Our discussions with students taking undergraduate Science, Technology, Engineering, and Mathematics (STEM) physics and astronomy courses reveal their difficulty transiting from everyday use of language to the mathematical calculations of the course. Neurological learning research can help “bridge this gap.”

Research on student learning and teaching requires a rigorously defined and well-tested task. This can be a content specific task, such as course material, or a cognitive assessment task such as is used in clinical tests of intellectual ability. In neuroscience research, the “Tower of London” puzzle assesses the frontal lobes of the cerebral cortex, the seat of higher level cognitive processing (Shallice, 1982). This is a well-tested and well defined problem-solving task. It requires multi-step planning toward a solution, similar to, but more flexible and wider in range of difficulty than, the Tower of Hanoi (Berg, Byrd, McNamara, & Case, 2010). The Tower of London task with increased levels of complexity has been used up through older adults for cognitive ability testing, both in neuropsychological behavioral testing and neuroscience research.
A number of studies have shown that preplanning prior to starting helps in the solution of the Tower of London task. This has been seen in preschool children when higher level cognitive processes are just beginning. Four- and five-year-old preschoolers serve as highly motivated participants as the task can presented as a game with colorful animations and stickers as rewards for efficient solutions. One important well-substantiated finding of the preschooler research studies is that talking about future moves (rather than just making moves) greatly improves children’s performance on the task (Byrd, van der Veen, McNamara, & Berg, 2004).

Brain imaging of regions of neural oxygenated blood flow, functional MRI (fMRI), also provides evidence that thinking through a solution before undertaking it engages higher level neural areas (movement such as speech is not possible during the actual fMRI). When adult participants were given preplanning time prior to solution, and then time to solve the Tower of London, more neural activation was found during the planning period, especially in the frontal areas of the brain serving higher level thinking (Newman, Greco, & Lee, 2009).

**Research Study**

In an application of these neuropsychological results to undergraduate science teaching, we carried out a preliminary modification of a University of Alabama on-line introductory astronomy laboratory course. We compared a standard introductory astronomy laboratory course with a slightly modified one that encouraged pre-exam solving of course material before the final exam. Only one modification was made to the course to enable evaluation of whether the modification helps the students.

In both the original and modified classes students buy lenses for a small telescope, spectroscopic grating glasses, a device to measure angular size and parallax, a cardboard “star and planet finder”, and a downloaded computer planetarium program. In the twelve modules of the course, students see lectures, learn to build and use equipment, take measurements, do calculations, and reach conclusions. Students submit digital camera photographs of their equipment, street light spectra, the moon, bright stars, and planets as part of an observational notebook. Students also answer open book multiple choice questions after completion. Finally, there is a closed-book multiple choice final exam which counts for one-third of the course grade.

Specific learning objectives were used in writing the course as a whole, and for each module. These course objectives were available for students to read before starting each module.

We examined closed-book proctored final exam scores of two groups of students (separate classes, all online). The first group consisted of those who were given the opportunity to discursively answer questions based on the learning objectives (Learning Objective Questions, LOQs). The students in the first group answered these LOQs for extra credit prior to taking the final exam. This would correspond to the preschoolers’
“talking to themselves” about steps in the solution planning prior to solving the task. The second group members were not given the LOQs for extra credit. All else was similar in terms of the students, material covered, format etc.

Results

There were \( N = 41 \) participants in the two groups combined. Students were college age or older. There was no prerequisite for the course. Assigning student gender based on names, 24 were female, 26 were male, and 1 was unidentifiable by name. There were 17 students in the “No Learning Objective Questions Group,” and 24 students in the “Yes Learning Objective Questions Group.”

The mean \( (M) \) of the final exam score for the sample of students who had the opportunity to answer the LOQs was better than that for the sample of students who did not. The Yes LOQ group \( M(SD) = 77.72 \% (15.97) \). The No LOQ \( M(SD) = 65.62 \% (16.00) \). Here, the quantities in the parentheses are the standard deviations \( (SD) \). Using Student’s \( t \) test, \( t (39) = 2.39 \), which corresponds to a probability \( p = 0.02 \) that the difference could occur randomly. The Yes LOQ group mean is significantly better than the No LOQ group by over 12 percent.

Within the class that was given the opportunity to answer the LOQ, were there differences in the final exam scores between those who answered the LOQ and those who chose not to do so? We investigated this question in several ways. Comparing means, those who answered the LOQ \( (N=13) \) had lower mean exam scores, \( M (SD) = 73.52 \% (14.98) \), than those who did not answer the LOQ \( (N=11) \), \( M (SD) = 82.69 \% (26.34) \). This is not a contradictory result to the overall 12% improvement of those in the “Yes LOQ” group. We think that students who needed the extra credit were the ones who answered the questions.

Finally, we looked at the exam scores as high, medium, and low performers, and the same pattern is clear. Again, this may have occurred because the lower-scoring participants desired the extra credit. Of the top third of Exam Grades (range 97.00%-89.92%) = 38% completed the LOQs. Of the mid third of Exam Grades (range 89.91%-76.59%) = 50% completed the LOQs. Of the bottom third of the Exam Grades (range 76.59%-36.96%) = 75% completed the LOQs.

Conclusions and Implications for STEM Courses

Despite the moderate size of our sample, the conclusions were statistically clear. Across the two groups, students who had the opportunity to answer the LOQs performed 12% better on the final exam than those who did not have the opportunity. This makes sense as the lower-scoring students may desire the extra credit. Answering benefits these students by raising their final exam scores. Answering the LOQs helps those students who really need help.
This project was only an initial application of a strategy based on earlier neuropsychological and neuroscience “Tower of London” results. More generally, these results show the efficacy of relevant discursive extra credit work, particularly for more poorly performing students. This approach should be useful in other STEM courses to bridge the language-mathematical gap.

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The dissemination of this material was partially supported by the National Science Foundation under Grant No. 0554594. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.
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