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Applying Neurological Learning Research to an Online Undergraduate Science Laboratory Course

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Abstract

Neurological research has demonstrated that pre-test verbal preparation improves performance. The well-tested Tower of London puzzle can assess cognitive skills of a wide age range of participants. Preschoolers who talked to themselves about future puzzle moves had greatly improved Tower of London performance over those without such preparation. For adults, similar results are found with more neural activation in higher brain areas. We previously demonstrated the benefit of verbal preparation on daily quiz scores in an introductory astronomy lecture course. Two separate classes were taught, one including students discussing a pre-test verbal multiple choice question and the other not. In the lecture course, the interactive group performed 23% better on their final exam than the conventional group, likely due in part to the neurological language learning process that occurred during discussions. In the present study, for an online astronomy laboratory course, we present the effect on final exams of discursively answering pre-test learning objective questions. The discursive group scored significantly better (12% higher) than the class without such preparation. These findings are consistent with neuroscientific research on the usefulness of language in improving performance even on non-linguistic tasks.

Our discussions with students taking undergraduate Science, Technology, Engineering, and Mathematics (STEM) physics and astronomy courses reveal their difficulty in coping with the mathematical calculations required for the course. We posited that neurological learning research on the active use of language in the learning of non-linguistic, higher-level cognitive tasks can be applied to modify courses to help ease this difficulty.

Research on student learning and teaching requires a rigorously defined and well-tested task or tasks, which can be content specific (such as course material) or involve cognitive assessment (such as those used in clinical tests of intellectual ability). In neuroscience research, the Tower of London puzzle accesses the frontal lobes of the cerebral cortex, the seat of higher-level cognitive processing (Shallice, 1982). This well-tested and defined non-verbal, problem-solving, multiple-step task is used in neuropsychology to assess planning skills (related to

executive functioning.) The Tower of London puzzle is shown in Figure 1 (Berg & Byrd, 2002; Berg, Byrd, McNamara, & Case, 2010). The Tower of London can be utilized to measure cognitive ability in a wide range of participants, from preschool through older adults, by increasing the levels of complexity (Berg & Byrd, 2002; Berg, et al., 2010). Data collected from this task can be used to determine cognitive ability via neuropsychological behavioral testing.

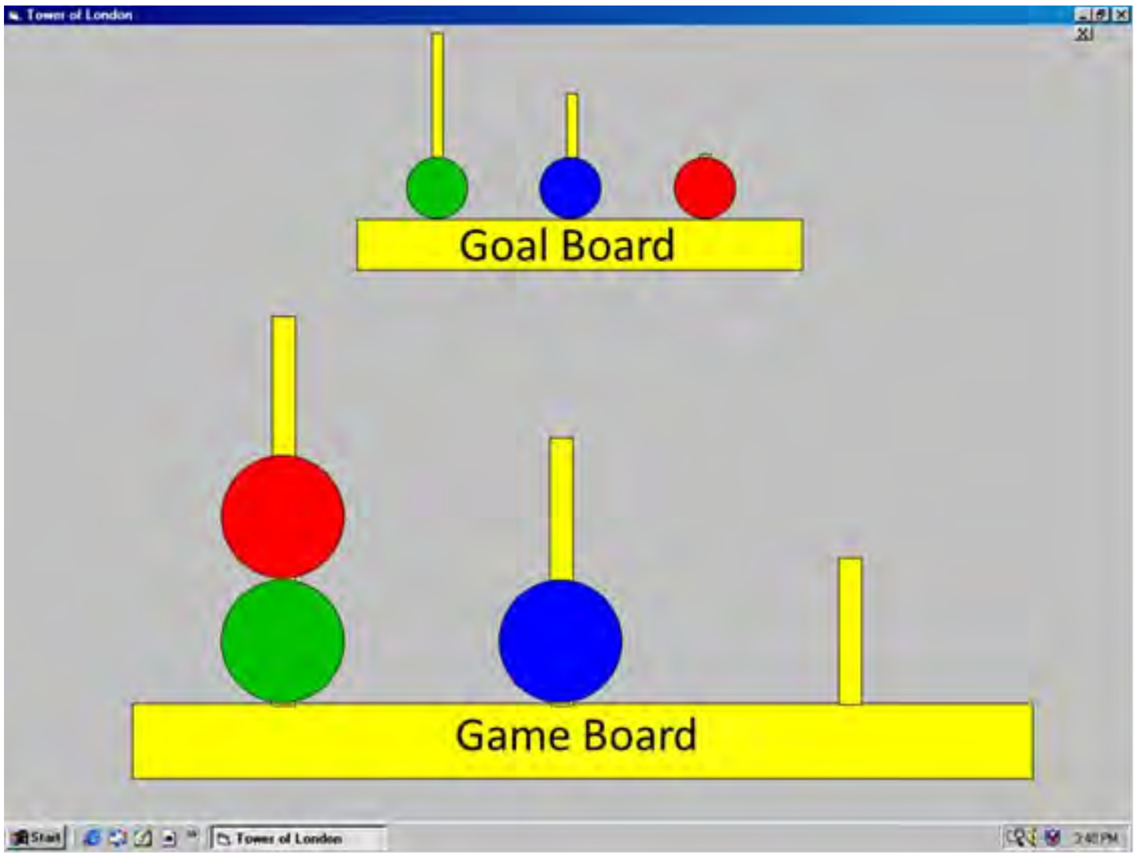

Figure 1. Depiction from a computer program of the Tower of London task. This task requires a minimum of two steps to move one ball at a time at the bottom of the screen to match the configuration at the top of the screen. The task can be varied to require as few as one and as many as nine steps to achieve the match, making it possible to create very easy to very difficult problems that can be used with children as young as preschool-age and through adulthood.

Studies have shown that preplanning prior to starting the Tower of London task helps individuals find the solution to the task. This effect of preplanning is seen even in preschool children, whose higher-level cognitive processes are just beginning to develop. Four- and five-year-old preschoolers can be highly motivated participants when the task is presented as a puzzle or game, with colorful animations and stickers as rewards for efficient solutions. Research involving preschoolers has found that children who actively talk about future moves in the Tower of London task (rather than making trial-and-error moves) greatly improve their performance on the task (Byrd, van der Veen, McNamara, & Berg, 2004).

Using functional magnetic resonance imaging (fMRI), Newman, Greco, and Lee (2009) demonstrated that adults who silently use words to think through a solution to a task prior to

undertaking the task engage higher level neural areas in the frontal lobe. Head movement, including speaking aloud, is not permissible during an fMRI scan, so the study participants had to reason silently. Newman and colleagues found that the fMRI scans from adults who used silent preplanning prior to solving the Tower of London task showed more neural activation during the planning period, especially in the frontal areas of the brain that serve higher-level thinking. The study suggested that the conscious but silent use of language resulted in a higher level of performance on the task.

Other studies have validated the use of verbalization by university students to learn specific course content. These studies are reviewed by Duncan (2006), and emphasize the value of in-class discussion of questions (along with a strong promotion of clickers) in undergraduate physics lecture courses. Duncan's review also summarizes our previously published work in which we describe the application of neurological learning research to college introductory astronomy lecture courses (Byrd, Coleman & Werneth, 2004). In this paper, we extend our previous research to ask, "Do neuroscientific findings of better task performance after use of task-related language apply to learning (as measured by final exam scores) in introductory college lecture and online astronomy courses taught by the same professor?"

Method

This study was performed in two steps. First, we compared final exam scores from two lecture classes in Astronomy 101, using data from our previous study on quiz performance (Byrd et al., 2004). Second, we compared final exam scores from two groups of students enrolled in otherwise identical online Astronomy 101 laboratory course sections, which differed only in the use of a pre-examination language assignment of answering a set of Learning Objective Questions (LOQs) before the final exam.

Astronomy Lecture Course Comparison

Two Astronomy 101 lecture classes were taught during successive May Interim terms at the University of Alabama; in these interim terms, students enroll in only one course that meets three hours daily for three weeks. As described previously (Byrd et al., 2004), one class was interactive, in which students discussed sample exam questions with their classmates. In the second class, a more conventional approach was taken in which students were given sample exam questions to study on their own.

Astronomy Online Laboratory Course Comparison

Online course design. In the 12 modules of the self-paced, online course, students view lectures, build and use equipment, take measurements, do calculations, and reach conclusions. In an observational notebook, students submit digital camera photographs of street light spectra, the moon, bright stars, and planets. As shown in Figure 2, students also study the optical components of a kit, construct a telescope, and then perform different observational activities.

Figure 2. Online laboratory assignment. Students assembled components into a 7x refracting telescope plus a steady mount made of boxes containing rolled aluminum foil, then used the telescope to perform various assignments for the course.

Course learning objectives were written by a Department of Physics and Astronomy faculty committee and were consistent with the formats found in Mager (1984), as recommended by a number of universities for use by new instructors and faculties for writing course objectives. The course objectives were written to provide an appropriate survey of astronomical observational discoveries and techniques typically covered in an introductory course, such as those in leading texts and by Brissenden, Duncan, Greenfield, and Slater (1999) in their survey of introductory courses in the United States. For example, learning objective*s* for the first module included identification of basic “astronomical observational processes” in the sky, such as “visual phenomena in the sky, the daily motion of all objects in the sky due to rotation of the Earth and differing locations of the observer.”

The course objectives for each module were available to all students. Students answered open-book multiple choice quiz questions for each of 12 modules and took a closed-book multiple choice final exam. Final exams were completed online, were closed book, and took place in an approved proctored setting. Both the module quiz questions and final exam multiple choice questions were derived from the learning objectives. The open-book module quiz multiple choice questions provided ample coverage of the course learning objectives. The final exam multiple choice questions were similar to those of the module quiz questions.

The lab course’s final examination demonstrated content validity and validity through item analysis of the individual test questions. The final exam showed content validity because its

multiple choice questions were written to reflect the stated objectives for the course as a whole and objectives for each of the 12 course modules. The shorter module exam questions also measured competence on materials reflecting course objectives for each module. The final examination was also shown to demonstrate criterion validity. All test questions in the final examination were selected from a 100-item test bank that represented material covered in the full range of the course.

The individual questions were developed and refined over a period of several semesters using standard statistical procedures such as item analysis to determine which questions discriminated best between higher versus lower performing students. Through experience, the course instructor determined 30 multiple choice questions to be the appropriate length for such an exam. By using the Blackboard course management system, the course instructor was able to present each of the students in the course with an individual computer-generated final examination whose 30 questions were selected at random. Thus, final exams for any two students are likely to be composed of different questions with only a modest fraction of questions in common. The most obvious advantage of this approach is to reduce student cheating; however, this approach also ensures that statistical conclusions are not likely to be skewed by individual questions.

Learning objective questions. To test the effect of a pre-assessment active language-based component on learning, we developed a set of Learning Objective Questions (LOQs) to be completed before the final exam. These verbalization questions are discursive, in contrast to the multiple choice module quizzes and final exam. The multiple choice open-book module quiz questions and closed-book final exam questions cover the learning objectives thoroughly for students who did not receive the LOQs. In this way, we can determine whether an active discursive language-based component helps improve scores on the multiple choice final exam.

Study groups. The first group of students were enrolled in Year 1 and designated as the "No LOQ" group. These students were provided with the open-book multiple choice quiz questions for the 12 modules. Students were given the individual module learning objectives plus the opportunity to chat with other students online. Students in the second group were enrolled in the course in Year 2 and designated the "Yes LOQ" group. These students were also provided with the quiz questions and access to online chat with other students. In addition, the Yes LOQ group was given Learning Objective Questions (LOQs), which they could answer in a short essay format for extra credit prior to taking the multiple choice final exam. Other than the short essay option for the Yes LOQ group, the course material and format were identical between the two groups.

Study participants. A total of 41 college-age or older students participated in the study. There was no prerequisite for the course. Assigning student gender based on first names, 24 were female, 26 were male, and 1 was unidentifiable by name. There were 17 students in the No LOQ group and 24 students in the Yes LOQ group.

Outcome measure. The outcome measure was the average final exam score of the No LOQ and Yes LOQ student groups. We determined the average final exam scores for each group by summing the scores and dividing by the number of students.

Statistical Analysis

For both the lecture and online course studies, we determined the average final exam scores for each student group by summing the scores and dividing by the number of students. In

addition, we performed a post-hoc, Bonferonni-corrected analysis of between-subject *t*-tests to demonstrate statistically significant differences between the two groups within each study (conventional vs. interactive in the lecture course study; No LOQ vs. Yes LOQ in the online course study).

Results

Astronomy Lecture Course Comparison

The final examination scores for the interactive lecture class, in which students discussed sample questions with their classmates, were significantly higher than the final exam scores of the more conventional class, in which students studied the questions individually. The final exam average was 80% for the interactive class compared to 57% for the conventional class. The value of the student's *t*-test parameter, $t\ (67) = 6.97$ gives a probability, $p < .001$ of the two score distributions being the same. A probability of $p = 0.05$ or smaller was taken as an affirmative indication of a non-random difference.

Astronomy Online Laboratory Course Comparison

The mean score for the Yes LOQ class was 77.72%; the mean score for the No LOQ class was 65.62%. The Yes LOQ group mean was significantly higher than that of the No LOQ group by more than 12%. Using student's *t*-test, $t\ (39) = 2.39$, which corresponds to a $p = 0.02$ that the difference could occur randomly, a highly statistically significant result.

Students within the Yes LOQ group had the option (but were not required) to submit written answers to the learning objective questions. We were interested in which students in the Yes LOQ group chose to use this study tool: the lower scoring students (who most needed the point benefit of this learning tool to earn a decent or passing grade) or the higher scoring students. A greater number of students with scores in the lower half chose to answer the LOQs. A student's *t*-test yielded $t\ (28) = 2.36$, $p = .025$, with almost two-thirds of the students with scores in the lower half answering the LOQs. There was only a 0.025 probability p that the difference between LOQ participation of the two sets of students could have occurred randomly.

Discussion

In this study, we found that application of neuropsychological research on the use of language, whether to lecture or online introductory college astronomy courses, improved final exam scores. We previously conducted a study on the use of task-related language to improve quiz scores in a college introductory astronomy lecture course (Byrd et al., 2004). We found that quiz scores were higher in the groups that used overt language, both spoken and written, to prepare for a multiple choice quiz given at the end of the class period, compared to a group that was given the questions to study individually. This study validates our previous findings, by demonstrating that, compared to the interactive lecture class, the final exam scores were lower in the conventional lecture class, which had been given sample multiple choice questions with answers to practice or study outside of class. This suggests that simple availability of the questions was not as effective as a learning strategy compared to studying through linguistic interaction.

Discussion among all students in the online course was allowed through posting comments on a chat space for each module; however, because students were working on

different modules at different times, discussions among students in real time—like those possible in the interactive lecture course—were difficult to replicate online. We therefore took the LOQ approach, which provided an opportunity for deliberate and conscious use of language as a means of enhancing student learning. Similar to our findings for the interactive vs. conventional lecture course, the average final exam score was statistically significantly higher for the group of students who received the LOQ prior to the exam compared to the group who did not receive the LOQ.

Of further interest is the determination of which level of student profited most from the deliberate use, or non-use, of language, spoken or written, to plan responses to questions related to course learning objectives. For the online laboratory course, a greater number of lower performing students in the Yes LOQ group chose to complete and submit the LOQ for extra credit, with an improved mean score on the final exam for the class as a whole.

The performance of the students in the two lecture classes corroborate the findings of the fMRI studies of adults described by Newman et al. (2009). These fMRI studies revealed that subjects who consciously and deliberately used words and phrases to think about the solution to a problem (i.e., the Tower of London task) prior to acting showed activation of a greater portion of the frontal lobe than those who did not make this conscious effort. The results indicated that this conscious effort to reason resulted in a higher level of performance on the task. Likewise, although the study materials presented to the two lecture classes were identical, the group that used more verbal interaction with their peers in class performed much better on the final exam than those who passively read through their material individually. This suggests that less of the frontal lobe was activated in the latter group, contributing to poorer final exam scores.

Likewise, the online laboratory course study compared the final exam scores of two online astronomy laboratory courses that had only one major difference: the opportunity to write and submit online responses to questions that were based on the course and individual module learning objectives. Again, the group who engaged in conscious use of language to learn the course content (the Yes LOQ group) performed better on the final exam than those who did not. It is likely that the frontal lobe was activated to a greater extent in the Yes LOQ group as they used language to think through their answers before writing them on the computer.

Summary of the Four Classes

In both research studies, the conclusions were statistically significant. In the lecture course study, the verbally interactive class performed 23% better than the conventional class. Similarly, students in the online lab course who had the opportunity to answer LOQs performed 12% better on the final exam than students who did not have the opportunity to submit written answers to the LOQs. Neuropsychological research shows the usefulness of language in improving scores on non-linguistic tasks because of the greater activation of the “higher-level thinking” part of the brain, the frontal lobe. We plan to perform a similar study of an online astronomy lecture course. The message teachers and professors can take from these studies is that even for online or conventional science courses, students learn better via inclusion of active linguistic learning activities.

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