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Abstract

Research shows brain-based learning is achieved best when the students are in an active, low-stress state (Jensen, 2008), and people have unique learning styles that facilitate the assimilation of new knowledge (Gardner, 1983). However, current testing practices hinder the creation of an optimal learning environment, because teachers feel they have to build test-taking skills and spend valuable educational time teaching in ways they believe are not best practices. Changes in the brain can be seen with highly sophisticated imaging technology such as magnetic resonance imaging (MRI), functional MRI, and positron emission tomography (PET) (Drevets & Raichle, 1998). This imaging technology is underutilized in educational applications, partially because of ethical concerns. The call to eliminate instructional practices which are counterproductive can be strengthened with studies such as MRI and PET scans which show imaging changes when brain-based learning and best practices are applied.

Introductory science courses serve as gateways to majoring in science, technology, engineering and mathematics (STEM). Each year a significant number of students, including those who enter college as declared science majors, are failing introductory college science courses (Seymour & Hewitt, 1997). The researchers' institution has recently been examining ways to improve student learning in these introductory classes. Of particular concern are high rates of students earning unproductive grades (D, Withdraw or Fail) in introductory science courses (often over 30%). Mathematics faculty also share this concern, and a placement test has recently been implemented at the researchers' institution to assist students in selecting the appropriate courses for their needs.

An understanding of the factors related to student performance in introductory science courses is necessary to help a growing number of students learn and succeed in STEM courses. There is reason to believe that students' self-efficacy beliefs regarding STEM courses are a factor in determining student performance in these courses. Previous research findings (Seymour & Hewitt, 1997; Zimmerman, 2000) also suggest that students' understanding of learning goals in their courses, scientific reasoning ability, and critical thinking skills may all be linked to success in science coursework. Identifying

the factors that predict student success in introductory science classes will allow resources to be more efficiently allocated and, ideally, will result in improved learning outcomes for students.

Self-Efficacy

Self-efficacy is a construct developed to describe the impact of a person's belief in her/his ability to complete a given task (Bandura, 1997). Self-efficacy is context-dependent; a person can have a high self-efficacy for a given task in one context (such as a study group meeting) and a low self-efficacy for the same task in a different context (like a classroom exam in science) (Bandura, 1997). Correlations have been reported in other academic content domains between self-efficacy and performance (Chemers, Hu & Garcia, 2001; Pajares & Miller, 1995).

Research on the impact of self-efficacy in mathematics has been an active topic of study, particularly in terms of vocational choice and academic course taking patterns (Campbell & Hackett, 1986). Results indicate that changes in math self-efficacy result from successes or failures on tasks, and that interest in the academic domain tends to change in a way that positively correlates with success or failure as well (Betz & Hackett, 1983; Campbell & Hackett, 1986). Data also indicate that female students tend to rate luck as a factor in success more frequently than do male students, which then becomes a factor in persistence rates for male and female students (Campbell & Hackett, 1986). Betz and Hackett (1983) further found that *math* self-efficacy plays a significant role in the selection of college *science* majors over other career choices.

In comparison, little research has been conducted on students' self-efficacy in the science classroom. However, this topic is becoming an area of interest by researchers. As self-efficacy is strongly correlated to performance on task, this construct is of interest for its' explanatory power. In Canada, a study involving high school and college science students examined how student science self-efficacy changed in the high school to college transition as measured by college success after their first year (Larose, Ratelle, Guay, Senecal & Harvey, 2006). They found that high school GPA was the best predictor of college success generally, and, along with socio-economic status, this was used as a control factor. The study found that "trajectories of science self-efficacy beliefs predicted interest in science, science achievement, and persistence in science and technology programs" (Larose et al., 2006, p. 388).

Fencl and Scheel (2003) examined student self-efficacy toward science. Their study found that drop rates and desire-to-drop rates in introductory science courses differ based on the type of pedagogy used in the classroom. Students in classrooms whose instructors used a mix of traditional and innovative teaching strategies fared the best. They also reported a small positive correlation between competition for grades and a positive overall classroom climate, which was unexpected based on other literature. However, the most traditional pedagogies in this study produced students with *reduced* confidence in their abilities. The classrooms using mixed pedagogies tended to produce increases in self-efficacy, and tended to be the classrooms reporting the most positive climate. Fencl and Scheel (2003, 2005) report that the self-efficacy mediated link between pedagogy and retention remains to be probed.

Recently, Lindstrom & Sharma (2009) developed a short, single factor instrument probing student self-efficacy in physics. This work is discipline specific, and development was based on a more general self-efficacy instrument that was used while

developing an instrument specific to the teaching/learning context for college physics students. Consistent with other work, they found that female students consistently reported lower self-efficacy in physics than male students, even when controlling for academic achievement. Male students with no high school physics background tended to have the highest physics self-efficacy, which may indicate "male overconfidence". Lindstrom and Sharma (2009) also found that, for females with high school physics experience, there is a correlation between self-efficacy and academic performance, which was not the case for males thus indicating that female students may be more receptive to feedback. No study is yet reported that indicates whether feedback could be better tuned to aid male students or whether male students simply tend to be more resistant to changes in self-efficacy.

Classroom Climate

Seymour and Hewitt (1997) performed a three-year ethnographic study to discover factors that influenced undergraduate students to leave science, math and engineering (SME) majors for non-science majors. One of the most important findings was that there was no difference by performance, attitude, or behavior between students that left SME majors, and those that continued in SME majors (Seymour & Hewitt, 1997). The difference between these students was the development of coping strategies, attitudes, and serendipity. The authors also found that, contrary to common faculty assumption, most switchers do not leave as a result of academic inadequacy – indeed, female switchers on average had higher GPAs than male non-switchers in this study.

In studies of physics programs that are high performers (consistently producing above the average numbers of female physics majors), it was found that the overall learning culture of the department is crucial in recruitment, retention, and graduation of all students, but particularly female and minority students. If a supportive and welcoming culture (one that still includes intellectual rigor, however) does not exist, attrition is not a cataclysmic event, but rather the proverbial "death by a thousand cuts" (Whitten et.al., 2003; Whitten et.al, 2004, Whitten et.al, 2007). Appropriate intellectual challenge and rigor are crucially important to a program, but challenges must have meaning to both the faculty and the students. Furthermore, there must be a purpose for these challenges other than simply culling out the undeserving. The learning environment should be one of respect, not one of ridicule or sarcasm. Aloof faculty can also (inadvertently) turn talented students away. This culture is established by the faculty, but is perpetuated from student to student.

Scientific Reasoning

A test of formal scientific reasoning was first developed in the 1970s (Lawson, 1978). This test has since been adapted to a multiple-choice format from its' initial open response format. As critical thinking is often one of the over-arching goals both for a university education as well as for courses in STEM fields, scientific reasoning abilities are also important. Further, the abstract nature of much STEM coursework means that students that are not capable of using deductive reasoning and abstract thought at the beginning of a course are at a distinct disadvantage, with a greater amount of material to master in order to succeed in a given STEM course. Recent work indicates that interactive coursework in the sciences, which requires students to develop, explain, and defend reasoning, holds potential for aiding students in developing these critical thinking abilities, as measured by Lawson's test. (Pyper, 2011).

In an effort to improve student learning in introductory science classes, the researchers felt it was important to understand what factors were influencing students performance and leading to high numbers of unproductive grades. Therefore, the researchers designed a pilot study that was conducted in 2007-2008 to examine factors impacting student success in STEM classes. Based on the results of the pilot study, the researchers then developed a list of potential factors believed to impact the success rates of students in introductory science and math courses and tested those factors in a follow-up study. The design and results of both studies are discussed below.

Pilot Study: 2007- 2008

Participants

The Fall 2007 undergraduate headcount was ~6500 students. Of those, the population was 32.1% African-American, 57.2% White, and 61.4% female. In that academic year, there were 1871 students with declared majors in the College of Science (Biology, Chemistry, Geology, Mathematics, Nursing, Health Science, Computer Science, Psychology and Sociology as well as associated secondary science and math majors). New undergraduates in Fall 2007 (regular admission) had an average SAT verbal score of 515, and an average SAT math score of 508. If taking the ACT instead, new regular admission students had an average ACT English score of 21.2, and an average ACT Math score of 20.3.

There were 247 participants in the pilot study. Of those participants, 132 had average verbal SAT scores of 518 and average math SAT scores of 514. 53 had average English ACT scores of 20.6 and average ACT Math scores of 20.7. These scores are statistically indistinguishable from the student population as a whole.

Instruments

Science and mathematics courses require students to link ideas logically about cause and effect. Logical thinking is a necessary, but insufficient, condition for success in science and mathematics. The fourth stage of development in Piaget's model is referred to as formal operational, which includes many skills considered necessary for success in science and mathematics such as proportional reasoning, abstract thinking, and control of variables during hypothesis testing (Inhelder & Piaget, 1958). Many studies have shown that the formal operational developmental stage is not automatic. College science and mathematics instructors may be unaware of these developmental milestones and may make the incorrect assumption that all students in their classrooms are equally ready to tackle the cognitive tasks required for reasoning in science and mathematics.

Lawson (1978, 2000) developed a multiple-choice version of a Classroom Test of Scientific Reasoning (CTSR) that purports to measure the level of development between concrete and formal operational. This test captures some classic Piagetan tasks and includes some tasks requiring students to reason through the meaning of experimental results by presenting the results in an easy to grasp pictorial form. This instrument was chosen because it is short, easily scored by machine, and readily available via the author. The CTSR has been shown to be a useful predictor for success in various academic classes (reviewed by Lawson, 1985) and has also been applied to a physics context (e.g., Coletta, Phillips and Steinert, 2007). At the time of the pilot study, no mention of using the CTSR as a University-wide diagnostic has been reported.

Method

In order to examine factors impacting student success in STEM classes, the authors conducted a pilot study in 2007-2008 by administering the multiple choice version of Lawson's Classroom Test of Scientific Reasoning (CTSR) (Lawson, 2008) to 247 students taking introductory courses in health science, geology, chemistry, physics, math and computer science in the Fall 2007 semester.

After collecting data in the pilot study, CTSR scores were examined looking for potential correlations between student scientific reasoning level and GPA, grade in the science course, grade in the most recent math course, and student admission status. ANOVA was also performed, analyzing gender, major, and CTSR score. In this analysis, majors were grouped into categories of life and health sciences, physical sciences, computational sciences, social sciences, and other.

Results of the pilot study

There was a relationship between student scientific reasoning abilities and GPA, student grade in the course, student grade in the most recent math course, and student admission status, although the largest correlation was that of student GPA. The correlation coefficient between student GPAs and scores on the CTSR was calculated to be 0.37. The correlation coefficient between student grades in their math or science courses and CTSR scores was calculated to be 0.224. The most recent math course grade was also marginally of significance, with a correlation coefficient of 0.204. However, the admission status of students only had a correlation coefficient calculated to be 0.19.

ANOVA results indicated that there was no significant difference between groupings of majors and CTSR scores, with overall mean scores reported at 13.9, with a standard deviation of 4.83. When CTSR score is examined for variance with respect to gender, mean scores for female students (12.8, standard deviation 4.80) and male students (15.7, standard deviation 4.33), the difference was significant at the $p = 0.003$, $F = 2.14$ level. While there is a significant difference by gender overall, for those students in physical science and in computational majors, the difference disappears. Descriptive statistics of the pilot study are provided in Table 1.

Based on the results of the pilot study, the authors developed a list of potential factors believed to impact the success rates of students in those introductory science and math courses. These factors included reading comprehension, classroom climate, intelligence quotient, scientific reasoning, science self-efficacy, self-regulation skills, temperament, work-school conflict, attitude, critical thinking skills, and mismatch of teaching goals with student perception of those goals. Factors that were identified as potentially changing over the course of a semester were pre- and post-tested in order to measure any changes.

Table 1: Results of ANOVA performed on pilot study data, examining Scientific Reasoning Scores by gender and by major. Results are significant (p = 0.003, F = 2.141)

Major (by category)	gender	Mean	Std. Deviation	N
life and health	female	12.41	4.566	61
	male	15.28	4.099	18
	Total	13.06	4.600	79
physical	*female*	*14.80*	*4.984*	*10*
	male	*15.70*	*3.840*	*20*
	Total	15.40	4.190	30
computational	*female*	*16.70*	*6.567*	*10*
	male	16.79	4.860	19
	Total	16.76	5.390	29
Social science	female	13.50	5.831	8
	male	14.60	3.847	5
	Total	13.92	5.008	13
other (not COS)	female	12.22	4.325	65
	male	15.48	4.634	29
	Total	13.22	4.652	94
Total	female	12.82	4.800	154
	male	15.71	4.326	91
	Total	13.89	4.829	245

Secondary Study: Fall 2008-Spring 2009

Participants

During Fall 2008 and Spring 2009, participants were recruited from introductory science classes to complete the surveys chosen to test factors developed in the pilot study. Participants completed some measures in a designated classroom on campus and the remaining measures were completed online. In Fall 2008, 62 students from first semester introductory chemistry and biology classrooms were initially recruited to participate in this study. In Spring 2009, an additional 75 students were recruited to participate, this time from geology and biology classrooms. However, due to the length of the overall study, attrition among student participants was high, and only 57 students completed all measures that were a part of the study. However, a larger number completed a fraction of the measures in the study.

At the researchers' institution, the Fall 2008 undergraduate headcount was ~6800

students, with a total headcount of almost 7900 students. The student body was 32.6% African-American, 56.2 % White, and 59.9 % Female. New regular admission undergraduate students in Fall 2008 had an average SAT critical reading score of 513 and an average SAT math score of 507. If taking the ACT instead, new regular admission students had an average ACT English score of 21.0 and an average ACT Math score of 20.2. (Columbus State University, 2009) The average age of participants was 22. The ethnicity of study participants broke down as follows: 63% White, 30% African American, 3% Biracial, 2% Asian, and 2% Hispanic. Females were 70.2% of the study population. As in the pilot study, participants reported mean SAT or ACT scores that were not statistically different from the mean of the institution's population as a whole.

Instruments

This study examined factors determined to potentially impact student success in math or science classes. These factors were

- intelligence quotient, measured using Raven's Standard Progressive Matrices (Raven, 1998).
- reading skills (comprehension, vocabulary, and rate), measured using the Nelson-Denny Reading Test (Brown, Fishco, & Hanna, 1993).
- scientific reasoning, measured using the multiple-choice version of Lawson's Classroom Test of Scientific Reasoning, as described above (Lawson, 2000).
- ability to analyze arguments, as measured by the California Critical Thinking Skills Test (Facione & Facione, 1993).
- Various dimensions of adult temperament including self-regulation, and extraversion, as measured by the Rothbart Adult Temperament Questionnaire (Rothbart, Ahadi, & Evans, 2000).
- Conflicts between work and school, including number of hours of work and how work and school relate to one another using Butler's Job-School Relations survey (Butler, 2007).
- Science self-efficacy beliefs, which have been demonstrated to correlate (in general domains) with success on tasks attempted (Fencl, & Scheel, 2003).
- Attitudes about science and the nature of science, and potential for self-success in science, using science attitudes surveys (Views About Science Survey for fall 2008 and Scientific Attitude Inventory for spring 2009).
- Student impressions of classroom environment, as determined via classroom interactions, curriculum relevancy, and their own attitudes towards the course.
- Students' ranking of learning goals as compared to the rankings of learning goals provided by their instructors.

The data from this study were then correlated with student data related to demographic and academic variables collected from the university database, including entrance exam scores (SAT/ACT and math placement exams), admission status, GPA at the beginning of the course where available, year in college, course grade, gender, and ethnicity. The factors that are of interest in this analysis were SAT/ACT scores, the CTSR score, science self-efficacy, and student perception of classroom climate.

Sources of Science Self-Efficacy Survey

The authors chose to use the Sources of Self-efficacy in Science (SOSESC) instrument developed by Fencl and Scheel (2003) at the end of the semester to ascertain which sources of self-efficacy were predominant and as an overall measure of

science self-efficacy. The researchers expected higher self-efficacy to correlate with prior academic success (e.g. GPA) and standardized test scores as well as grades in the course. We expected prior academic success (e.g. GPA) to lead to a sense of performance accomplishment and to positive emotional arousal. Scores on this instrument are normalized to 5.0 maximum, in replication of the Likert score used by students.

Classroom Environment

Classroom climate is a way of describing the learning environment that the student experiences. By this, we do not mean to discuss the facilities, the pedagogical methods, or even the content of the course and its' pace. The classroom climate is a construct that includes all of the factors that aid or encourage students to succeed, or to fail, in their efforts to master the material presented in the course. The learning environment should be one of respect and support, perhaps even enthusiasm, not one of ridicule or sarcasm. Students in STEM "weed-out" classes often describe the environment as one in which only the worthy or chosen students receive positive attention, and worthiness does not always correlate to ability. Success in science has been linked to classroom factors such as level of interactivity in class and classroom climate (Seymour and Hewitt, 1997).

For this study, the authors developed a classroom environment questionnaire based on factors from the research literature. The questionnaire had 30 questions that students rated on a 5-point Likert scale (strongly agree to strongly disagree) and 5 short answer questions. The Likert scale questions were split into four sub-scales: instructor climate (how the instructor impacts the learning climate for an individual student – welcomes questions, wants the student to do well, comfort in asking instructor for help); curricular issues (difficulty and pacing of the content, grading on a curve); attitudes (student attitudes about the classroom and learning science); and environment (competitive vs. collaborative, study groups, etc).

Implementation of the Study

Data Analysis Techniques

The data analysis focused on examining factors that would be predictive of student success (as defined by end of course grade). First, descriptive statistics were run on all variables of potential interest in order to determine mean values and potential correlations with end of course grade. At this point, a hierarchical regression analysis was performed on the data set, using end of course grade as an outcome variable. Results and implications of this analysis are reported below.

Internal Correlations and Descriptive Statistics

Descriptive statistics for variables of interest are provided in Table II. Correlations were used to explore the nature of relations between end-of-course grade and potential predictors. Mean and standard deviation values are also reported below for each factor. Course grades were calculated, using a scale of 0.0 to 4.0 to represent a grade of A, 3.0 to represent a grade of B, and so on, in replication of calculations for GPA.

Table II: Descriptive Statistics and Correlations with potential factors that may relate to student end-of-course grades

Variable	Mean	SD	N	r Between course grade and other factors
Course Grade	2.44	1.24	63	
Age	22.19	7.156	62	-0.382**
Lawson's CTSR (pre-test)	13.49	4.62	63	0.426**
Lawson's CTSR (post-test)	14.32	5.076	63	0.402**
SAT/ACT Z score – math	0.198	0.718	51	0.326*
SAT/ACT Z score – verbal	0.329	0.754	51	0.285*
Self-Efficacy	3.44	0.663	63	0.511**
Classroom Environment	3.50	0.441	62	0.249

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

The maximum possible score for the CTSR is a 24. Scores between 12 and 18 on this instrument indicate that the student is in a transitional phase between concrete reasoning and hypothetical-deductive reasoning skills. Science self-efficacy scores were normalized, and so the maximum score for this instrument would be reported as a 5.0. To maximize the utility of the standardized test scores, these scores were normalized to a 'Z-score' using the national mean and standard deviation (further broken down by year for SAT). A Z-score has a value of zero if the student scored the mean score. The Z-score has a value of 2 when the score is two standard deviations (SD) above the mean. Using the Z-score allowed us to combine the SAT and ACT scores for the math into a single variable and the SAT score for critical reading and ACT score for English into a single variable. Factors that correlate with end of course grade include pre-test score on Lawson's CTSR, the Z-score for SAT/ACT in both math and verbal domains, and science self-efficacy.

Hierarchical Regression

The researchers performed a hierarchical regression of the data, using end of course grade as the outcome variable. Age and SAT/ACT Z-scores were predictors used in the first step as factors that were not subject to change in any way through instruction. Lawson's CTSR pre-test scores were predictors in the second step as these scores were potential predictors of success in introductory classes. Finally, self-efficacy and classroom environment scores were the predictors analyzed in the third step of the hierarchical regression. From the initial regression model, it became clear that SAT/ACT Z scores (both math and verbal) and Classroom Environment did not contribute to this predictive model. For this reason and because of the sample size, these factors were removed from the hierarchical regression (Results are presented in Table III). The model indicates that pre-test scores (t-value, p-value) for scientific reasoning as well as science self-efficacy appear to be predictive of student grades in introductory science classes, explaining 46% of the variance ($F= 15.089$, $p<0.01$).

Table III: Results of Hierarchical Regression Analysis with End-of-Course Grade as Outcome Variable.

Hierarchical Regression	R^2	F	*df*1, *df*2	β
Step 1: Age	0.066	3.887	(1,55)	-0.257
Step 2: Lawson's CTSR (pre-test)	0.210	7.198	(2,54)	-0.224 0.382
Step 3: Science Self-Efficacy	0.461	15.089	(3,53)	-0.231** 0.251** 0.517**

Implications and Conclusions

In this study, the researchers' aim was to examine the role of several factors as they relate to student success in introductory science courses with particular emphasis on scientific reasoning and self-efficacy beliefs. To best fit the purpose of this study, student success was represented by the grade in the course. As recent work indicates that certain types of science instruction hold potential for building scientific reasoning abilities, instructors should examine their courses to ensure that students are given ample opportunities to develop and explain their reasoning about scientific ideas (Pyper, 2011). More lecture-like formats, while "efficient" at delivering content to students, appear less effective at providing students the opportunity to develop desired critical thinking and scientific reasoning skills.

The researchers expected that self-efficacy and classroom environment would contribute to success as determined by course grade. From the data, self-efficacy does indeed contribute to these students' success, but classroom environment does not contribute any additional information to this model. Data reported elsewhere indicate that classroom environment factors are important to student success but that these factor appears not to be independent from other factors examined in this study. Little work exists in science self-efficacy, but what does exist indicates that mastery experiences, such as those that are available in an interactive classroom where students develop their own models of scientific reasoning and defend their reasoning, have some potential for allowing students to build stronger science self-efficacy (Lindstrom & Sharma, 2009).

There are implications, however, to be considered within the results presented here. Work in the literature indicates that instruction can address the development of scientific reasoning skills. Introductory courses could further emphasize the methodology of science and the systematic use of scientific principles over fact memorization and trust in authority. Although faculty may touch upon these ideas, truly integrating this into coursework is challenging and may require significant time, effort, and support. As well, self-efficacy is an important non-academic factor in student success. Increasing student self-efficacy in science may be an avenue to reducing unproductive grades in science. Ensuring students are challenged appropriately in their introductory science classes and that they are placed into courses for which their background will allow them to succeed will allow students to enhance their self-efficacy. This requires that there be appropriate and enforced pre-requisites for these courses. Mechanisms to accomplish improvements in science self-efficacy are a current topic of research, however, and a subject for future work for the authors.

Further work will also examine the impact of other variables examined in the data acquisition part of the study. It will be of interest to determine whether academic factors such as critical thinking skills, intelligence, or reading skills have any relationship with student success rates in introductory STEM classes. This will also have further implications for retention of students in STEM majors at the researchers' institution and others.

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