating that problem solving skills improved significantly. In addition, the use of the computer-based modules and the information technology offer significant benefits to the teaching staff.

Key words*: computer-based modules, assessment, science laboratory, molecular biology.*

Resumen

Con el método tradicional de laboratorio de ciencia de la Universidad de Puerto Rico, los estudiantes realizan un experimento, toman apuntes sobre sus datos, y posponen el análisis y la verificación de los resultados para períodos fuera de las horas de clase. Esto tiene la desventaja de separar la obtención de los datos del proceso de análisis. La meta del Departamento de ciencias naturales de esta Universidad en Aguadilla es, mejorar el laboratorio del curso de biología celular y molecular a través del desarrollo de módulos computacionales para ser utilizados como manual de laboratorio. Este proyecto se comenzó recientemente con la colaboración financiera de la compañía Hewlett Packard con su programa Tecnología para la Enseñanza, que fomenta la transformación del aprendizaje y la enseñanza a través de la tecnología. Se desarrolló un conjunto de 10 módulos computacionales. Cada módulo puede contener animaciones, simulaciones computacionales, videos, preguntas focales y de análisis, y conexiones con información relacionada. Los estudiantes tomaron pre y post-pruebas en línea para demostrar su preparación y los conocimientos adquiridos al completar el ejercicio de laboratorio. Los resultados de estas pruebas sugieren que hubo un aumento significativo en la comprensión de las técnicas de laboratorio y su aplicación en la investigación y los trabajos de la industria, al igual que destrezas para resolver problemas. Al mismo tiempo, el uso de los módulos computacionales y de la informática ofrece beneficios significativos a los profesores.

Palabras clave*: módulos computacionales, evaluación, laboratorio de ciencias, biología molecular.*

INTRODUCTION

Students in the Natural Science Department at University of Puerto Rico at Aguadilla have traditionally been taught laboratory procedures on Cellular and Molecular Biology by lectures preceding practice. Students were required to hear verbal descriptions of various topics, watch demonstrations of several experimental techniques, and afterwards perform an experiment. This narrative process of teaching multifaceted biology processes and procedures encourages the students to interpret natural sciences as loosely connected facts (WILSON *et al*., 2006). Data measurements were recorded by taking notes and the analysis and verification of outcomes postponed until a later opportunity arose usually out of the laboratory. This has the disadvantage of separating the process of recording the data from the process of data analysis. If doubts or problems should arise after students finish the lab exercise, they could not consult with an instructor to clarify or correct their errors. The students were encouraged to consult either an instructor or a reference textbook if they had questions about the analysis or the verification of the outcomes. Comments from students suggested that, since the analysis of the data was conducted later in out-of-lab periods, they could not be sure if the procedures were in fact carried out correctly. Instructors realized the difficulties stated by the students were hindering the development of a good understanding of the laboratory techniques and their applicability to research and industrial work. In response to this situation a new approach of integrating computer-based modules into an online manual is now being trialled. This use of computer-based instructional modules in undergraduate practical classes is becoming more widespread (DEWHURST *et al*., 1992, 1994; GIBBONS *et al*., 2004; HUGHES, 2000).

The instructional and technical expertise of The Multimedia Educational Technology Center (MET-Center) has been instrumental towards the development and creation of ten computer–based modules. These modules have been developed as flexible resources for use as a manual for the laboratory course on Cellular and Molecular Biology. Since commercial multimedia products and laboratory manuals did not address the specific concerns raised by our students, nor reflect the exact content of our curriculum, multimedia units have been created that include animations, computer simulations, video clips, focus and inquiry questions and links to related information. We are using Tablet PCs to access the modules and do most of the experimental and analysis procedures in-class. Thus real-time results enrich the laboratory experience. For example, instructional modules have been developed that include Excel worksheets to immediately generate graphs of data placed into pre-configured Excel tables. Students can also vary data input to study what would happen if data results were different.

This paper examines the effect of the use of computer-based modules and Tablet PC technology in the:

1) students understanding of the laboratory techniques and their applicability to research and industrial work,
2) students using the computer as a research tool to obtain more information to solve the problems they encounter in the development of a particular technique,
3) students strengthening their problem solve skills by using the computational capabilities of a computer for numerical and graphical analysis.

METHODS

Course description

The laboratory of Cellular and Molecular Biology (BIOL 4019) course comprises of a three hour/ per week laboratory course component of the Cellular and Molecular lecture (BIOL 4018). The prerequisites are genetics, microbiology and organic chemistry. In BIOL 4019, students learn and practice various biomedical techniques applicable to the Cellular and Molecular area such as cell isolation, DNA extraction and purification, restriction enzyme digestion, protein extraction, purification and characterization, agarose gel electrophoresis and polyacrylamide gel electrophoresis. The students work in group settings where they isolate, purify and characterize a macromolecule and present their results in oral and written reports. During the semester, students are able to integrate the knowledge

acquired in BIOL 4018 with biology (immunology, genetics and microbiology) and chemistry from previously taken courses.

Student profile

Most of our Cellular and Molecular students are junior and senior biology majors, belonging to five different areas of interest: general biology, genetics, biomedicine, quality control, and bioinformatics. During the last five years an average of 68% of the students per year have received need-based assistance under Title IV of the Higher Educational Act.

Our undergraduate program in biology has the objective of providing students with the necessary skills, knowledge and competence to work successfully in industries, government agencies and to pursue graduate degrees in related areas.

Graduates of this program will be able to:

- develop new chemical and molecular techniques in the prevention, diagnostics and disease control,
- identify and recommend procedures for the solution of biological problems,
- solve genetics and immunology issues such as molecular structure comparisons using computers
- execute quality control validation tests of techniques and procedures that guarantee the product
- perform DNA and protein analyses
- develop basic science related computer skills that will help graduates improve their performance at the workplace or graduate school environment.

Technology integration and course redesigned

A set of ten instructional modules has been developed to be used as a laboratory manual for BIOL 4019 (http://cetempa.upr.edu/prof/pa0501/cursos/pa0501c01/login.asp).

Each instructional module includes:

- objectives- state the learning outcomes and what students are going to perform
- pre-test- a quick online quiz
- introduction- relevant information on the specific topic that include animations, computer simulations, video clips, as well as other related web links
- materials needed to perform the practical experience
- experimental activity- detail scientific protocol to accomplish the objectives. It may include computer simulation, video clip and virtual laboratories showing students how to assemble and use a specific equipment
- focus and inquire questions - provide an outline upon which more detail can be integrated into an appropriate perspective
- laboratory report- students present their findings and conclusions in an organized manner
- post-test - a quick online quiz
- references.

Each instructional module has been uploaded onto a server to be accessed online through the MET-Center website Course Management Software. Before starting a laboratory exercise, students were expected to have reviewed the explanatory components of the corresponding module and were subject to a quick online quiz, which is immediately graded, to demonstrate preparedness. On each laboratory exercise students have the opportunity to use a Wireless Tablet PC to access specific instructional modules, follow instructor explanation, take notes about important concepts and experimental observations, perform all the mathematical calculations needed for the experimental procedure, analyze data, and answer the pre-test and post-test. Partial analysis of the data could include preparation of graphics and tables, and completing *what-if* exercises. For quick reference on the instructional module, students could find the information needed to answer inquiries that usually arise during the implementation of a particular technique. At the end of each laboratory section, the students were given a quick online post-test that is graded immediately to demonstrate the knowledge obtained after the completion of the laboratory exercise.

The instructor uses a Tablet PC to explain the technical information and the laboratory procedures, as well as to create and organize concept maps and show related mathematical calculations. Classroom assessment techniques can also be used by the instructor to assess the students' misconceptions or adequate preparation for the laboratory exercises.

ASSESSMENT

BIOL 4019 is taught twice a year. This study was conducted with two different groups of students, the first one on the spring semester of 2006 and the second group on the fall semester of 2006. Student outcomes were assessed by group oral presentations, student satisfaction surveys, assessment on gains between pre- and post-test results and the instructor's critical observations. The online pre-test and post-test contain 7 multiple-choice or matching/ordering questions. The students also completed an end of the semester online survey. Answers to survey questions measure the degree of student's satisfaction with the new teaching techniques as well as how the new technologies have positively or negatively affected them. The pre-test, post-test and survey results for each student were saved and maintained in a database.

RESULTS

Assessment between pre- and post-test

The averages for the pre- and post-test scores for the spring semester of 2006 and the fall semester of 2006 are show on Figure 1 and Figure 2, respectively. On the spring semester of 2006 the post–test for module seven were not saved on the data base due to a technical malfunction, therefore those results were missing in the graphics and the statistical analysis. Students on the spring semester of 2006 showed an increase from pre-test to post-test average score (figure 1). Except in module 2 and 10 where some students fail to answer correctly the quantitative problems on the post-test. This shows that more time has to be dedicated to teach the areas where quantitative problems are relevant to the topic.

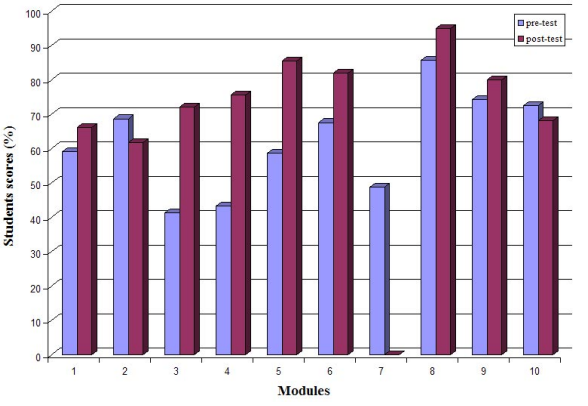

Figure 1. Pre and post-test average scores for the spring semester of 2006. The post–test for module seven were not saved on the data base due to technical malfunction.

This difference was statistically significant (pair sample t-test, $t = -5.27$, $p < 0.001$; Table 1).

Table 1

Results for the assessment on the spring semester of 2006

	N	Mean	StDev	SE Mean
Pre-Test	105	60.68	33.60	3.28
Post-Test	105	77.55	28.51	2.78
Difference	105	-16.88	32.79	3.20

95% CI for mean difference: (-23.2222, -10.5302)
T-Test of mean difference = 0 (vs not = 0): T-Value = -5.27 P-Value < 0.001

Students on the fall semester of 2006 showed an increase from pre-test to post-test average score (figure 2). This difference was also statistically significant (pair sample t-test, $t = -3.38$, $p = 0.001$; Table 2). Although there are noticeable differences in outcomes, modules 2 and 10 show declines in post-test scores both semesters. Similarly, three additional modules (4, 5

and 8) showed negative trends the second semester. The consecutive declines in module 2 (Cellular environment: pH and buffers) and 10 (SDS-PAGE: Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis) may be due to misunderstanding of the mathematical concept presented on them such as: buffer dilution from a stock solution and protein molecular weight estimation using excel graphics, among others. This will be addressed in future semesters. Students registered on the fall semester of 2006 had a previous knowledge of the pre-and post-test system, which may increase their desire to be more prepared prior to class. This perhaps explains the smaller difference between the pre and post-tests and also the negative trends in modules 4, 5 and 8.

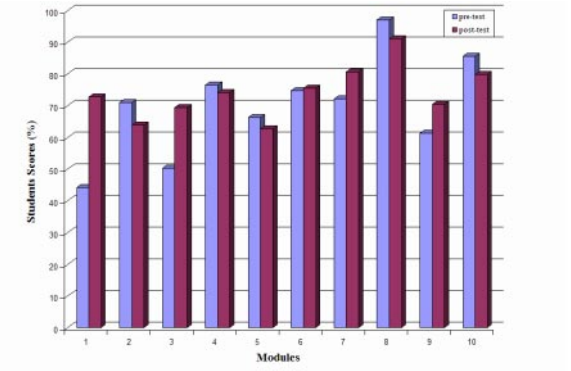

Figure 2. Pre and post-test average scores for the fall semester of 2006.

Table 2
Results for the assessment on the fall semester of 2006

	N	Mean	StDev	SE Mean
Pre-Test	159	65.16	30.59	2.43
Post-Test	159	73.34	24.68	1.96
Difference	159	-8.18	30.57	2.42

95% CI for mean difference: (-12.97022, -3.39456)
T-Test of mean difference = 0 (vs not = 0): T-Value = -3.38 P-Value = 0.001

Student survey

The satisfaction survey evaluated in general the value of the computer-based modules in relation to the learning goals. It also evaluated the value of the Table PC technology for the analysis of experimental data and for strengthening the students' computers skills. The results for the spring semester of 2006 and the fall semester of 2006 survey are summarized on Tables 3 and 4, respectively. The responses were generally positive. Students found the modules useful as learning tools, as well as user-friendly, interactive and visually oriented, and a discovery-based method of instruction. Sixty seven percent of the students for the spring semester of 2006 and 88% of the students for the fall semester of 2006 found the Tablet PC as highly valuable tool to solve research problems and for numerical and graphical analysis. It is clear that the concept of using a computer as a research tool was taught more effectively on the second semester than on the first one.

Oral presentations

The group oral presentations for the spring and the fall semesters of 2006 were compared with the previous fall semester of 2005. Although the score for the spring and the fall semesters of 2006 were 3.4% and 5% higher, respectively, than the spring semester of 2005, these differences were not statistically significant (One way ANOVA, f = 2.19, p = 0.154).

DISCUSSION

The integration of instructional modules and Tablet PC multimedia learning tools helped the students to develop a good understanding of the laboratory techniques and their applicability to research and industrial work. Students were able to come out of the lab with a better grasp of the experimental outcomes, rather than postponing data analysis well after the experiment takes place. The survey results showed for the spring semester of 2006, first semester using the modules and the Tablet PC technology, - that some students have problems with regarding the computer as a research tool. To overcome this in the second semester (fall semester of 2006) the instructors designed and included in the first laboratory exercise an introductory Tablet PC workshop. In the workshop, students learn the necessary basic skills to operate the Tablet PC and the multimedia tools present in the computer-based modules. They also learn how to use of computer as a research tool to obtain information toward solving the problems they encounter in the development of a particular technique.

One of the most important aspects of the project is its potential to substitute the traditional method of teaching the science laboratory course for a new model that facilitates the learning process and provides time

Table 3
Results of the student's satisfaction survey for the spring semester of 2006

	NA*	Poor	Fair	Good	Excellent
Were the modules helpful in your comprehension of the material?	0	0	0	67	33
Was the material easily understandable?	0	0	0	83	17
Was the subject matter covered in depth?	0	0	17	50	33
Were the pre and post-test helpful in preparing you for the test?	0	0	33	50	17
Were the videos, images, and animations helpful in your understanding of the experimental procedures?	0	0	33	33	34
How helpful was the integration of the Tablet PC technology to the comprehension of the material?	16	17	0	17	50
How helpful was the integration of the Tablet PC technology to the analysis and interpretation of data generated by the experiments?	17	16	0	0	67
How helpful was the integration of the Tablet PC technology to the development of basic computer skills?	0	16	17	17	50
How helpful was the integration of the Tablet PC technology as an investigative instrument to the development of problem solving skills?	0	16	17	17	50
How would you categorize your experience utilizing the computer-based modules and the Tablet PC technology?	0	0	16	17	67

Values are percentages
* Not Applicable

Table 4
Results of the student's satisfaction survey for the fall semester of 2006

	NA*	Poor	Fair	Good	Excellent
Were the modules helpful in your comprehension of the material?	0	0	0	25	75
Was the material easily understandable?	0	0	0	25	75
Was the subject matter covered in depth?	0	0	12	25	63
Were the pre and post-test helpful in preparing you for the test?	0	0	12	13	75
Were the videos, images, and animations helpful in your understanding of the experimental procedures?	0	0	0	13	87
How helpful was the integration of the Tablet PC technology to the comprehension of the material?	0	0	0	50	50
How helpful was the integration of the Tablet PC technology to the analysis and interpretation of data generated by the experiments?	0	0	0	38	62
How helpful was the integration of the Tablet PC technology to the development of basic computer skills?	0	0	12	38	50
How helpful was the integration of the Tablet PC technology as an investigative instrument to the development of problem solving skills?	0	16	17	17	50
How would you categorize your experience utilizing the computer-based modules and the Tablet PC technology?	0	0	0	0	100

Values are percentages
* Not Applicable

flexibility for the students (GIBBONS *et al.*, 2004; HEERMAN & FUHRMANN, 2000). This model allows the students to take control of their learning process by making predictions, performing experiments and mathematical calculations, and strengthen their problem solving skills (FISHER, 2001; MILLER *et al.*, 2006; SMITH *et al.*, 2006) as opposed to having the material presented to them orally by an instructor. The fact that many students prefer this model is evidenced by their request to extend it to other Biology Laboratory courses such as Immunology, Virology and Zoology. A very positive sub product of the model is that it also contributes to develop the much needed basic information technology skills of the undergraduate students that can later carry on to other courses and, after graduation, to their future jobs.

This project has significantly contributed to improving faculty academic and professional performance. In essence, the tools and methods utilized in this project transform the instructor's roles from being a lecturer to being a laboratory facilitator who guides and coordinates student performance in the laboratory setting (SMITH *et al.*, 2006). The use of the Tablet PCs enables the instructor to reduce the time required for classroom management. This additional time can be used to provide guidance and assistance to students, thus improving student-instructor interaction. The use of the Tablet PCs also does improve the teaching of some topics because it allows easy access to content from web pages that contain relevant information. This instrument also helps to introduce new student activities for in-class group. The Tablet PCs will also make possible the design of new and stronger assessments tools that will allow the instructor to receive instantaneous feedback on student comprehension. Through this project the instructors developed the technical and instructional competencies to serve as an in-house trainer for those interested in learning how to use computer-based modules and the mobile technology in an educational setting.

In the present study, the author used pre-test and post-test tools to evaluate student learning and knowledge achievement throughout particular laboratory exercises. The author also compared the results for the 2006 group oral presentation with those of a previous semester where the traditional approach was conducted. The researcher believed that effects in pre-test, such as memorizing it's results and carry on to the post-test (SCHARFENBERG *et al.*, 2006) may not exist in her research environment. For future works a control group will be included in the treatment design. This approach will allow to control as many variables as possible, as well as finding out additional valuable information besides the original intended (KEEVES, 1998).

CONCLUSIONS

The use of the computer-based modules and the mobile technology in science laboratory courses significantly contribute to improve on student, and faculty, academic and professional performance. These provide students with computer and problem solving skills and a depth of comprehension of laboratory techniques and experimental procedures. The faculty, on the other hand, gains the opportunity to constantly revise the course, adopt new outcomes and assessment strategies and share the results of experimenting new teaching methodologies. Projects like the one presented here help increase the quality and quantity of minority students who successfully complete baccalaureate degrees in science, technology, engineering, and mathematics (STEM; HOLTZCLAW *et al.*, 2006). The University of Puerto Rico at Aguadilla and the Natural Sciences Department are committed to continue with the successful integration of new Information Technologies into the teaching-learning process and are especially interested in enriching the teaching of traditional courses with multimedia resources and applying computer-based instructional methodologies.

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Physical science lab quizzes: results from test item analysis

Exámenes en laboratorios de física: análisis de los resultados de las preguntas de selección múltiple

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Abstract

Teachers have a difficult task when they assess students properly because they cannot directly measure mental constructs such as "knowledge" and "understanding". Teachers can use multiple choice items as a way to estimate student knowledge in a fast, inexpensive and reliable way, assuming that the items are properly designed and validated. Test item analysis borrows from large-scale test theory and can reveal significant facts about a classroom test, including technical flaws and errors of judgment made by the item writer, multiple interpretations of ambiguous items, poor distractors, and student misconceptions. This paper applies the concepts of item difficulty and discrimination in the context of the analysis of lab quizzes offered to more than 100 students enrolled in the "Introduction to Physical Science" course at Arkansas Tech University. The author found that most of the test items were easier than expected but with reasonable and high discrimination. However, several items were flagged as too easy or too difficult. Given their marginal level of discrimination, these items should be further analyzed for possible modification.

Key words*: assessment, testing, multiple-choice items, difficulty, discrimination, physical science*

Resumen

Dada la naturaleza abstracta de los constructos "conocimiento" y "entendimiento", evaluar directamente el aprendizaje de los estudiantes es difícil. Los ítems de opción múltiple son una manera rápida, accesible y confiable de estimar cuánto los estudiantes aprendieron en clase, pero sólo si se redactan de manera válida y confiable. El análisis de los exámenes por el maestro, utilizando algunas técnicas comúnmente aplicadas a las pruebas estandarizadas, puede revelar problemas con los ítems, tales como ambigüedad, errores de juicio del que redacta el ítem y distractores de poca calidad. También puede revelar aspectos positivos, tales como concepciones erróneas de los estudiantes. El propósito de este artículo es aplicar los conceptos de dificultad y discriminación al análisis de varios exámenes de selección múltiple completados por más de 100 estudiantes matriculados en el curso Introducción a las Ciencias Físicas en Arkansas Tech University. Se descubrió que muchos de los ítems tenían poca dificultad y mediana-alta discriminación. También se observó que algunos ítems eran muy fáciles o muy difíciles y de baja discriminación, por lo cual se examinarán y revisarán posteriormente.

Palabras clave*: evaluación, preguntas, selección múltiple, dificultad, discriminación, ciencias físicas.*

INTRODUCTION

The college faculty have the ineludible task of assessing students, which is one of the most difficult tasks because mental constructs cannot be measured directly. In fact, many publications address the theoretical foundations of assessment, the best ways to measure student learning, and the limitations of different types of assessments (CROCKER & ALGINA, 1986; HOGAN, 2007; JOHNSTONE & AMBUSADAI, 2001; NITKO, 1996; RACE, 2003; THORNDIKE, ANGOFF & LINDQUIST, 1971). A subgroup of these, focalise on science assessment (MINTZES, WANDERSEE, & NOVAK, 2000; ENGER & YAGER, 2001; HEDGES, 1966). Recently, many physics education researchers have turned their attention to assessment (DANCY & BEICHNER, 2006; HAZEL, LOGAN & GALLAGHER, 1997; SLATER, RYAN & SAMSON, 1997; O'BRIEN-PRIDE, VOKOS & MCDERMOTT, 1998; THORNTON & SOKOLOFF, 1998).

According to EBEL & FRISBIE (1986), tests as a whole can be assessed for a number of characteristics, including:

1. *Relevance*: Is the test a reflection of the content that was covered in class?
2. *Balance*: Does the test contain a weighted sample of all the important knowledge, skills, and understandings covered based on teacher emphasis in class?
3. *Efficiency*: Does the test yield a large number of independently scorable responses per unit of testing time?
4. *Specificity*: Is the test score near chance levels for a person not familiar with the subject matter?
5. *Difficulty*: Does the test have manageable difficulty levels?
6. *Discrimination*: How good is the test in identifying students with different levels of subject matter knowledge?
7. *Validity*: Does the test measure what it is intended to measure?
8. *Reliability*: Will students with the same level of subject matter knowledge, obtain about the same score on the test?

Multiple choice items are one of the most common ways to assess student knowledge in a fast and an inexpensive way. If instructors properly design and validate them, the multiple choice items can yield much information about the students' physics knowledge. Instructors may find a problem with the use of multiple choice items on a class test because they might not have the proper pedagogical content knowledge (SHULMAN, 1986) to prepare them, especially in how to write clear and concise stems, one unequivocally correct answer, and four plausible but unequivocally incorrect distractors to reduce guessing (EBEL & FRISBIE, 1986). Even if the items come from a publisher's test bank, how does the instructor knows that the items are high-quality?

Item analysis reveals significant facts about a test, including technical flaws and errors of judgment made by the item writer, multiple interpretations of ambiguous items, and student misconceptions (EBEL & FRISBIE, 1986). In order to improve test validity, instructors must analyze multiple choice items *ex post facto* and use that information to modify or eliminate