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Supplemental Learning in the Laboratory: An Innovative Approach for Evaluating Knowledge and Method Transfer

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Abstract

The Multi-Rule Quality Control System (MRQCS) is a tool currently employed by the Centers for Disease Control and Prevention (CDC) to evaluate and compare laboratory performance. We have applied the MRQCS to a comparison of instructor and computer-led pre-laboratory lectures for a supplemental learning experiment. Students in general chemistry and analytical chemistry from both two- and four-year institutions performed two laboratory experiments as part of their normal laboratory curriculum. The first laboratory experiment was a foundational learning experiment in which all the students were introduced to Beer-Lambert's Law and spectrophotometric light absorbance measurements. The foundational learning experiment was instructor-led only, and participant performance was evaluated against a mean characterized value. The second laboratory experiment was a supplemental learning experiment in which students were asked to build upon the methodology they learned in the foundational learning experiment and apply it to a different analyte. The instruction type was varied randomly into two delivery modes, participants receiving either instructor-led or computer-led pre-laboratory instruction. The MRQCS was applied and determined that no statistical difference was found to exist in the QC (quality control) passing rates between the participants in the instructor-led instruction and the participants in the computer-

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ASSOCIATED CONTENT

Supporting Information

Supporting information includes laboratory protocols and instructor guides.

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led instruction. These findings demonstrate the successful application of the MRQCS to evaluate knowledge and technology transfer.

ABSTRACT GRAPHIC

Keywords

First-Year Undergraduate; Second-Year Undergraduate; Upper-Division Undergraduate; Continuing Education; Analytical Chemistry; Laboratory Instruction; Computer-Based Learning; Distance Learning; Assessment; Learning Theories

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Evaluation of knowledge and method transfer in the laboratory setting has been the source of growing interest with the increase in education technology resources and the availability of technology in the classroom.[1] Curriculum delivery methodology continues to evolve, offering many courses as virtual learning experiences tailored to the individual student.[2, 3] While a number of studies show resulting improvement in student understanding and notional application, the effects on laboratory practice are not as widely explored. We therefore present the use of the Centers for Disease Control and Prevention's (CDC's) Multi-Rule Quality Control System (MRQCS) to compare knowledge transfer for the two pre-laboratory lecture delivery modes received during a supplemental learning experiment.

EVALUATION TECHNIQUES IN THE LABORATORY

Research Design

In the following study, two laboratory experiments were monitored in which all participants (>18 years old) were enrolled as part of their normal laboratory curriculum. Students were selected by convenience sampling of laboratory sections, and students had the same instructor throughout the period of the study. Beer-Lambert's Law and spectrophotometric absorbance measurements were introduced to students in a foundational learning experiment. During this foundational experiment, students used a Beer-Lambert's Law calibration curve to determine the amount of red food coloring in common soft drinks (see supporting information for instructor and student laboratory guides).[4] The foundational learning experiment was instructor-led, and participant performance was evaluated against the instructors' characterized performance using the Centers for Disease Control and Prevention's (CDC's) Multi-Rule Quality Control System (MRQCS).[5] The second laboratory experiment was a supplemental learning experiment in which students were asked to build upon the methodology they learned in the foundational learning experiment and apply it to a different analyte of interest. In this experiment, participants used a biuret method combined with a Beer-Lambert plot to determine the aspartame concentration in an unknown (see supporting information for laboratory protocol and instructor guide).[6] Performance was evaluated in the same way for this experiment using CDC's MRQCS, but the instruction type was varied randomly between two delivery modes: 1) participants receiving either instructor-led pre-laboratory instruction or 2) participants receiving computer-led pre-laboratory instruction.

Participants were from four academic institutions, varying in two- and four-year degree programs (granting both Associates and Bachelors degrees) and enrolled in either general or analytical chemistry laboratory. Participant performance was not evaluated until both laboratory experiments were completed and all data was submitted for analysis. Laboratory instructors also submitted system characterization data sets for each laboratory experiment. The system was defined as the laboratory, the laboratory's spectrophotometers, and a particular lot of quality control (QC) materials containing the analyte of interest. Performance parameters for the system were established using the characterization data set submitted by the instructors and was used to evaluate successful application of the experiment by the participants. A characterization data set consisted of at least 20 analytical analyses carried out by laboratory instructors, each containing a calibration curve and high- and low-level quality control (QC) materials. No more than two analyses were performed daily, and the characterization was conducted over the course of two to four weeks.

For the supplemental learning experiment, the content of the instructor-led and computer-led pre-laboratories were the same. The computer-led curriculum was developed using Lectora Inspire vX.6 (8457), ©Trivantis Corporation 2010 (Figure 1). The computer-led instruction consisted of content slides and interactive questions capable of providing immediate feedback on student responses and emailing student responses to instructors prior to the laboratory. The computer-led pre-laboratory was completed by participants prior to the laboratory experiment, and since no technical difficulties were reported by the participants, application of the software was not suspected to affect the final laboratory assessment outcomes. Knowledge transfer was evaluated for both the instructor- and computer-led laboratory lectures using the MRQCS.

Data Collection and Analysis

The MRQCS was used to evaluate a single lot of QC materials in each laboratory's experiments. The benefits of this evaluative technique were that false assay rejections were reduced when compared to single rule QC procedures. Each laboratory experiment was validated in one laboratory, transferred to the three additional laboratories, and characterized in all four of the laboratories. The characterization data generated by the laboratory instructors was used to establish QC parameters for subsequent data collected within each laboratory system. The participants' data were evaluated against the QC parameters established by the instructors using the MRQCS (Figure 1). All enrolled students (n=77), including general chemistry students and advanced analytical chemistry students, participated in the foundational laboratory with only the instructor-led pre- laboratory lecture. The same students then participated in the supplemental learning laboratory but were randomly separated into groups that received either instructor- or computer-led pre-laboratory lectures, respectively. Both groups still had access to the instructor during the laboratory session and were allowed to ask questions. A flow-chart describing the foundational and supplemental laboratories is provided in Figure 2A. Of the 77 participants who collected data for analysis in both laboratories, only 54 participants passed the foundational laboratory. Only these 54 students' data were used to evaluate the success of the delivery modes in the second laboratory since these participants were the only ones who demonstrated mastery of the foundational knowledge and method transfer. The resulting MRQCS evaluation of laboratory application outcomes is provided in Figure 2B. Sample populations were compared by two population proportions, and the p-value was determined using the standard normal (Z-) distribution table.(7)

Data Interpretation

In the foundational learning experiment, there was no statistical difference found between participants with either a general or advanced background (students enrolled in analytical chemistry laboratory) in chemistry laboratory experience. The passing rates of the general and advanced students were 81 and 83 %, respectively (Figure 2B). The passing rate for the laboratory activity was evaluated based on a QC comparison to the laboratory's characterized QC values using the MRQCS. These passing rates indicate that both the general and advanced populations were successfully provided the knowledge and skills needed in order to complete the foundational learning exercise.

A comparison of the pre-laboratory lecture delivery platform for the supplemental learning laboratory revealed no significant difference between the instructor-led and computer-led training. The modes of delivery were assigned randomly, and both groups included both general and advanced students. The instructor-led participants passed 86% of the runs, whereas the computer-led participants passed 85% of the runs, demonstrating that the computer-led supplemental learning was as effective as instructor-led supplemental learning. The advanced students had a 100% QC pass rate for the supplemental learning, while general students had a 76.5% and 76.2% pass rate for instructor- and computer-led, respectively. A statistically significant difference (p-value < 0.01) was seen between the general and advanced students in the supplemental laboratory, however, with the more advanced group demonstrating higher levels of assay precision and accuracy compared to the group with only general laboratory experience. This result was not unexpected since the second experiment was supplemental to the first, and the advanced participants had additional laboratory experience. In fact, all the participants from the advanced group passed the supplemental exercise. This result further supported that whether the advanced-level participants were subjected to computer-based learning or instructor-led lecture, they were able to successfully complete the laboratory experiment, likely due to the benefits of their additional experience in laboratory training.

Discussion

The laboratory design including foundational and supplementary learning was based on Lev Vgotsky's Zone of Proximal Development (ZPD), also known as scaffolding.(8) Students were projected to experience two of the three zones in ZPD. The initial foundational learning experience introduced the students to Beer-Lambert's Law, where most students were expected to experience learning in their comfort zone, or ZPD zone 1. The second laboratory experiment or supplemental learning experience built upon the students' ZPD zone 1 learning. New topics such as reaction chemistry, which required mixing and a wait time before analysis, were added to the supplemental laboratory, where the majority of students were expected to experience proximal development, or the ZPD zone 2. It was also during the supplemental learning laboratory that students received either instructor- or computer-led pre-laboratory lectures. An evaluation of the knowledge transfer during the two lecture delivery modes was completed using the MRQCS.

The MRQCS has provided QC evaluation for millions of measurements at CDC, including the National Health and Nutrition Examination Survey.[5, 9] The MRQCS employs multiple QC pools and evaluates both within-run and among-run variability. The multiple rules allow the QC system to detect unacceptable systematic or random error. The advantage of multi-rule as opposed to single-rule QC systems is the decrease of false-rejections while maintaining high-confidence in the accepted or passing runs.[10] For example, in this study, a single-rule QC system would have rejected any result outside of two standard deviations from the mean. The MRQCS, on the other hand, applied additional rules to evaluate a run outside of two standard deviations, such as determining if the preceding run was also outside of two standard deviations.

There have been a number of evaluations of laboratory training,[11–13] but the one reported here uses application-based outcomes to inform the instructor of successful knowledge and method transfer. By applying the MRQCS to evaluate the two lecture delivery modes during a supplemental learning experiment, no significant difference was observed between the computer-based and instructor-based pre-laboratory lectures. These results suggest that computer-led pre-laboratory instruction can be used as an alternative to traditional instructor-led instruction for supplementary learning.

CONCLUSION

Since instructor-led training can be difficult to accommodate in a larger population, through distance learning, or during inter-laboratory exercises, it is important to evaluate the capability of different modes of knowledge and method transfer. This study uses CDC's previously published MRQCS to provide a statistical evaluation of data obtained during a supplementary learning experiment. The delivery mode for the supplemental learning experiment was varied to compare instructor- and computer-based lectures. The MRQCS was successfully applied and used to determine that no significant difference was observed between the two modes of delivery for the supplementary experiment. These results suggest that computer-led pre-laboratory instruction is an operative alternative to traditional instructor-led training in supplementary learning laboratories.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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The study protocol was approved for exemption by the institutional review board of Emmanuel College and coverage extended to Cumberland University, Lander University, and West Kentucky Community and Technical College. The Centers for Disease Control and Prevention provided non-research technical assistance which was determined not to constitute engagement in human subjects research, 45 CFR 46.101(b) (1) and (2).

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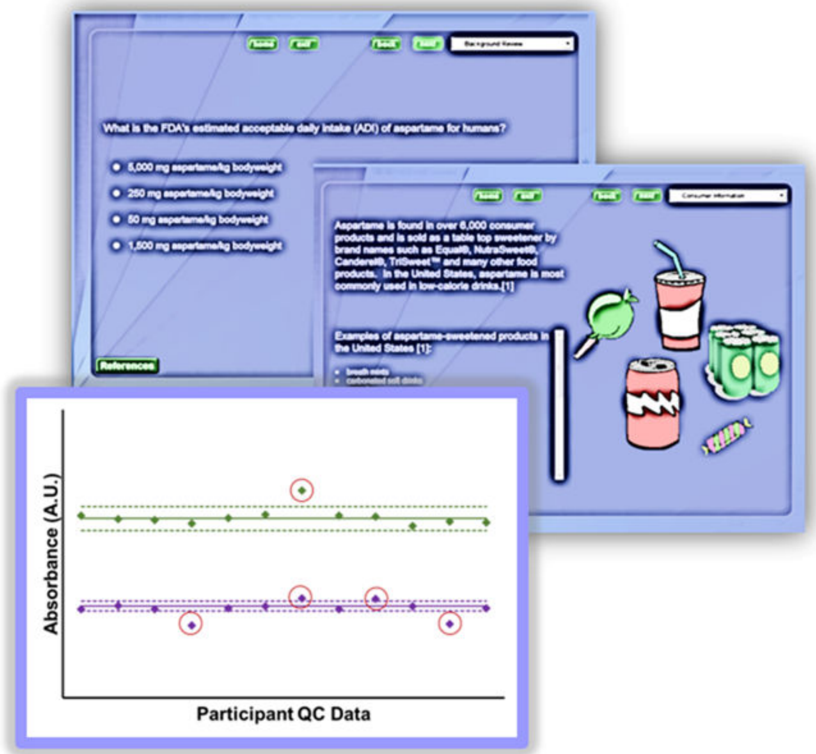

Figure 1. Example screen capture of computer-led training and MRQCS evaluation.
Participants received either computer-led or instructor-led pre-laboratory training prior to the supplemental laboratory exercise. The participants were asked questions throughout their training and were provided immediate feedback on their responses. The plotted QC high (green) and low (purple) values from participants are shown within the performance parameters of the system collected by the laboratory instructor, where the solid line is the average response of the QC, and the dotted line is three standard deviations of the average. Data points circled in red are outliers and were marked as fails during MRQCS evaluation.

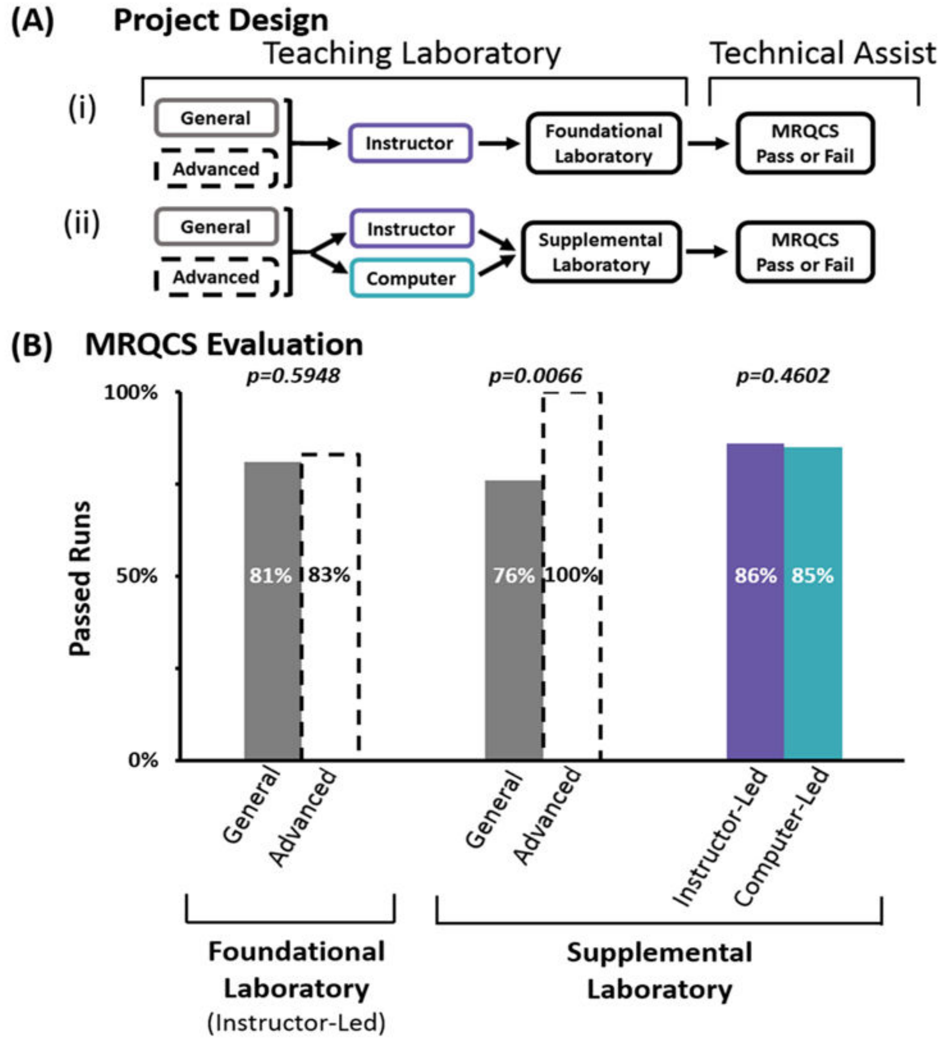

Figure 2. Statistical Analyses of Laboratory Application Outcomes.

(A) A flow-chart describing the teaching laboratories performed by the students is provided for both the foundational laboratory and the supplemental laboratory. **(B)** The MRQCS evaluation of student data is shown, where the gray bars represent the general chemistry students, the dashed outline bars represent the advanced students enrolled in analytical chemistry laboratory, and the purple and teal bars represent the instructor- and computer-led instruction for the supplemental laboratory, respectively.