Impact of coursework preparing math-deficient university students for sustained STEM achievement

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ABSTRACT

A priority among multiple institutions is to expand the number of students graduating from Science Technology Engineering and Mathematics (STEM) disciplines. Ironically, increasing demand coexists with a decreasing student population who display interest and adequate performance in abstract mathematics. To fill the void, math-deficient students are conditionally accepted into college and university STEM disciplines. Typically these students are not retained. The current study examines the impact of a lab-intensive developmental course, ENTC 1500 on engineering technology students. ENTC 1500 is intended to build foundational problem solving skills and promote linkage of fundamental concepts. This study employs an RD (Regression Discontinuity) design to examine longitudinal data from a 7 year period (2008-2015). The treatment group members (ACT math scores 15 to 21) who pass ENTC 1500 are compared with students they join in a cohort (ENTC 1505). The control group members are not required to take ENTC 1500 by virtue of an ACT math score of 22 or above. Results disclose the treatment effect (cut score = 21.5) is large and statistically significant in mathematics, large and statistically non-significant in major and negligible and statistically non-significant in science. Results suggest ENTC 1500 intervention provides a positive sustained impact.

Keywords: lab-intensive, longitudinal study, Regression Discontinuity design, STEM, student achievement, student retention

INTRODUCTION

According to a recent NCES report, the growing need to get students interested and enrolled into STEM disciplines is being outpaced by the attrition rate of students who leave STEM disciplines once they begin their coursework (NCES, 2014). The NCES report indicates upwards of 69% of students enrolled in STEM disciplines between 2003 and 2009 changed majors or dropped out completely from their post-secondary program. More concerning is that nearly 80% of under-represented minorities drop out; only 20% persist (Pittalwala, 2014). STEM attrition occurs most frequently among students with weak academic backgrounds. Other barriers responsible for the exodus from STEM disciplines include difficulty completing introductory STEM courses; especially in mathematics and science (Barr, Gonzalez & Wanat, 2008; Crisp, Nora & Taggart, 2009). In addition, there is stress to learn competitively; as opposed to cooperatively and impersonal large lecture classes (Seymour & Hewitt, 1997).

In an attempt to fill the deficit, math-deficient students are conditionally accepted into college and university STEM disciplines. Typically, these students are not retained. The issue plagues multiple institutions: educational, industrial and governmental but it can be solved. One sustainable and demonstrably successful solution is presented in this investigation.

The current investigation confronts the practical real-world issue of retaining students who enter a university seeking a STEM degree (in this case a Bachelor of Applied Science in Engineering Technology: civil & construction, electrical, or mechanical) who present with weak math backgrounds and typically lack effective problem solving skills. The solution required ongoing, applied research into the facts—first, to understand the problem; second, to figure out how to solve it (Booth, Colomb, & Williams, 2008).

The forerunner of ENTC 1500 was created in 2002 as a strictly remedial course typically run in parallel with a remedial elementary algebra course (MATH 1501). Then as now, it was intended to address needs of students looking to matriculate into engineering technology. Over time, math standards to enter into engineering technology were raised and the first major overhaul of the course occurred in 2006. Because students were struggling with math, the primary track instituted from 2006 to 2008 was to dedicate the course to strengthening math skills. This resulted in providing a double dose of mathematics; an approach shown to have spotty results (Nomi & Allensworth, 2009). It was an honest attempt but it was the wrong approach.

While reviewing and refocusing of mathematics occur in the current version of ENTC 1500; the goal is to shift from the concept of teaching the substance of what mathematics is to why is it a useful tool for (application) engineers and how engineers in the field apply mathematics in general problem solving and trouble-shooting.

At the study location, a state university, the double dosage of math produced a doubling in attrition in the ENTC 1500 class itself; around 67% of initial signups did not pass the course. A more successful approach was teaching students a problem solving methodology while setting the stage for small group learning in the form of practical lab activities. The attrition rate dropped to 25% following the 2008 redesign. Where prior to 2006, degree completion rates stood at around 6% (AAS & BSAS) of total engineering grads; the 2006 version completion rates dropped to around 3%. The Spring 2015 graduating class snapshot showed 33% of total engineering technology grads (AAS & BSAS) received the “new” ENTC 1500 treatment.

The redesign also produced long term enrollment impacts. Between Fall 2007 and Fall 2008; a time when university undergraduate enrollment had a modest 1.7% increase; engineering technology enrollment fell by 12.1%. On the other hand, a snapshot of the change from Fall 2012 to Fall 2013 showed university undergraduate enrollment declined by 8.1% while engineering technology enrollment suffered a modest 0.8% decrease (University Office of Institutional Research & Policy Analysis, 2013). The percentage of students enrolled in engineering technology who came from the ranks of the treatment group rose from 18% in 2008 to 40% in 2012 arriving at a peak level of 50% in 2013.

In Fall 2014, an alternate mathematics path into calculus (college algebra and trigonometry rather than pre-calculus) was introduced. An unintended consequence was a drop in engineering technology enrollments in ENTC 1500 during academic year 2014. There is a need, as in 2008, to reconfigure flow through the curriculum. For additional details and effects upon this study, see Limitations in the Methods section of this paper.

Preparation of students in engineering and engineering technology should inform practices in other STEM fields (and vice versa). According to the National Research Council (NRC), weaving connections across the STEM disciplines is central to understanding the essence of STEM itself. By this perspective, attention needs to shift from what content should be held in each discipline to the epistemic questions: (1) What is the source of STEM knowledge; and, (2) What assembly of practices and processes transcend each discipline? The NRC-proposed framework speaks to crosscutting concepts (ideas that cut across the STEM disciplines), core ideas (ideas with power across science, engineering, and technology), and shared practices (assembly of practices and processes that transcend the disciplines) (National Academies, 2012). This vision has implications that tie this engineering technology study to wider STEM application and thereby provides a navigational aid to future research.

"Learning always builds on a store of prior knowledge. We interpret and remember events by building connections to what we already know … Repeated … practice helps integrate learning into *mental models*, in which a set of interrelated ideas … are fused into a meaningful whole that can be adapted and applied in later settings" (Brown, Roediger, & McDaniel, 2014, 100, 101).

Because remedial and developmental coursework is often unsuccessful, some researchers have proposed alternatives to produce successful students from those who come to the university unprepared. Due to the complexity involved in the engineering field, Cabrera, Colbeck & Terenzini (2001) recommend "[s]tructuring classroom activities to promote gains in occupational awareness, problem solving, and group skills" (p. 350). For general STEM success targeted at students with low math placement scores, Koenig, Schen, Edwards, and Bao (2012) recommend development of a set of skills: "the ability to create and interpret graphs; proficiency in unit conversion; and the ability to … [write] coherent lab reports on the basis of experimental [empirical] evidence" (p. 24).

The ENTC 1500 course, redesigned in 2008 in the STEM College, School of Engineering Technology, corresponds with the recommendations above as regards problem solving, group skills, graphical creation and interpretation, unit conversions, and write-ups of lab reports (5) all based upon gathering and interpreting empirical data.

The need to shift from providing instruction to producing learning; a movement from means to ends; methods to outcomes was succinctly expressed by John Tagg as he examined the role of undergraduate higher education. "Teaching is valuable if and when it leads to learning … To say that the mission of a college is instruction is like saying the mission of General Motors is to produce assembly lines" (Tagg, 2008, p. 18). In application, John Wooden, legendary basketball coach expressed the role of teacher best. "When I became a high school teacher … it was my responsibility to help every one of my students learn … You don't just throw material out for someone to get … you're always teaching … but you have not taught until they (the students) have learned" (Nater & Galimore, 2006, p. xv, 103).

Tagg is specific as to what the new learning paradigm should be as he contrasted the essence with the traditional college learning paradigm. The mission and purpose should be improving quality of learning rather than quality of instruction. The criteria for success should be a focus on quality of exiting; not a focus on quality of entering students. In other words, to maximize impact, do not fixate on getting ever better students but rather on continuously improving what you do with the students you get. The teaching and learning structure should seek specific learning results; not merely cover necessary material. Learning theory should be based upon an interaction of frameworks; not the mistaken notion that learning is cumulative and linear (Fink, 2003).

Learning is decidedly non-linear; it is best fit by the wave structure of a logistic (S curve) (Son & Sethi, 2006) as are a multitude of dynamic changes: establishment of startup companies, introduction of new products and technologies, biological growth processes and other long-term, long-lasting potential effects (Dent, 1993). Productivity should be defined as cost per unit of learning per student not as cost per hour of instruction per student. The primary faculty role should be to act as designers of learning methods and environments not as lecturers (Fink, 2003).

Educators operate in three modes or roles analogous to theatre production. The first of these is the *sage on the stage*. Exclusivity of this mode of operation; as typically employed, fosters passivity on the part of those students not involved in the dialogue (Dinerstein, 2011). By regarding students as empty vessels whose minds are to be filled; educators discourage the powerful learning effects of student action/reflection and autonomy/self-regulation (Friere, 1970; Greene, 1988; Hooks, 1994). In ENTC 1500, we utilize this mode of operation but strive to toggle down usage as the term progresses.

The second role is the *guide on the side*. Mentoring also provides a means to encourage learning. Where this is regarded as either/or choice; sage on the stage or guide on the side, it can be argued that the former is far more effective (Vizcarrondo, 2006). However, the roles are not mutually exclusive; nor are they the only options. The third role; the one that takes on increasing emphasis in ENTC 1500 as the term proceeds is that of *set designer*. More focused than guide on the side; less obtrusive than sage on the stage; this function places students center stage, encourages collective action/reflection, individual autonomy and self-regulated learning. This approach fits comfortably with the Tagg and Wooden shift from means to outcomes—it's not about teaching; it's all about learning!

The educator role is a "quest for knowledge that enables us to unite theory and practice … To the extent that professors bring this passion, which has to be fundamentally rooted in a love for ideas we are able to inspire, [then] the classroom becomes a dynamic place where transformations [occur]" (Hooks, 1994, p. 195). So the question became what form should this transformation take in ENTC 1500; where a poetical goal could easily slide to a prosaic implementation. Should this be considered student success?

For an insight, look again to John Wooden who noted early in his high school coaching and classroom (English) career that success must be an internally derived quality rather than an externally applied judgment. "Success is the peace of mind which is a direct result of the self-satisfaction in knowing that you made the effort to become the best of which you are capable"

(Nater & Galimore, 2006, p. 25). It is the quality of the effort and the journey itself, wherein each individual finds success. A college degree might be one by-product (Wooden, & Jamison, 2005). So, the measure of ENTC 1500 impact will not be on an external judgment of success but rather on the achievement of these one-time math-deficient students in subsequent mathematics, major and science courses.

John Hattie (2009), noted measurement and research design specialist concluded that good teachers left to their own devices attain annual student achievement growth effects of between $d = 0.20$ and $d = 0.40$. He suggests that achievement gains above this average effect size imply a guideline; a reference or hinge point ($d = 0.40$). To take aim at approaches at or above this hinge point, to incorporate moderators that enhance the overall average effect, and to attain long term sustainability provide a practical means of attaining visible learning.

Upon these guiding insights, Hattie began his 15 year quest to synthesize 800 meta-analytic studies on student achievement based on roughly 50,000 studies and millions of students. From this analysis of analyses, it is possible to filter some 38 student achievement factors with effect sizes at or above 0.40 ($d \geq 0.40$) that apply to post-secondary STEM education of which 31 are under educator/institutional control (Hattie, 2009).

Complementary to Tagg's learning paradigm, 11 of the 31 Hattie quantified, controllable factors are integrated into the ENTC 1500 design: student motivation, concentration/engagement, teacher-student relationships, feedback, creativity (program), spaced vs. massed practice, teaching strategies (in terms of problem solving teaching), homework (moderator), high teacher expectations, cooperative learning and self-regulated learning (Hattie, 2009). An expression of self-regulated learning is the *growth mindset* advocated by Carol Dweck, 2015. Attainment of this attitude is predicated on the "simple but profound realization that the power to increase your abilities lies largely within your own control" (Brown, Roediger, & McDaniel, 2014, 183).

Finally, consider the matter of consistency in the university learning process. John Tagg asks a provocative question in this regard:

> What if the lesson they [students] learned in their first semester was not that every class must be approached [as] What does *this* teacher want?—but that each class builds toward a common goal, that they are connected in ways. . . that are vivid and meaningful and lead someplace that students want to go (Tagg, 2010a, p. 6).

CONCEPTUAL FRAMEWORK

Using IPD (Individual Participant Data) meta-analytic techniques, George (2013) found that students in ENTC 1500 from 2008-2012 performed as well and in a surprising majority of instances better than their non-remediated peers in later required core classes. The following suspect variables were considered but found not to moderate this boost in performance: (1) SES (Socio Economic Status as measured by average Effective Family Contribution (EFC)) (2) Race (3) Previous Achievement (H.S. GPA) (4) Age when taking ENTC 1500 and/or ENTC 1505 (5) Years since high school graduation (6) Type of high school (Ohio cluster type) (7) Prior involvement in Reading & Study Skills classes (transcripts) (8) Prior or concurrent involvement in a university Student Progress program (7 indicators) (9) Work hours when taking ENTC 1500 (within reasonable limits) (10) Course load when taking ENTC 1500 (within reasonable limits). We were able to focus in on several factors internal to the treatment that did show high correlation with the improvement. These include first half homework, attendance, soft skills in total (e.g., cooperative work skills, self-regulated learning, motivation, sense making prior to solution).

The methodology that promoted making sense of a problem prior to punching calculator keys approach is employed routinely by engineers in the field whenever they face a novel problem. Start by listing what is known (the givens) and what is to be obtained (the find). A very important step that students often overlook is the need to visualize problems. This can take the form of a sketch or table which can be marked up during solution. The next step is to write out applicable equation(s) followed by plugging in the numbers typically accompanied by units. Then, work through the equation (the chug step as in plug then chug) arriving at a potential solution. At this point, a reality and units check are performed to connect reasonableness to the solution.

Even though potential patterns were uncovered and ten likely suspects ruled out that could have moderated the positive result; the possibility exists within this, as with any research, that some omitted variable moderating this improved performance was not examined. While due diligence was followed by considering likely suspects; the nature of statistical tool employed prevents us from clearing the obstacle of potential omitted variable bias. A different tool needs to be employed, to attain reliable causal knowledge leading to true understanding.

RESEARCH QUESTIONS

Building on the George (2013) IPD meta-analytic investigation, the current probe is organized around the central precept that given sufficient time and hence a critical mass of student size, a Regression Discontinuity (RD) design can be used to make causal inferences where a Randomized Control Trial (RCT) is not practical, feasible, or ethical (Lesik, 2006; Shadish, Cook, & Campbell, 2002; Trochim, 2008). Could a causal argument be constructed that the ENTC 1500 intervention positively affects students' subsequent academic achievement? Throughout the study, ACT mathematics scores (or equivalent SAT mathematics scores, or COMPASS mathematics placement scores) were operationalized as a baseline measure of mathematics preparation. These measures are used by university student advisers to inform placement of students; e.g., into developmental math and courses like ENTC 1500; or STEM 1513 (beginning Fall 2012) for similar math-deficient students in STEM disciplines other than engineering technology.

The current investigation sought to answer the following research questions:

Question 1

What treatment effect is predicted by RD in a three course pre-calculus/calculus sequence for a theoretical student with an ACT math score of 21.5?

Question 2

What treatment effect is predicted by RD in a three course major sequence for a theoretical student with an ACT math score of 21.5?

Question 3

What treatment effect is predicted by RD in a two course science combination (chemistry & algebra based mechanical physics) for a theoretical student with an ACT math score of 21.5?

Question 4

What treatment effect is predicted by RD in the average of six core courses (math plus major) for a theoretical student with an ACT math score of 21.5?

METHODS

Participants

Students who desired entry (ENTC 1500) or were already granted entry (ENTC 1505) into the engineering technology program from Fall 2008 through Fall 2014 make up the sampling frame for the current investigation. Treatment students were those in ENTC 1500 with an identified ACT math score (or equivalent) 15 - 21. These students (n = 111) were enrolled in ENTC 1500 with the purpose to remediate them for the low mathematics placement score. Control group students (n = 157) include students enrolled in the engineering technology program who entered through ENTC 1505 with ACT math score (or equivalent) 22 or above. These students were not remediated. ENTC 1505 acted as a common cohort group for both treatment and control.

Treatment

The treatment is the fifteen week course ENTC 1500; class sessions occur twice per week for 3 hours per session. Expectations as to quantity and quality of work in ENTC 1500 are extremely high, as evidenced by syllabus, homework list, labs and objectives, Lab Guide (Appendix A). Student motivation, concentration, engagement and teacher-student relationships work synergistically. For example, Lab 3 (Appendix A) deals with the concept of area. It has an extreme emphasis on calculations and a surprising requirement for creativity. Although this is a very time consuming and exacting lab, students generally come away from it with a very positive attitude and a greatly enhanced ability to manipulate composite (geometric) shapes.

When labs are assigned, students (typically paired in teams of two) were required to run, write up and submit each lab within one class period. Over time, both as a necessity (e.g., classes meeting 3 times per week for 2 hours per session) and as a perceived strength; lab times were extended over multiple sessions. On the two earliest labs, this allowed students to concentrate on structuring their labs with the opportunity to write or re-write an analysis with a fresh perspective. As students were given more total time (and reflective time between creating patterns and analyzing them) the quality of labs and the quality of learning improved.

The cooperative learning style develops around the labs. The emphasis is on students working together (typically as a group of two) and teaching/peer learning within this context. While the first half semester remains somewhat heavy on lecture and twin disciplines of homework and a consistent problem solving methodology; the second half flows rather seamlessly from labs to tests with less time devoted to lecture and less emphasis on book style homework. The practice is taken up primarily by the labs.

Completion of homework and attendance are key to student achievement in the ENTC 1500 class; students are informed of the connection of homework and attendance to successful completion of the course (Syllabus: Charts 1 and 2). Problem solving teaching is multilayered within ENTC 1500. As a result of reflecting on where students go awry in problem solving, George (2013) posits that central to the nature of a problem solving methodology is getting STEM students over the hump to approach ever more complex problems focusing on problem solution rather than on fear of failure. The emphasis on a structured approach paradoxically stimulates creativity.

Variables

The independent variable; the variable that determines treatment (ACT math score) is termed the running variable. Analysis was performed as a sharp RD design; that is treatment switches off or on based on whether the student scored a 22 or above. Fuzzy RD designs indicate that the probability or intensity of treatment changes at the cut-off (Angrist, J.D., & Pischke, J-S, 2015).

The dependent variable measures used for comparison of student achievement with treatment to control students (no treatment) are student final grade point average in nine core classes. A complete course description of each class noted below is available at http://www.ysu.edu/stem/engtech.

- ENTC 1505 (central cohort for treatment and control groups)
- 3 course mathematics sequence (MATH 1513, MATH 1570, and MATH 2670)
- 3 course engineering technology major sequence (MET 1515, MET 2616, and CCET 3705 for mechanical and civil & construction engineering technology; EET 1502, EET 2620, and CCET 3705 for electrical engineering technology)
- 2 course science combination (CHEM 1505 or 1515, and PHYS 1501)

Design

A random assignment makes all observed and unobserved factors equal between treatment and control groups (Lesik, 2006; Murnane, & Willett, 2011). This allows Randomized Control Trials (RCT) to establish causality because the assignment of participants has been done exogenously; that is, by an external cause (Lesik, 2006). A Regression Discontinuity (RD) provides a research design that focuses on assignment to treatment group based on some predetermined cut-off score. The cut-off score was itself determined exogenously; hence, all observed and unobserved factors are equal between treatment and control groups within the neighborhood; a narrow bandwidth of the cut-off score (Murnane, & Willett, 2011).

Limitations

There are at least three assignment limitations to consider as threats to validity before interpreting the results of our study. First, a small percentage of students in both treatment and control did not take the ACT math, SAT math or COMPASS math placement test and were eliminated from the study. Second, a small percentage of students in treatment and control did not adhere to the assignment cutoff. Occasionally a student with ACT math ≥ 22 was admitted to ENTC 1500 or a student with ACT math < 22 admitted to ENTC 1505 without taking ENTC 1500. In the former case, this would typically be a student out of school for some time who elected to take a developmental math class and ENTC 1500; in the later, a student (likely transfer from another department or university) who succeeded in getting into pre-calculus prior to entering the engineering technology program. Students in either case were eliminated from the study. Third, a control or treatment student who had already taken MATH 1513 (pre-calculus) prior to entry into engineering technology or control student who tested out of MATH 1513; e.g. placed directly into MATH 1570. In these cases, no grade was entered for MATH 1513; instead the grades for MATH 1570 and 2670 alone were averaged. In Fall 2004, an alternate mathematics path into MATH 1570 and a new cut-off score (22 to 24) were introduced. Consequently, the entry of new treatment students into the study was finalized with the Spring 2014 ENTC 1500 group. For any lagging treatment students who take the alternate math path; grades for MATH 1570 and MATH 2670 alone will be averaged.

At least four limitations apart from assignment are also in play. First, since ENTC 1500 is a specific engineering technology intervention at a single university, the results may not generalize to other treatments, settings, or outcomes. Second, the students in both treatment and control groups were predominately male (94%) so generalization to female students is suspect. Third, there is a balance between having a small bandwidth around the cutoff value and obtaining reasonable power by maximizing total treatment and control sample sizes. A larger bandwidth can introduce nonlinearity. A classic Regression Discontinuity provides linear fits to the treatment and control sides of the data and then extrapolates each to the point of discontinuity. The nonlinearity will be addressed by over-fitting to a polynomial for the treatment and control fits. If the treatment effect at discontinuity is robust to over-fitting then the value should be stable independent of functional form. The bandwidth will also be reduced to see what change occurs to the treatment effect. Fourth, ceiling and floor effects can result in a selection-instrumentation effect (Shadish, Cook, & Campbell, 2002). This limitation will be obviated by excluding treatment students at the floor of ACT math scores (e.g., ACT math < 15).

RESULTS

Regression Discontinuity results reveal a large statistically significant treatment effect for the math sequence, a large statistically non-significant treatment effect for the sequence of classes in major, a small statistically non-significant treatment effect for the science combination, and a large statistically non-significant treatment effect for the average of six of the nine core courses (math plus major).

Figure 1A indicates a treatment effect $d = 0.57$ (gain in GPA) at the point of discontinuity for the math sequence; statistically significant at $\alpha = 0.05$. In order to disclose possible non-linearity, Figure 1B was created. The treatment effect change is negligible moving from 0.57 to 0.58. If bandwidth is limited to $\pm$ 2.5 (ACT math [19, 24]) then the corresponding linear graph (Figure 1C) indicates treatment effect at 0.59 (gain in GPA). The treatment sample size is n = 64; marginal for RD studies. An important consideration with RD is statistical power; so that while a sample size of 36 is considered reasonable for a large effect on a Randomized Control Trial (RCT) the corresponding sample requirement would be n = 1.75 x 36 = 63 (Shadish, Cook, & Campbell, 2002).

Based on data currently available, the best estimate visually would be reflected in Figure 1B, a treatment effect of 0.58. The primary conclusion though is that the treatment effect appears to be robust to both nonlinearity and (within constraints of our treatment samples close to the cut off score) to bandwidth.

Figure 2 indicates a treatment effect $d = 0.42$ (gain in GPA) at the point of discontinuity for the sequence of classes in major; statistically non-significant at $\alpha = 0.05$. Note: Sample size of treatment group should be sufficient a large effect in an RD study at n = 79. This sample size should increase to around 95 after Fall 2015.

Figure 3 indicates a negligible treatment effect $d = 0.01$ (gain in GPA) at the point of discontinuity for the combination of science classes; statistically non-significant at $\alpha = 0.05$.

Note: Sample size of treatment group is low at 64. This sample size should increase to around 80 after Fall 2015. For a small effect in a Regression Discontinuity study, the sample requirement would be around n = 2.00 x 36 = 72 (Shadish, Cook, & Campbell, 2002).

Figure 4 indicates a treatment effect $d = 0.47$ (gain in GPA) at the point of discontinuity for the average of six core courses (math plus major); statistically non-significant at $\alpha = 0.05$.

Figure 5 summarizes 4 characteristic and 5 contextual features that surfaced as predominant themes in a focus group of former ENTC 1500 students conducted 3/19/15. The table conjoins the emergent features with John Hattie's synthesis of effect sizes (Hattie, 2009). The makeup of this qualitative study group included engineering technology students at various stages of their academic careers.

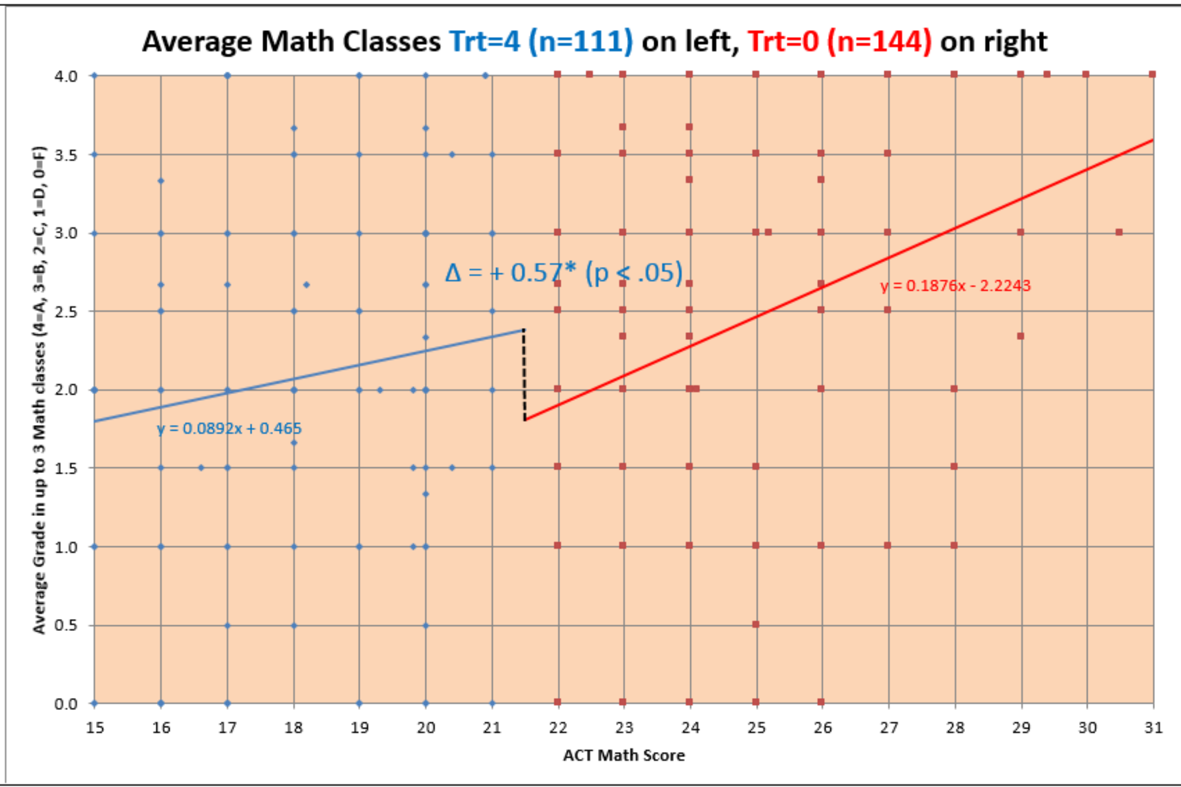

Figure 1A: Average of Math Sequence through Spring 2015

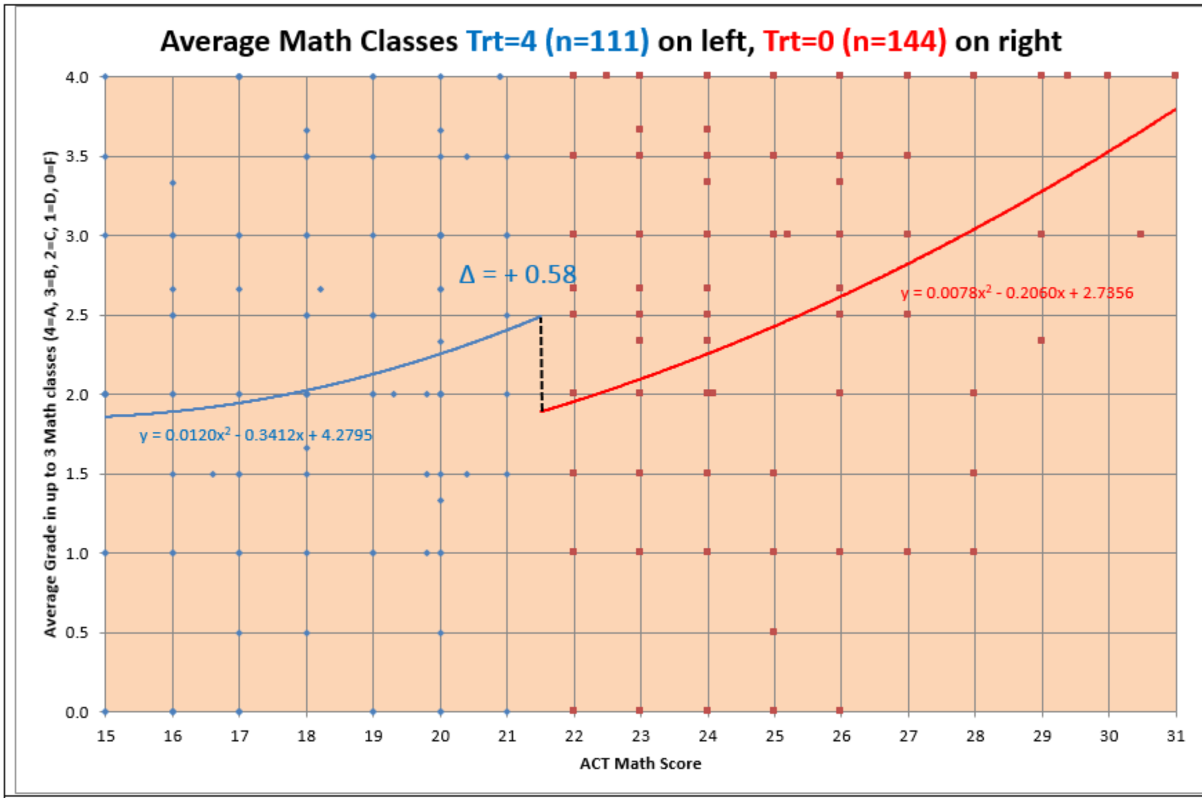

Figure 1B: Average of Math Sequence Nonlinear Fit through Spring 2015

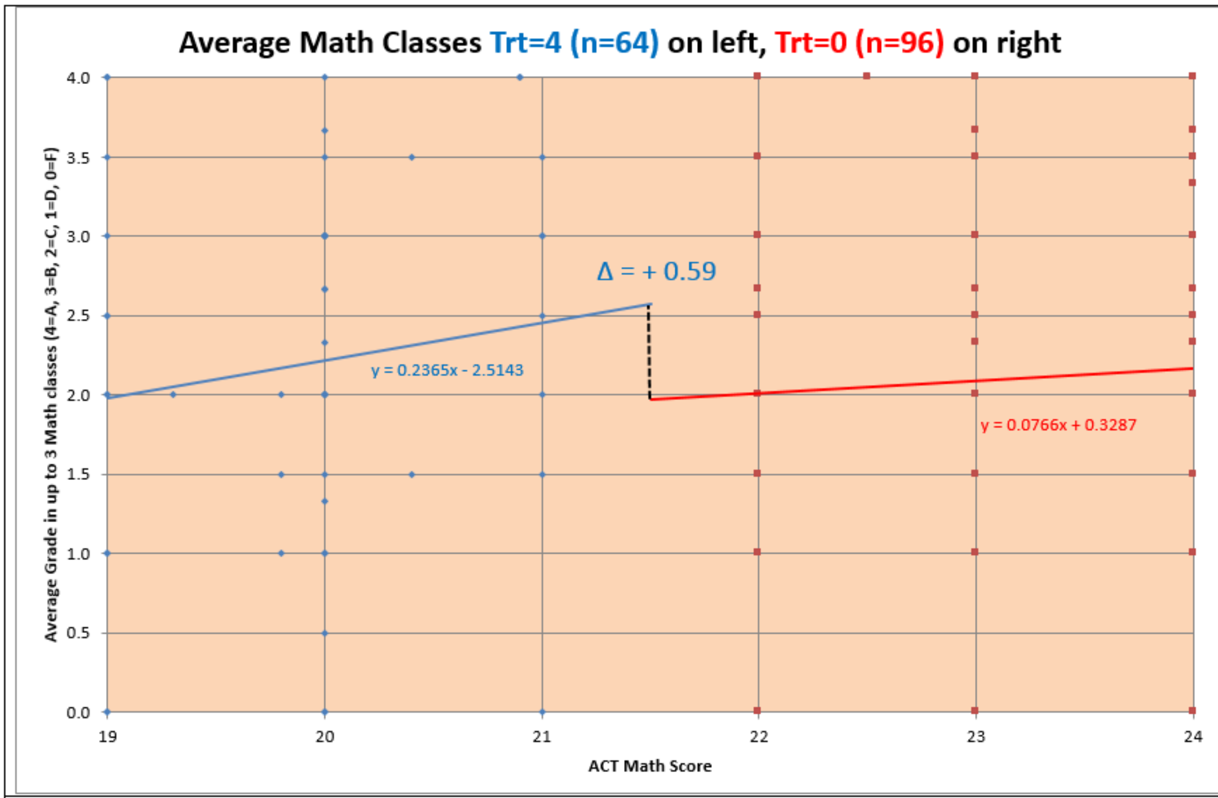

Figure 1C: Average of Math Sequence Reduced Bandwidth (19-24) through Spring 2015

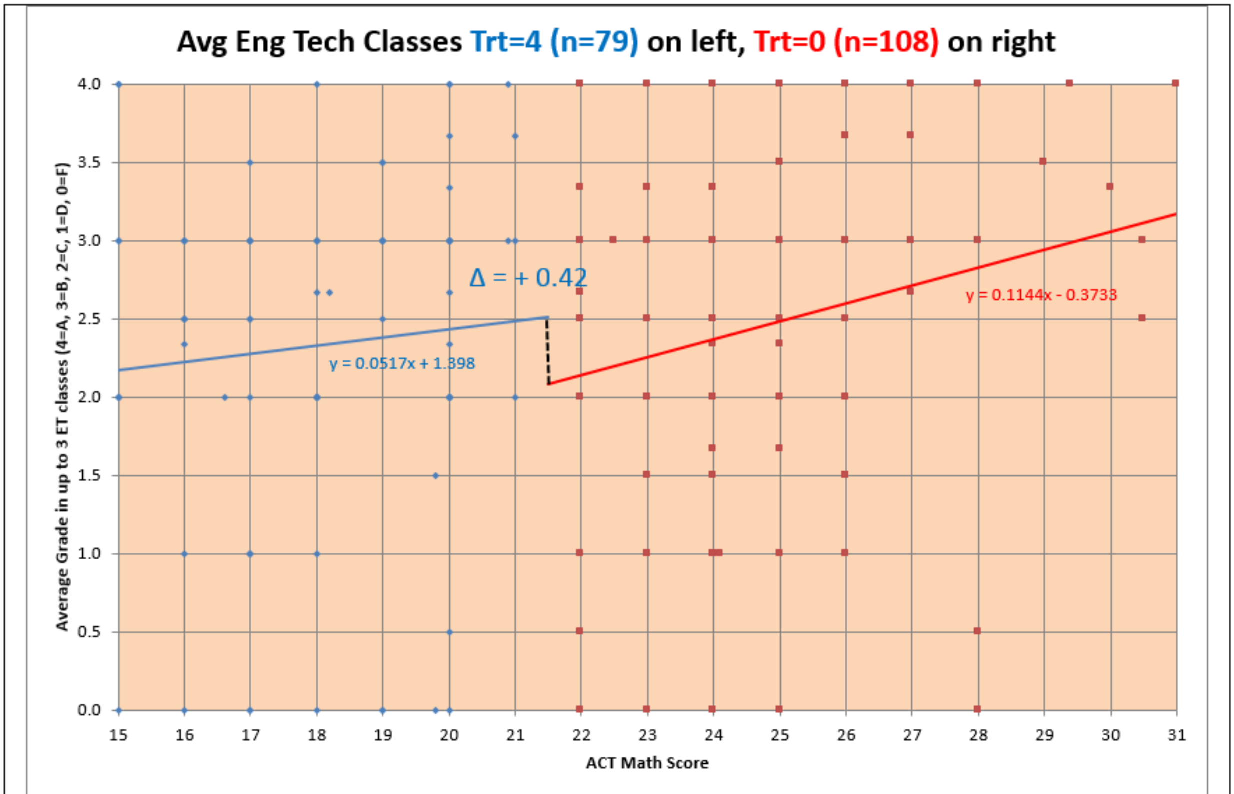

Figure 2: Average of Major Sequence through Spring 2015

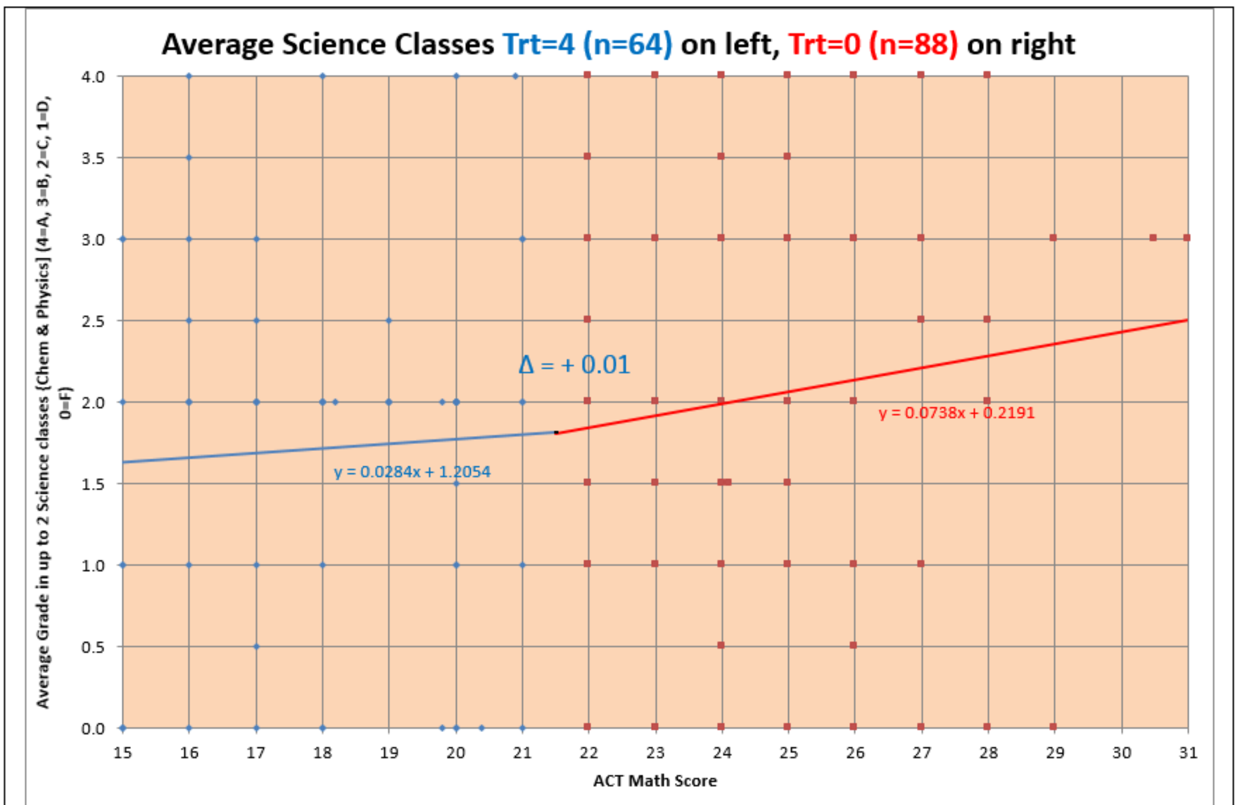

Figure 3: Average of Science Combination through Spring 2015

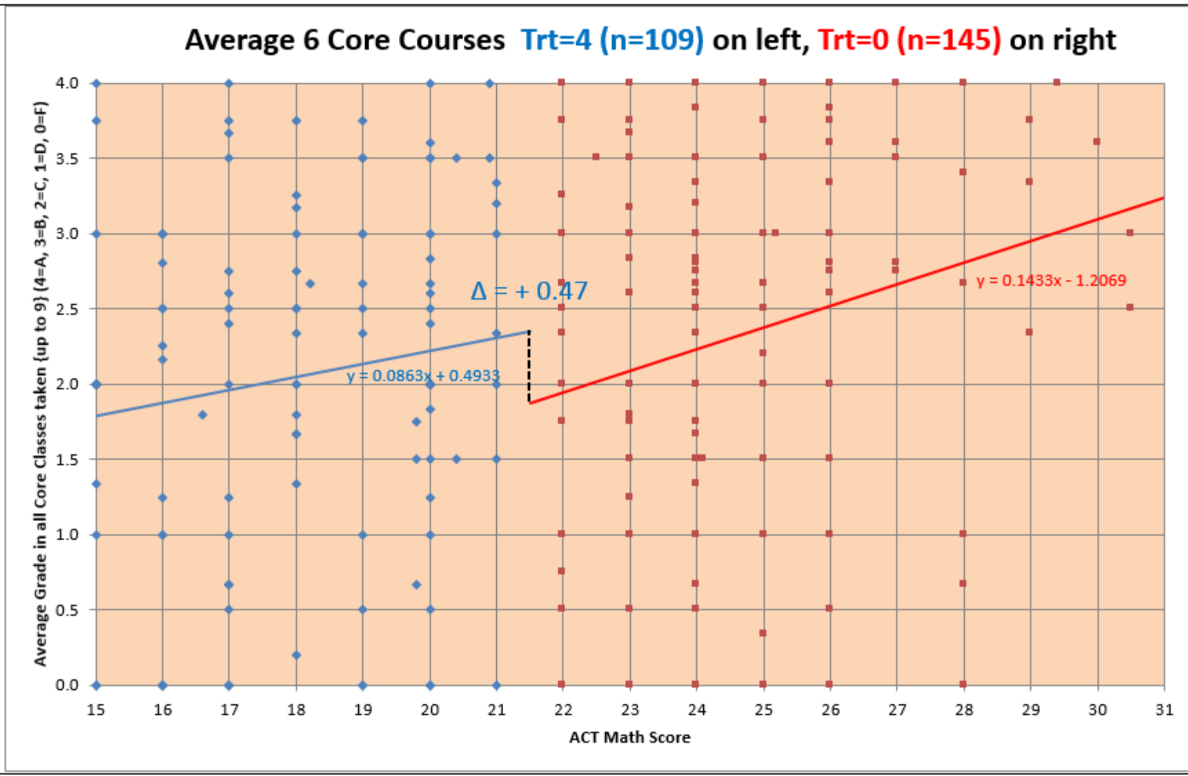

Figure 4: Average of 6 Core Courses (math plus major) through Spring 2015

Characteristic Feature	ENTC 1500 Implementation	Effect size
1) Motivation*	(Paired) Cooperative Learning	L (*d* = 0.48)
2) Cognition*	Problem Solving Teaching* (Sense making before solution)	XL (*d* = 0.61)
3) Meta-Cognition*	Self-Regulated Learning*	XL (*d* = 0.69)
4) **Teacher-Student Relationship***	**T-SR** maximizes impact on 3 features above while minimizing impacts on ❖ Prior achievement * ❖ SES, Race, etc.	XL (*d* = 0.72) XL (*d* = 0.61)
Contextual Feature	**ENTC 1500 Implementation**	**Effect size**
❖ Strategies/Heuristics	Engineers' solution method (novel problems) Sense making before Solution	---------- *Essence of **PST***
❖ Practice*	1st Half homework emphasis	XL (*d* = 0.64)
❖ Creativity*	2nd Half Lab emphasis	XL (*d* = 0.65)
❖ Feedback* (2 way)	Rapid grade turnaround	XL (*d* = 0.73)
❖ Formative Evaluations*	Prelim exams & labs	XXL (*d* = 0.90)

Figure 5: Characteristic & Contextual Features of ENTC 1500 matched against Hattie Effect Sizes

DISCUSSION

At both national and state levels, an emphasis is on Science Technology Engineering and Mathematics (STEM). At its heart is a demand for a more technologically trained workforce. Paradoxically, the foundation for a practical college level solution in the first three fields rests with reaching a population increasingly displays both disinterest and poor performance in abstract mathematics. The purpose of the current investigation is to explore what can be done for students who possess both a desire and ability to matriculate into technical fields but who present in need of math remediation and typically lack effective problem solving skills.

This investigation looks at the impact of a lab-intensive remedial course on student achievement in subsequent core courses at a mid-size public university. Specifically, the current investigation sought to understand the impact, if any, of a lab-intensive developmental course on student learning, particularly regarding student performance in subsequent core courses. Grades from subsequent core coursework for students who previously participated in the lab-intensive developmental course, ENTC 1500 were compared to core coursework grades of students who did not participate in this intervention. By employing Regression Discontinuity (RD) to examine students' performance in successive coursework, the current investigation provides an indication of the impact of ENTC 1500 on sustained student learning. It was found that students who were remediated performed as well as or better than students not identified for remediation, in subsequent courses, however, due to limited sample size, not all findings were statistically significant.

The first research question asked what treatment effect is predicted by RD in a 3 course pre-calculus/calculus sequence (math core) for a theoretical student with an ACT math score of 21.5. Results of the RD analysis indicated that the intervention had a statistically significant impact on student performance in their core pre-calculus/calculus sequence. The remaining three research questions; focused on the impact upon engineering technology core, science core and six core courses (math plus major) in combination revealed large, negligible and large statistically non-significant results. These large non-significant results are likely due to a lack of sufficient power.

In implementation, experience has uncovered three characteristics and one context puzzlement. First, class size matters. The class size for maximizing the impact of this type of intervention encompasses groupings of 12 to 24 students. This pedagogical approach becomes less effective with fewer than six students. Similarly, courses of this type that have been run with as many as 30 students are difficult, due to a need to compromise general operation guidelines. For example, lab groups are typically limited to two students; rarely do 3 collaborate as seamlessly and effectively as two but in practice, groups of three are necessitated for class sizes larger than 24 students. While the current investigation included no experiences with running classes in excess of 30, it is suspected that for class sizes stretching beyond 36; other approaches should be considered. In particular, the pedagogy employed by Eric Mazur for large class sizes comes to mind (Mazur, 1997).

Secondly, experience suggests that setting is important. Classrooms with tables rather than student desks facilitate the success of this type of lab-intensive developmental class. It is constraining to run classes with high emphasis on lab exercises in a classroom set up for lecture mode. It is helpful if a computer lab can be reserved for exercises showing the value of spreadsheets (e.g., Excel™) for organizing tables and graphs (charts) as well as student assembly of the labs themselves. If available, most students will take advantage of word processing to handle cover sheet, table of contents, bulleted procedures, and analysis of results.

Thirdly, for the current investigation, homogeneously organized groups were most effective. However, there is little consensus in the literature as to whether heterogeneous or homogeneous groupings are superior. Proponents of heterogeneous grouping (Heltemes, 2009) suggest that students who are lower performing benefit in heterogeneous groups. This philosophical perspective clashes with those who favor homogeneous grouping. Some studies find homogeneous grouping very beneficial for higher performing students and the difference neutral for lower performing students (Baer, 2003). Other studies find homogeneous grouping superior for all students; including those with identified lower abilities in the topic area (Abodo, & Agbayewa, 2011; Smieja, 2012). A meta-analysis specifically examining the dynamics of grouping students for such work in university level lab-intensive classes would prove useful.

For the ENTC 1500 treatment, homogeneous groupings were used across the board. The authors like the "iron sharpens iron" analogy (King James Bible, Proverbs 27:17). The concept of putting groups together based on seeking diversity for how group members get things done is also appealing. This is expressed by Kathy Kolbe's Conative Index (KCI) which has been applied successfully to formation of groups in sports and industry (Kolbe, 2004; Kolbe, Young, & Gerdes, 2008). Unfortunately, the authors have not yet determined how to apply this insight in a clean, cost-effective manner for the application.

In practice, effective lab groups are maintained while re-combinations of less effective groups continue through at least the first three of five labs. Students submit a single lab report but are required to identify which group member performed each component of the lab activity. In a majority of lab groups, this delineation is crystal clear and variance in individual student lab grade is common (although rarely more than ± 6 %). However, in the best of groups, students (typically two) will work together so seamlessly that each will check the other, to the point where the product is truly collaborative and the grading variance minimal.

Finally, to the source of bewilderment: ENTC 1500 is not an island. It needs to fit into the context of follow-up classes; especially within the STEM disciplines. University level courses that are intended to "weed out" students are said to be killing STEM achievement (Koebler, 2012). For competitiveness (sink or swim) such classes are often graded by the curve based on an underlying belief that engineering (and science) must be rigorous to separate the cream of the crop. The authors philosophically oppose such freshmen weed out classes. Surprisingly, former treatment students in the aforementioned 3/19/15 focus group shared a feeling that ENTC 1500 itself is a weed out class. ENTC 1500 is a collaborative class, not graded on a curve that has a very low attrition rate. But, as we reflect; perhaps it comes down to a definition of what weeding out in STEM traditionally is and what it should be.

The weed out process in and just beyond ENTC 1500 appears to be a self-selected process rather than a directive; you can't make it here. Those students who pass ENTC 1500 generally appear to have high self-efficacy as to ability to do well in engineering technology and related STEM coursework (e.g., mathematics and science). Those treatment students who leave the field of engineering technology appear to do so not because they feel they can't handle the work, but rather because they decide the time and quantity of work required to be successful is not for them. This sort of self-selected weeding does make sense, as a central tenet of ENTC 1500 is that students need to become self-regulated and self-directed learners.

IMPLICATIONS

The results of the current study provide a promising solution to the crisis in retention of students, specifically in STEM disciplines. Based on the current investigation; collaborative-experiential, lab-intensive, high-expectation developmental courses can act as a needed boot camp bridge for students lacking skills and/or confidence in their foundational knowledge. This bridge will allow successful navigation through early college coursework and if such courses promote self-regulated learning; to degree completion and beyond. More qualitative research is needed to draw out additional experiences of former treatment students both in the ENTC 1500 class and in subsequent core classes. Only by way of a richer understanding of the dynamics involved than is currently portrayed by Figure 5 will more precise knowledge be attained.

This paper alludes to STEM 1513 intended for a broader audience of STEM students (e.g., biology, chemistry, medicine, traditional engineering) with math deficiencies; i.e., not ready for pre-calculus (MATH 1513). Whereas ENTC 1500 is a four semester hour class meeting for 6 hours per week; STEM 1513 is a three semester hour class meeting three hours per week. ENTC 1500 is male dominant with a substantial mix of nontraditional students; STEM 1513 is less gender specific with a heavier concentration of traditional students.

While the 2008 redesign of ENTC 1500 was conceived and fashioned by the lead author, the STEM 1513 course was written by the Associate Dean of the STEM college and first taught/ implemented by an adjunct chemistry professor and the lead author in Fall 2012 under direction of the Associate Dean. The original design was based in part on discussions of STEM leadership in collaboration with professors from mathematics, chemistry, and mechanical engineering technology. Nonetheless, intent and general direction of the two courses are in harmony.

The follow-up core coursework to STEM 1513 includes a four course pre-calculus/calculus sequence, a four course chemistry sequence, and a two course physics sequence. A new feature of this data set is the likelihood of performing a gender study to determine whether a similar approach to what was undertaken with ENTC 1500 might provide corresponding benefits to female as well as male university students.

Preliminary results based on roughly 1/3 treatment sample sizes of those currently attained in ENTC 1500 for items (1) and (2) and a tiny sample for (3) are encouraging:

(1) Large treatment effect of 0.55 gain in GPA for the four course math sequence for a hypothetical student with ACT math = 21.5 (point of discontinuity).
(2) Medium treatment effect of 0.27 gain in GPA for the four course chemistry sequence.
(3) Extra-large treatment effect of 1.17 gain in GPA for the two course physics sequence but again based on a tiny treatment group size, n = 13.

This research and near term future research are important first steps toward addressing calls for greater numbers of STEM graduates by greatly reducing the attrition rate among those historically most vulnerable. Student learning can be improved; especially by bridging these students into a connected, consistent, streamlined university learning process. This is a time of increasing demand for STEM graduates and decreasing STEM ready student supply. The true role of the university will be fulfilled, that of a learning institution; if the institution can take students who come in below requirements, bring up their skill set, and help lead them to where they want to go (Tagg, 2010a). As a by-product (Wooden, & Jamison, 2005), this journey will likely take many to an advanced degree followed by a rewarding career. [For a college or university] it's not about providing instruction; it's all about producing learning (Tagg, 2008)!

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APPENDIX

SAMPLE ENTC 1500 XXX Syllabus

XXX University

STEM, ENGINEERING TECHNOLOGY

42990 ENTC 1500 Technical Skills Development

42990 ENTC 1500	W F	1:00-3:50 pm	Moser 3290
Prof. George	Office: Moser 4108 via 4120		(330)-941-**xxxx**
	Office Hrs: Mon 10 am - Noon, Wed 10 am - 11 am Fri 10 am - Noon		
	Final Exam: Mon. 12/10/xx 1:00 pm – 3:00 pm		

Text: Cleaves & Hobbs, Essentials of College Math, 2nd Edition, Prentice Hall, 2006. $133 new, $ 50 used

AVAILABLE HELP:

Formal **office hours** above. If these times don't work let me know; we'll set up a time that does.

If you have a **documented disability** and require accommodation(s) to obtain equal access, contact the Office of Equal Opportunity and Disability Services at the beginning of the semester. If appropriate; they will provide you a *letter of accommodation*. It's your responsibility to present this letter to me. Verify your eligibility through the *Office of Disability Services*, 330-941-**1372**, 8 am till 5 pm Mon-Fri.

Campus assistance: *FREE* campus services:

Center for Student Progress	330-941-3538	Kilcawley Center West
Maag Library	330-941-3677 330-941-3099 & 3055	Maag R&SS 154, Writing 171
Math Assistance Center	330-941-3274	Lincoln Building 408
Advisement	330-941-2292 & 1743	Moser 2305 & Lincoln 632
VA Office	330-941-2503	Tod Hall 310A

COURSE DESCRIPTION/OVERALL OBJECTIVES:

Develop the technical, analytical and **problem solving** skills of students planning to enter an engineering or technical career. Complement Algebra class work by stressing the importance of mathematics and by working through technical math applications. Gain an understanding of the roles of technicians (ATS or AAS), application engineers (BSAS or BE) and development engineers (BE) in the workforce. I will try to help you achieve the following **Course Goals**:

1. *Training*: How do I develop a dependable problem solving approach? ←6 Step Method
2. *Training*: How can I ethically max scores on technical exams? ← Above + "understanding units" + "no blanks"
3. *Training*: How can I use Excel as an analysis tool? ← Ref 6)

   ----

4. *Education*: How to develop an **e**ffective **p**ersonal **l**earning **s**trategy?

epls = f(*1*-**Practice** time {10K hr rule}{interleaved reps Rule of 5} [*1st half hw*], *2*-**Attendance**, *3*-**Self-Reg Learning {<u>A</u>**ction →**<u>R</u>** e f l e c t →**<u>A</u>**ction, *4*-**Collaborative Learning** {group labs})

5. *Education*: How can I "<u>make sense of mathematics</u>"? ←Applications (contextual learning) & visualization (see 6))
6. *Education*: How can I <u>spot</u> <u>trends</u> & <u>analyze</u> <u>data</u> to produce effective technical (lab) reports? ← Data: 1) Gather, 2) Tabulate), 3) Graph (visualize), 4) Analyze (to understand relationships)

<u>MEASURABLE OBJECTIVES</u>:

Table 1—Success Rates for ENTC 1500 "new" approach

Section	Instructor	Raw pass Numbers	Success Rate	True Success Rate*
Total "new"	08-2013	264 of 353	74.8 %	79.5 %*
Total "old"	2006-08	93 of 275	33.8 %	

* Factor in no shows, financial withdrawals, suspensions and medical withdrawals.

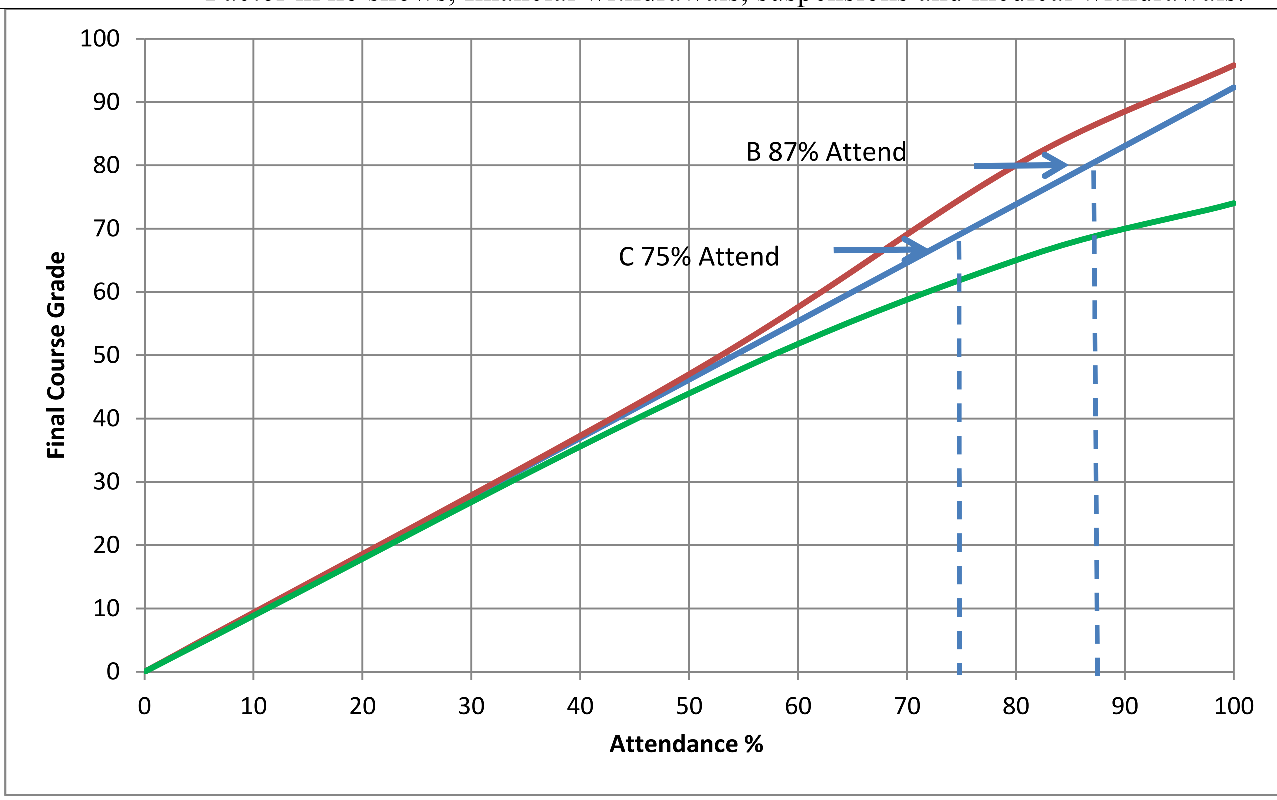

Chart 1—Overall Grade vs. Attendance n = 302

Attendance trend: 97% (A), 87% (B), 75% (C)

→ {10/302 ≈ 3.3% who attended 77% of classes did not pass}.

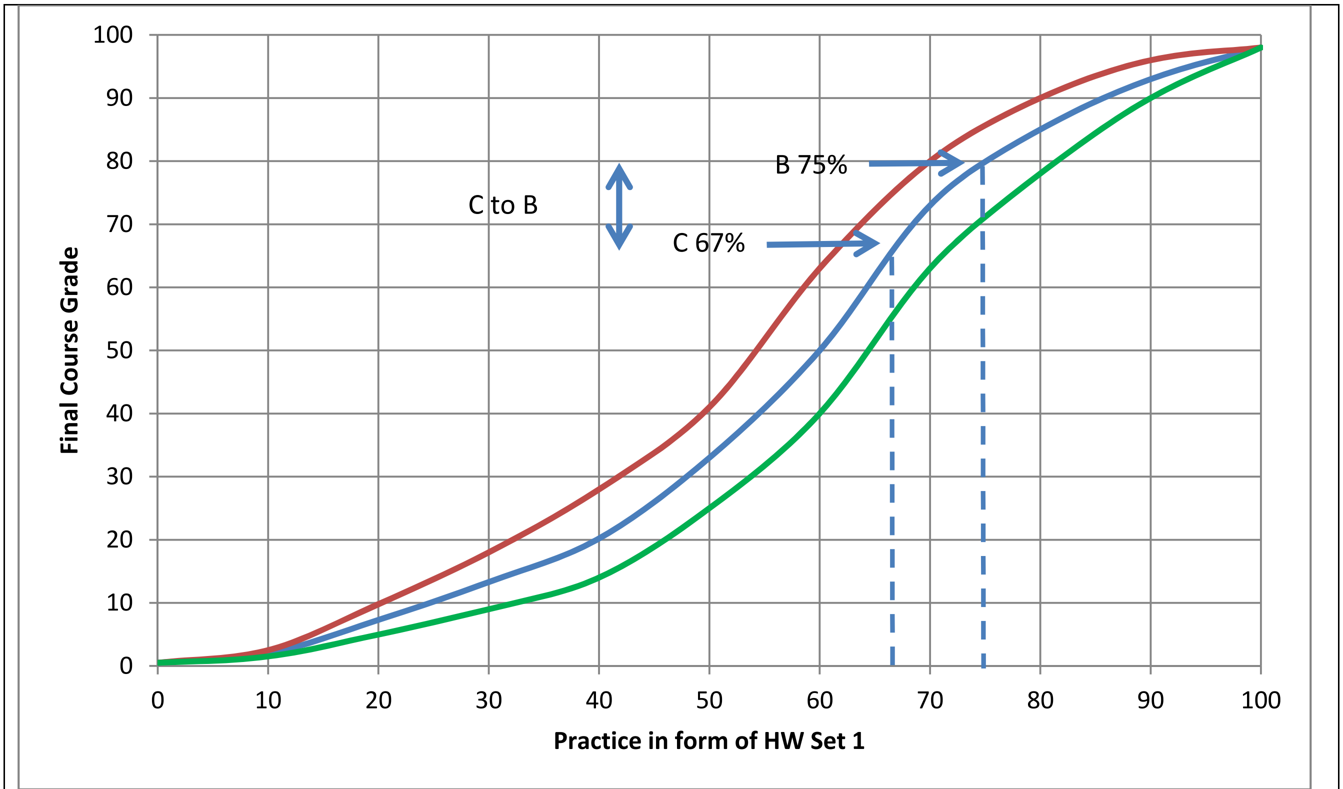

Chart 2—Overall Grade vs. 1st 7 week HW Score n = 302

HW #1 set trend (1st 7 weeks): 85% (A), 75% (B), 67% (C)

→ {10/302 ≈ 3.3% who did better than 67% on initial homework did not pass}.

PREREQUISITES and REQUIREMENTS:

→ Concurrent or Prereq: **MATH 1501** Elementary Algebraic Models or Level 2 Math Placement ←

All homework problems and Lab Sample Calculations MUST be done on **8-1/2 x 11***Engineering Technology paper (blue), Engineering Calculation paper (green)* or ***8-1/2 x 11*** *(4 or 5 block per inch)* ***quadrille paper***. With generic quadrille paper you will need to create your own Name, Course/HW Assignment, Date and Page # of Total Pages block.

Regular notebook paper is NOT acceptable for homework. If you use backside expect a deduction; if you cram problems expect a deduction. On green "Calc" paper backside is the heavy ruled grid side; use front side. Engr Technology paper available only from the bookstore; "Calc" paper and generic quad paper are available at most office supply stores as well as bookstore. If you use generic quad paper make sure it is 8-1/2 x 11; preferably 3 hole punched.

Besides the text, a **scientific calculator** is required. A basic CASIO fx-260 calculator will be provided. A **3 ring notebook** (D ring, 1-1/2" recommended) is also required. Notebook dividers, pencils, erasers, a key (flash) disk and basic sketching tools are recommended.

You can use your Banner number to log on to any of the Moser computers. Send saved files to your TANK ≡ *personal reserved disk space* (or flash drive). Computer Room 4050 has been reserved to be available as needed.

Homework problems are assigned regularly. I encourage students to work in small groups. However, working together should NOT extend to outright copying of homework. Learn from each other but do your own work.

GRADING POLICY

Homework problems and/or spreadsheet exercises will be assigned at each lecture.
Some or all of a homework assignment will be collected. Late homework will be accepted up to the beginning of the following class. Expect a 10% late penalty. Beyond this date expect ZERO credit. Generous partial credit is given for all reasonable attempts as it is on tests. On homework you will get limited credit for setting up the problem (i.e., Steps 1 & 2) of 6 step methodology, additional credit for additional steps (i.e., Steps 3 & 4) whether you obtain "answers" or not. I am much more interested in **HOW** you approach solving a problem than the "final answer(s)". Working together is encouraged; copying is NOT.

5 Preliminary exams, at least 5 labs and a **comprehensive final** are planned. No makeups except in extraordinary circumstances where arrangements made PRIOR to the exam date. Expect any approved makeup to be significantly TOUGHER than the class exam. Tests—closed book, closed notes, outline provided unless otherwise specified. You can skip Givens & Finds on the tests. **Do all you can to avoid missing exams**.

Late labs accepted up to the beginning of the next class. Beyond this expect a score of zero. Missing running a lab carries a 10% or 20% penalty depending on how much was missed and a late lab submittal carries its own 20% penalty. **Do all you can to avoid either missing labs or submitting them late**. Note: 10% penalty translates to 1 grade level drop; 20% to 2 grade levels.

COURSE GUIDELINES:

1. The class SCHEDULE (*ref HW list for more details*) is subject to change depending on individual class needs. Schedule changes will be announced ASAP.
2. Rule 3: All **cell phones**, **pagers**, **blue tooth** & **media players** are to be turned **off** during class. Rule 2: Mutual respect. Umbrella Rule 1: Make life as easy as possible for instructor . . . For detailed description of what the university views as inappropriate classroom behavior refer to the Student Code Handbook found on the university website.
3. **Attendance** in **class** does not directly affect your grade *except* for missing TESTS or LABS. Nonetheless, attendance and homework are 2 key factors associated with grades. See Page 3. To ensure no loss of homework points turn in the full assignment prior to any class you'll miss. Whether you attend or not; you are responsible for handouts, lecture material, readings and corresponding assigned problems.
4. All **exams closed book & closed notes** unless otherwise specified. Students permitted or more typically provided a FORMULA SHEET on exams. If student prepared, formula sheet must be on a single 8-1/2" x 11" paper (single or double sided) and contain **only** text formulas.
5. There will be **NO MAKEUPS for missed exams without PRIOR approval** by the instructor. Expect approved makeup to be significantly TOUGHER than the class exam.
6. **Attendance at LABS** is mandatory. Lab report format to be supplied. *See HW list for dates to especially avoid missing.*

7. **Late labs** will be accepted up to beginning of next class but expect a 20% REDUCTION IN GRADE. Labs more than 1 class meeting late typically receive NO CREDIT.
8. **GRADE SCALE**:

   100-90 A   89-80 B   79-67 C   < 67 NO CREDIT

   Instructor reserves the right to adjust the grade scale DOWNWARD.
   Consideration will be given to final exam score, homework scores, attendance, effort and attitude if student is just below a cutoff ("on the bubble"). However: no student will "jump" above another student based on these factors.
9. COURSE GRADE will be determined as follows:

   ENTC 1500 (4 s.h.)

   5 Prelim Exams, 5 Labs (1 double) (100 pts each) = 50 % (1000 pts)

→Double median exam score if only 4 tests. **Drop lowest of 11 scores be it exam or lab** ←

☆ 1 score ONLY dropped 1100 → 1000 pts ☆

Comprehensive Final (500 pts)	= 25 %	(**500** pts)
HW, Excel, Other Assign's (200 pts)	= 10 %	(**200** pts)
Median Preliminary Exam (100 pts)	= 5 %	(**100** pts)
Median Lab (100 pts)	= 5 %	(**100** pts)
Better of Median Prelim Exam & Median Lab (100)	= 5 %	(**100** pts)
Total	=100 %	(**2000** pts)

Assignment (Homework) List for ENTC 1500

Wk	Day	Date	Sect	Subject	HW Assign
1	M	08/20/xx	No class		
	W	08/22/xx	Handout	Unit Conversions	#1: Unit Conversion Worksheet
					Read Ch 15 Statistics pp. 611-627
2	M	08/27/xx	15-2	Descriptive Stats	# 2: 15-2 (622): 1,4,7,10,13← mean, S.D., median, Range
		08/27/xx			Read Ch 1 pp. 2 thru 44 (*p. 43 very important*)
	W	08/29/xx	1-1,2& 3	Problem Solving	#3: 1-3 (45): 31→45 odd; 1-3Rev(54): 93,95⇨*#1E*
2	M	09/03/xx	**Holiday**		**(Labor Day)** ** Last Day add classes 08/29/12 **
	W	**09/05/xx**	Handout	**Lab #1**Reflexes	⇨**L1**Reflexes Lab
3	M	***09/10/xx***	2-5, 2-7	Percentages	#4: 2-7 (125): 5→25odd
	W	09/12/xx	3-1, 3-2	Measurement units	#5: 3-1 (154):17,21,24,25,39→49; 3-2(159):13→23 odd
4	M	09/17/xx	3-3, 3-4	Accuracy, Precision	#6: 3-3 (166):7→19 odd; 29;
		09/17/xx	Handout	Excel	⇨*#2E: Handout in class or on own (TBD)*
	W	**09/19/xx**		**Test #1**	⇨**T1**
5	M	09/24/xx	4-5, 4-6	Powers of 10	#7: 4-5 (225): 25→45 odd; 4-6 (232): 13→29, 43→53odd
	W	**09/26/xx**		**Lab #2** Bouncing	⇨**L2** Conservation of Energy (Bouncing Ball)
				Ball	Read Ch 5 pp. 244 thru 257
6	M	***10/01/xx***	5-2	Algebra	#8: 5-2 (258): 9,13,15,19,23,27,31,35,41,43,49,53,55
			5-3,4	Solve Linear Eqs.	#9: 5-3 (261): 15→29odd; 5-4 (274): 31→47odd
	W	10/03/xx	5-4,5	Linear Equations	#10: 5-5(279): 15→31odd
			6-1,2	Proport/VarDir/Inv	#11: 6-1 (296):17→53odd; p. 304 15→29odd
7	M	10/08/xx	6-3	Variation	#12: 6-3 (311):3→17odd *#3E*
	W	**10/10/xx**		**Test # 2**	⇨**T2**
8	M	10/15/xx	11-3,12-3	Quad Eq.; Circles	#13: 11-3 (449): 3→17 odd; 12-3 (504); 11→23 odd
	W	10/17/xx	12-3	Radians	#14: 12-3 (504):27→49 odd
				Composite Areas	#15: Handout
				Ellipse	#16: Handout
9	M	**10/22/xx**		Comp Area+**St Lab**	⇨Start **L3**
	W	**10/24/xx**		**Lab #3** Area	⇨**L3**Area Lab ** Last day Withdraw 10/27/12 **
10	M	10/29/xx	12-4	Volume & Surf	#17: 12-4 (514):6→20evens
			12-5	Area PythagThm	#18: 12-5 (520):10→20 evens
	W	**10/31/xx**		**Test #3**	⇨**T3**
11	M	11/05/xx	12 Rev	Composite Volume	#19: Ch12Rev (528):31,40,50,51,52,55,56,59,60,63,64,75
			13-1	Right Triangle Trig	#20: 13-1 (542): 13→25 all; ⇨*#4E*: Excel;
	W	**11/07/xx**		**Lab #4** Volume 1	⇨**L4**Volume Lab 1
12	M	11/12/xx	**Holiday**		**(Veterans Day)**
	W	11/14/xx		**Test #4**	⇨**T4**
13	M	**11/19/xx**		**Lab #5** Volume 2	⇨**L5**Volume Lab 2 *Thanksgiving Holiday 11/22/xx *
	W	11/21/xx	**No class**		**University open but no classes**
14	M	***11/26/xx***	13-2	More trig	#21: 13-2 (553): 13→19 all, 43→49 all⇨*#5E*: Excel
	W	**11/28/xx**		**Test #5**	⇨**T5**
15	M	12/03/xx	13-2	More Trig	#22: Ch 13 Rev (561): 40→50evens
	W	12/05/xx		Review for Final	#23?: 14-4 (592): 10→20 evens; p. 598: 1, 5, 9, 11
	M	**12/10/xx**		FINAL	**5:00-7:00 Monday 12/10/xx**

Lab Topics

Lab	Title	Objectives
Lab 1	Lightning Reflexes?	Simple + Lab Assembly + Statistics (esp. standard deviation)
Lab 2	Bouncing Ball	Simple + Patterns in rebound + Analysis of Results + Concept of Conservation of Energy + Direct Proportion
Lab 3	Area Lab	Concept of Area + Emphasis on Calculations + Creativity
Lab 4	Volume Lab 1	Concept of Volume + Concept of Composite Volume
Lab 5	Volume Lab 2	More advanced Composite Volumes + Creativity

Lab Guide

The Engineering Report" circa 1990. //www.ecf.utoronto.ca/handbook-lab.html, 08/19/2002.

A. **Title Page**: Title Page should include the Lab Report Number, Title of Lab, Section and Course (i.e., 24517 PHYS 1500L), Name of Student Reporting, Names of co-workers, Test Date and Submission Date. Title Page is unnumbered.

B. **Table of Contents**: Table of contents. All pages in the report after the Table of Contents should be numbered sequentially and titled so that they are clearly referred to from the Table of Contents. Starting Page Number for each of the 6 standard Sections that follow are all that is necessary.

   1. **Description of Apparatus**: First make a simple **complete and accurate list** (table) of all Materials and Equipment used. **Complete** implies all manufacturers, serial numbers and attributes (e.g., color, size {diameter if circular}, hardness, etc.). Sketches (or pictures) of equipment used and how arranged shows the Apparatus.
   2. **Test Procedure & Theory**: Typically the procedure and theory will be furnished to the student. The procedure explains all steps in the order they actually happened. If you did not follow the procedure exactly then document the exceptions (e.g., "At step 4 we performed four repetitions instead of three and ignored the data from the second repetition"). **Inclusion of the supplied procedure is acceptable**. Unless you enhance the Theory you don't need to include it at all.
   3. **Results**: Results are typically dominated by tables and figures (synonyms include graphs, curves or charts).
      A. **Tables**: All calculated data observed or calculated should be included in tables. Headings identifying sets of data should be included. Numbering (i.e., Table 1, Table 2, etc.) is recommended since necessary for involved labs.
      B. **Charts**:
         i. For Y vs. X scatter-gram plots place the independent variable on the horizontal axis and the variable that depends on it on the vertical axis.
         ii. Choose reasonable scales (e.g., increments of 1, 2, 5, 10 etc.)
         iii. Draw a smooth average curve that approximates the shape of the data but *do not force the curve through each and every point*.
         iv. Place a title on each curve. Numbering (i.e., Chart 1, Chart 2, etc.) is a helpful reference for callouts in your Analysis of Results.
         v. Identify each axis and include the units; (e.g., Distance (cm), time (sec))

4. **<u>Analysis of Results</u>**: As you develop your ability to write reports the analysis of results will clearly be the most important part of your report. Here, you show that you understand the experiment beyond the level of completing it. **Explain. Analyze. Interpret**. Focus on "**What is the significance or meaning of the results?**"

   A. **<u>Pure Analysis</u>**: **What do results indicate? What did you find?** Explain what you know with certainty based on your results and draw conclusions.

   B. **<u>Interpretation</u>**: **What is the significance of the results? What is ambiguous? Questions raised?** Find logical explanations for data problems.

   C. **<u>A Strategic Approach to Writing an Analysis of Results</u>**:

      i. **Compare expected results with those obtained.** If there were **significant differences** (i.e., typically > 5%) **how can you account for them?** Claiming all error as human error ⇒ *your group wasn't very competent*. Be specific (e.g., instruments not sufficiently accurate, sample was contaminated or effect of friction was ignored in calculated values).

      ii. **Analyze experimental error.** Was it avoidable? Was it equipment related? To determine if the experiment was within reasonable tolerances (typically 5% but sometimes more) **calculate a % difference from theory or from a different method**. Again, values within 5% are almost always good. For some experiments a reasonable difference will be even higher. **How could the experiment be improved?**

      iii. **Explain your results in terms of theory.** How well was theory illustrated?

      iv. **☆Relate results to lab objectives☆.** How well did you match up with any objectives stated at the beginning of the lab?

5. **<u>Sample Calculations</u>**: This section should provide clear detail on *<u>one</u> <u>typical sample</u> of a complete calculation* (i.e., show equation, plug in with units and then solve for the calculated value) of <u>each</u> type involved in determining calculated data.

6. **<u>Original Data Sheet(s)</u>**: The original lab data sheet(s) should be the last page(s) of the report. It should be an original (substitute Xerox or hand copy if original unavailable). Meter readings should be recorded as read (i.e., before any corrections). Record serial numbers and other identifying descriptors of all equipment used in test.