Review of a First-Year Engineering Design Course

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Abstract
Research shows that the first year experience affects retention and success of engineering students. Many studies document positive effects of interventions that involve active learning approaches. In this paper we summarize the factors affecting retention and satisfaction in engineering, provide an overview of active learning methodologies, and describe an intervention that combines three of such methodologies (project-based learning, inquiry-based learning, and collaborative learning) in a first-year introduction to engineering course at Rutgers – School of Engineering, a mid-sized engineering institution. The course had positive effects on retention and satisfaction of engineering students. Specifically we found that three-year retention increased by 19%; and students reported higher satisfaction with their experiences compared to the students enrolled in a traditionally taught introduction to engineering course. These findings support previous studies that an engaging first year experience can have dramatic effects on the future engineers and offer some practical recommendations for the institutions that consider similar reforms.

I. Introduction

An engaging first-year engineering experience is crucial in encouraging excitement, retention, and satisfaction in engineering.[1,2] The development of an engaging experience often involves instructional reforms, specifically the introduction of active learning. Hake defines active learning or interactive engagement as: methods designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors, all as judged by their literature descriptions.[3] Project-based courses and other active learning-based strategies are becoming increasingly common interventions used to improve retention and student satisfaction in engineering programs across the nation.[4,5,6] Educators and practitioners use various active learning methodologies in reforming the first year curriculum. With several available active learning methods, choosing one or more specific reform methods, implementing them, and assessing their effectiveness can be a complex task.[7,8]

It is common for engineering institutions to have liberal arts subjects such subjects as calculus, physics, chemistry, and other general education requirements dominate the first year engineering curriculum, leaving students with very little exposure to engineering and a lack of opportunity for seeing engineering as a dynamic field. In order to increase engineering exposure, to improve retention, and make a connection between the first year courses to engineering practice, we created an interactive project-based engineering design course, called Engineering Exploration, at Rutgers University – School of Engineering (RU-SOE) as a replacement to the traditional first-year introductory course.[9,10] The traditional course is an attendance based lecture type course that surveys the engineering majors. We found that for students who took the Engineering Exploration course instead of the traditional course, that three-year retention increased by 19%; and students reported higher satisfaction with their experiences.

The goals of this paper are to document the effects of the Engineering Exploration course on the first year engineering students who took it, and to understand why the course affected student persistence in and satisfaction about engineering the way that it did.

II. Literature Review

In this section we will explore the elements needed to create a dynamic engineering learning experience including: what engineers need to learn, factors affecting retention, active learning reform pedagogies, the engineering design process, and communication of ideas.

What Engineers Need to Learn: Engineers must be problem solvers, creative thinkers, and leaders in order to be successful in the profession.[11] For this to happen, students need to stay in engineering programs, be pleased with their choice of major, and develop engineering identity.[12,13,14] According to ABET's criterion for accrediting engineering programs, all programs seeking accreditation must demonstrate that they satisfy the General Criteria for Baccalaureate Level Programs, including Student Outcomes and Curriculum. Criterion 3- Student Outcomes indicates that future engineers should develop mastery of the traditional STEM concepts, the foundations of the engineering design process, and professional skills like team work, leadership, and communication before they enter the workforce.[15,16,17,18,19] ABET's Criterion 3 addresses the traditional STEM related skills (a-e) and professional skills (f-k).

ABET Criterion 3. Student Outcomes: The program must have documented student outcomes that prepare graduates to attain the program educational objectives.

(a) an ability to apply knowledge of mathematics, science, and engineering;
(b) an ability to design and conduct experiments, as well as to analyze and interpret data;
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
(d) an ability to function on multidisciplinary teams; and
(e) an ability to identify, formulate, and solve engineering problems.
(f) an understanding of professional and ethical responsibility;
(g) an ability to communicate effectively;
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;
(i) a recognition of the need for, and an ability to engage in life-long learning;
(j) a knowledge of contemporary issues;
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Additionally, Criterion 5-Curriculum states that: Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints. Therefore an engineering experience that introduces the students to the practice of engineering should speak to the acquisition and use of traditional skills, development of professional skills, and the fluency of the engineering design process. With these learning goals in mind, engineering educators are challenged to design curricular

interventions that will help students develop these requisite skills. In the development of such a curricular intervention, it is important to understand that attrition can negatively impact the quality and quantity of qualified students pursuing engineering.

Factors affecting persistence in engineering: Attrition is a serious problem in engineering education. NSF reported a national engineering graduation rate of 60% for the students who start in engineering major and graduate with an engineering degree.[20] This means that nearly half of the students who set out to pursue engineering never achieve that goal. In order to increase the quality and quantity of qualified engineers entering the workforce, this figure needs improvement. Several factors affect persistence in engineering. Some of those, such as curricular rigor and the development of engineering community relate to the educational process.[21] Others, such as race, gender, and interest in other fields depend on a particular student.[22,23,24] Engineering identity and self-efficacy are the factors that are influenced both by an individual student and the educational process.[24,13] The first year curriculum is where many universities start tackling all of these retention-related factors.[4,25,26,27] Developing experiences in the first year that actively engage the student in learning, such as an integrated curriculum, updated teaching methods, or a cornerstone course, can be used to counteract attrition by improving the educational process and addressing issues related to student specific variables.[28,29,30,31,32] Educational experiences that engage the student in learning include active learning pedagogies.

Active Learning Pedagogies: Teaching and learning methods need to evolve to meet the needs of today's students. Traditional or deductive teaching methods like lecturing (or chalk and talk) and routine problem solving have been in place for centuries, and have been shown to be ineffective in helping students learn.[3,25,30,33,34] Conversely, inductive or active learning pedagogies are likely to be more effective.[35] Active learning is an instructional style where the student is actively engaged in constructing her/his own knowledge in an environment created by the instructor as opposed to passively listening to the instructor transmitting the new knowledge. Active learning reform strategies including inquiry-based learning, case-based teaching, problem-based learning, project-based learning, collaborative learning, and integrated curricula are described below.

Inquiry-based learning is based on the investigation scientific or engineering questions, scenarios or problems. Those 'inquiring' will identify and research issues and questions to develop their STEM knowledge or solutions, guided by an instructor. Inquiry-based learning activities are designed for students to investigate, apply prior knowledge, examine, broaden conceptual knowledge, and to assess the growth of developing new knowledge.[36,37,38,39] Inquiry-based learning is most effective when students are able to make a connection between their learning and real life applications.[40,41]

Using an authentic engineering scenario provides a connection between STEM concepts and life. *Case-based learning* is where students analyze accounts of real world STEM related problems. In the process of analyzing this highly contextualized problem, underlying scientific concepts comes into play.[42] In some instances, students work together in case-based learning. Additionally, institutions with custom facilities can use case-based learning to construct authentic engineering problems.[43]

The acronym PBL refers to one of two often confused active learning strategies: problem or project based learning. *Problem-based learning* is where students work in teams on open-ended

ill-structured problems in order to identify learning outcomes and needs. Instead of a traditional professor, who would normally provide ample un-contextualized information, the professor acts as a facilitator as the learners tackle the contextualized problem. Solving this problem could be a pencil-paper activity, it could include working out a logistical or technical issue, or it could include doing engineering related research to determine solutions.[44,45,46] With problem-based learning, students could work independently, in pairs, or in groups.

In *project-based learning*, often confused with problem-based learning, students complete a project, typically in a group, that is well-defined, semi-defined, or ill-defined. [47] The project is something tangible and must use a hands-on approach.[46,48,49] Project-based learning can be very exciting for students. With this type of learning strategy, working on a project goes hand-in-hand with collaborative learning. [39] Students in a team work together to identify: what they already know, what they need to know, and what resources are needed to produce a feasible solution.[50] This excitement of project-based learning also comes with realistic price tags including: small section sizes, financial costs of the projects themselves, engaging instruction, challenges of group dynamics, and more.

The decision to have students work with each other, as noted in case-based learning and PBL, can have considerable and lasting effects. *Collaborative learning* is a strategy where the classroom activities are organized into academic and social learning experiences, where students work together towards solving a particular goal. Collaborative learning is designed to be, as the name suggests, collaborative rather than the competitive nature of individual learning. In this method, students learn in part by benefitting from each other's knowledge and ideas.[51,52,53] Collaborative learning can assist in the development of engineering community and engineering identity. Owing to students' individual differences in personality, skills, and abilities, the design and management of collaborative learning is complex with several benefits and challenges. [54,55,56,57] Collaborative learning is often used in conjunction with case-based learning, project-based and problem-based learning.

Many times, when solving a problem or project, several STEM concepts could be involved concurrently. Another method of reform includes combining content knowledge from several subjects at the same time. An *integrated curriculum* is one where math, science, engineering, and sometimes English courses are taught in an 'integrated' format. These courses may be taught together as combined courses, or taught separately, but with corresponding content.[6] For example, in a math course, vector addition may be introduced just prior to vectors in the physics course. Often in integrated curricula, the introductory engineering course spans all subjects (engineering, math, science, English, art, etc.). An integrated engineering curriculum refers to the combination of disciplines concerning course content, learning outcomes, and/or projects.[58] When designing a dynamic engineering learning experience, in addition to using active learning strategies, it is important for engineering students to develop mastery of the engineering design process.

The Engineering Design Process: Engineering by definition is the *application* of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems. The application of the science and math conceptual knowledge to solve a problem is a part of the engineering design

process.[2,6,48,59] Engineering design begins with the identification of a design problem, followed by translation into required science/math concepts, see Figure 1. At this point, the critical step occurs of applying the STEM concepts to fit within the engineering design constraints. This step is critical because it is the science (or math) that drives the *engineering design* decision, as opposed to 'guess and check'. Once the scientific concepts have been used to drive the engineering design decision, a physical model is formulated. The mastery of and comfort in using the engineering design process is a requisite skill for engineering students to cultivate, as it is a fundamental element of a successful engineering career.[60,61] Lastly, engineers must demonstrate their depth of knowledge by communicating their ideas and design decisions to their relative audience.

Communication of ideas and professional skill development: The philosophies of Engineering Education began to grow and drastically transform in the mid 1990's, valuing a more wholesome engineer. Surely the focus continues to include the traditional solidly rooted STEM skills, but also includes professional development skills such as: communication, teamwork, global and ethical awareness, and skills for life-long learning.[12] In addition to learning the foundations of design, helping future engineers master such professional skills as team work, leadership, and communication before they enter the workforce is key.[15,16,17] Communication of ideas in engineering takes the form of lab reports, technical papers, research papers, and oral presentations. The communication of ideas in written and oral format is a culmination and demonstration of the depth of conceptual and process level understanding of STEM concepts and the engineering design process.[18,19]

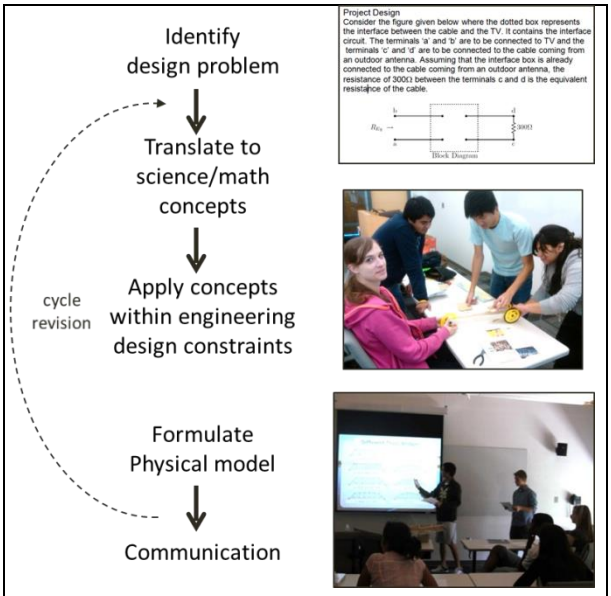


Figure 1. Engineering Design Process

III. Chosen Reform

As there are many options when designing an engineering learning experience, choosing appropriate reform measures must be done with careful thought and logistical planning. At RU-SOE, we assessed the traditional introductory course, examined logistical constrains, and chose reform measures for a new course.

Traditional Course: The traditionally taught course, called Introduction to Orientation Lectures, is currently the required survey course in the engineering curriculum. The course is in the format of eight 1hr 20min attendance-based seminars where a faculty member from each engineering department talks to the students about that specific engineering major. The course is held in a lecture hall, serving over 100 students in each section. With each seminar, the faculty member uses a slide show as a visual descriptive aid. This attendance based course is worth 1cr and is graded as 'pass' or 'no-credit'. The traditional lecture format is a cost effective method to

provide a large group of students with basic information about the available engineering majors. However, the traditional lecture format is a completely passive experience for students. The passive lecture style in conjunction with the purely attendance-based course grade can lead to inattention, boredom, and attrition, as referred to by Ercolano as "Sleep 101".[62] This traditional lecture style seminar course requires pedagogical enhancement in order to address concerns related to retention, academic success, satisfaction, and the needs of the engineering workforce.

Reformed Course: The goals of Engineering Exploration are threefold: to introduce students to the different engineering majors, to counteract factors relating to attrition, and to prepare students for success in engineering. To achieve these goals, we designed Engineering Exploration with a combination of active learning strategies. This new course borrows elements from project-based learning, inquiry-based learning, collaborative learning, and in part from an integrated curriculum. Additionally, the engineering design process is an integral component in the curriculum. Engineering Exploration utilizes discipline-based design projects to introduce the various engineering majors to the students and incorporate scientific driven design within engineering constraints.

We chose semi-structured project-based collaborative learning approaches for the hands-on nature that facilitates engagement and increased learning potential. Project-based learning can be well-defined, semi-structure, or ill-defined. Well-defined projects, while easier to facilitate, can leave the students with a lack of development of their own approaches to solving the problem at hand. Engineers need to be self-starters, capable of working independently and in groups, and able to think out of the box. Ill-defined projects would work well in this regard. However ill-defined projects would require that ample supplies and equipment be available to accommodate the broad spectrum of solutions. Semi-structured projects allow the students to generate the approach and do relevant conceptual research which are both needed to solve the problem. The semi-structured projects typically have a few valid outcomes which ensure that certain STEM concepts will be addressed. With only a few valid outcomes, the semi-structured approach also narrows the required supplies and equipment. Students working in groups allows for them to learn from each other and build off of individual strengths. This provides for demonstration of individual strengths, supports the increase in overall knowledge of the group, and nurtures collaboration.

The discipline-based engineering design projects are contextualized within realistic engineering problems. The discipline-based nature exposes the students to the various engineering majors. The contextualization of the engineering problem with an authentic topic is important in generating interest in a real world engineering issue. This enables students to develop a sense of importance and knowledge about the impact that their education and career can have on the world. As students move through the project, they will come to certain scientific or mathematical concepts that are required to continue. A common term for this concept that is used for adult learners is 'the need to know', which was developed by Malcolm Knowles.[63] The design projects require the use and application of scientific concepts. Only with the understanding of the relevant concepts, will students be able to make the important engineering design decisions and complete the project. Understanding that science drives engineering design is important in relating their first-year core courses in science and mathematics to their future coursework in engineering.

Each project concludes with some form of communication, usually in the form of a technical report and an oral presentation. The technical report is modeled after a scientific research paper. While the Engineering Exploration curriculum does not purely model and integrated curriculum, several relevant topics are addressed simultaneously. An example of the curriculum integration is the use of scientific concept knowledge, the engineering design process, and technical writing all within one project. The use of technical writing also ties into the first year writing requirement for all engineers. Students must utilize initiative, design, testing, analysis, cycle revision, communication, and teamwork. Group projects that are framed as contextualized engineering problems which require the application of scientific concepts in order to make engineering design decisions, followed by communication of these ideas comprise the backbone of the Engineering Exploration curriculum.

In contrast to the traditional course, Engineering Exploration has a much richer and engaging curriculum. Engineering Exploration is a 3 credit course and bears a letter grade. Student work is assessed both in group format and individually. This allows students to shine individually and to support each other to have success as a group. The class size is approximately 32 students per section, as opposed to the 100+ of the traditional course. A summary of both courses can be seen in Table 1.

Table 1: *Traditional vs. Reformed Course*

Course structure	Traditional Course Orientation Lectures	Reformed Course Engineering Exploration
Credits	1cr	3cr
Grading	Pass/No-credit	Graded (A through F)
Style	Lecture/seminar	Project based
Class type	Lecture hall	Group based classroom
Class size	100-150	32

IV. Curriculum

In this section, we will review the projects used in Engineering Exploration, a sample of one of the projects, a sample of the technical writing.

*Projects***:** As noted in the previous section, each project follows the same basic regiment, namely: the group project is framed as a contextualized engineering problem which requires the application of scientific concepts in order to make engineering design decisions, followed by communication of these ideas. This is the backbone of the Engineering Exploration curriculum. In the Engineering Exploration curriculum, there are there are 4-5 projects completed each term. Below is a list (A-H) of the projects that were used in the course at some point.

A. Bridge construction: construct a bridge out of balsa wood to withstand highest load.
B. Building construction: construct a building out of balsa wood to withstand largest earthquake tremors (simulated via unidirectional shake table).
C. Circuit design: design a basic circuit with resistors to match specified design constraints.
D. Reverse engineering a coffee maker: dissect a coffee maker to understand how it works as well as perform a heating efficiency comparison on two different models of coffee makers.
E. Mousetrap racecar design: design a car powered by a mousetrap to go the fastest or furthest.

F. Solar panel circuit design: design a circuit (resistors) that will optimize power output of a solar panel.
G. Stress/strain data analysis: analyze stress strain data in excel to find the approximate modulus of elasticity value.
H. Blood pressure analysis: collect real-time blood pressure data and analyze it in Excel to determine typical BP and other variables, relating them to biomedical applications.

As the semesters progressed, we gained useful in-class experience of how the course runs. With our classroom experience and student feedback, we modified the projects and activities to maximize the effects of the course.[7,8] A summary of the projects completed in each term that the course has been offered is seen in Table 2.

Table 2: *Summary of Engineering Exploration Projects by semester*

Semester	Projects
Fall 2009	Bridge, Circuits, Reverse Engineering, and Mousetrap Car.
Fall 2010	Building, Circuits, Solar Panel, Mousetrap Car
Spring 2011	Building, Circuits, Solar Panel, Mousetrap Car
Fall 2011	Building, Data Analysis, Circuits, Blood Pressure, Mousetrap Car
Fall 2012	Building, Data Analysis, Circuits, Blood Pressure, Mousetrap Car
Spring 2013	Building, Data Analysis, Circuits, Blood Pressure, Mousetrap Car
Fall 2013	Building, Data Analysis, Solar Panel, Blood Pressure, Mousetrap Car

*Project Example***:** While some projects were modified or changed completely, the backbone of the student projects remained the same. For each project, the students receive a description of a project or problem, which was written based on an authentic engineering topic. The problem is framed as a hypothetical real life scenario within an authentic engineering topic. The contextualized description used in each project is in paragraph format, and takes between 3 and 10 sentences. The Circuit Design Project involves students designing an interfacing circuit made of resistors to have an equivalent resistance of a specified value. Details of this project are in Figure 2.

The contextualized description for this project gave the students a glimpse of the types of higher-level projects that might be involved in Electrical Engineering. Due to the varying levels of exposure to electricity, students complete a set of structured activities prior to attempting this project, some in class and some at home. These activities provide them with basic knowledge of a circuit and electricity. See the appendix for the complete project. In designing this circuit, students had to utilize physics concepts within engineering constraints. Borrowing from principles of problem-based and collaborative learning, in this semi-structured project, in groups, students were expected to make a self-assessment of what they already knew, what they needed to know, and where to go to find obtain information needed to solve the problem.

There are multiple expected outcomes that students can use in their design of the semi-structured project, but they do not have to use any particular design element or any combination of design elements. Also, because the class is not held in a laboratory with specialized equipment, students' design decisions are limited by the supplies that we provide. With these supplies, there are still several design modifications that the students can choose. These limitations and

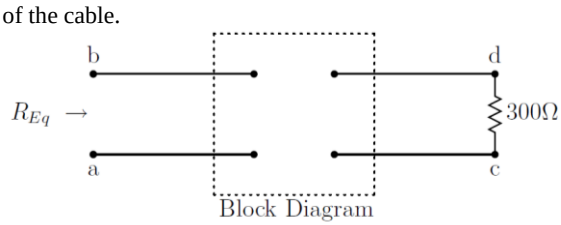
constraints can be considered engineering constraints. In a real life situation in engineering, there are always constraints. Where applicable, we include 'useful terms' in the project description as a means to add a layer of scaffolding. The use of these useful terms and the availability of certain supplies are meant to help steer the students down the path of one or more possible design considerations. The students are expected to conduct individual and collaborative research and inquiry into basic circuits and the physics concepts involved. Upon completion of the project, students demonstrate their depth of comprehension by communicating what they have learned. The communication is in the form of a group presentation and technical report detailing the entire project. The technical paper is similar to a scientific research paper.

Background

Comvision is the largest cable company that supplies cable services to hospitals for patient rooms. In many hospitals, cable tv service is run from an outdoor antenna to several locations in the building. The standard cables used in the past were 300Ω cables. However, recent TVs have a 40Ω to70Ω cable connection, depending on the brand. If the resistance of incoming cable does not match what the TV cable connection requires, ghosts of previous images will linger on the TV screen making it impossible to watch the TV. One obvious solution to the problem is to replace all the 300Ω cables in the building cables that are 40Ω-70Ω. This is expensive. A smart solution is to design an interfacing circuit between the 300Ω cable and the TV. Comvision is hosting a competition for the best circuit design. The best design wins the contract and receives a permanent job offer from Comvision.

Project Design

In the figure given below, the dotted box represents the interfacing circuit between the cable and the TV. Terminals 'a' and 'b' are to be connected to the TV and terminals 'c' and 'd' are to be connected to the cable coming from an outdoor antenna. Assuming that the interface box is already connected to the cable coming from an outdoor antenna, the resistance of 300Ω between the terminals c and d is the equivalent resistance of the cable.



Design the interfacing circuit such that the equivalent resistance R_{Eq} between the terminals 'a' and 'b' is a value between 40-70Ω (exact figure given by instructor).

Design Constraints: The terminal b cannot be interconnected to terminal d, They need to be distinctly different. The terminals a and c can be interconnected. The interfacing circuit needs to be electrically symmetrical. Below are examples that satisfy the design constraints.

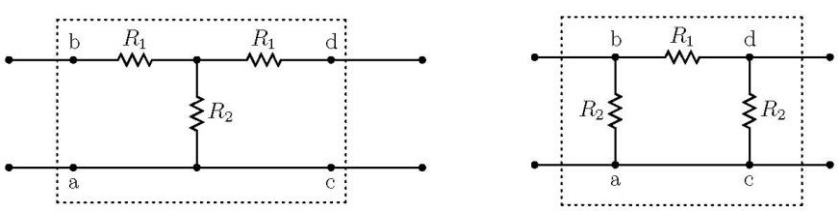


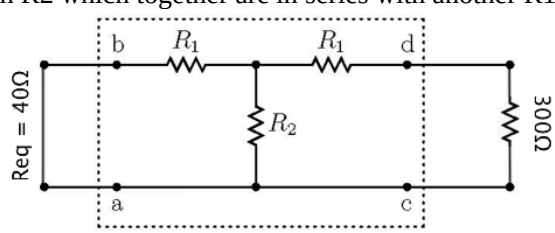
Figure 2. Circuit Design Project

Communication: Communication of ideas is a key aspect to professional skills that are needed for today's engineer. In Engineering Exploration, students finish their project with an oral presentation and/or a technical report. The presentations and technical papers are the dominant form of assessment in this course. The assessment component is included in the project description and reads as follows:

- Each group will be evaluated in terms of the circuit design calculations.
- Each team will make a group presentation describing project specifications, concepts, data, and conclusions that describe how it works, why it works, and physics/math involved.
- Each group member will write their own technical report detailing all of the information about this project, requirements, limitations, design modifications with relevant math/science concepts, pictures, diagrams, etc.

In the papers and presentations, students must indicate the scientific concept that supports their design decisions. For example, when solving for unknown resistor values in a complex circuit, students must have a firm understanding of series and parallel circuit calculations. The oral presentation mirrors the technical report, including all elements of the report, but in a summarized format. Figure 3 shows an excerpt from a student's technical paper. Students are given a rubric before writing the report (see the Appendix). This same rubric is used in assigning a number grade for the assignment.

The equivalent resistance of the two resistances in parallel is less than either of the two resistances, so a interfacing circuit can be used to reduce the resistance from 300Ω between C and D to 40Ω between A and B. The circuit that is being used for this interface works with resistor R1 and 300 Ω being in series. Both of these together are in parallel with R2 which together are in series with another R1 resistor.



By writing a mathematical equation, there can be found a pair of values appropriate for the two unknown resistances shown in figure 5. Using Ohm's Law and the rules for series and parallel portions of a circuit, the equation: $\frac{(R1+300)(R2)}{R1+R2+300}+R1 = 40$ describes the value of the two unknown resistances when interfacing between 300Ω and 40Ω. Two values that have been experimentally verified to satisfy this equation are R1=10Ω and R2=33.2Ω.

Figure 3. Excerpt of a student technical paper.

With the curricular design stepped in active learning pedagogies, a cohort of students is able to take Engineering Exploration in their first year. In the next sections, we will describe the instruction and student recruitment processes.

V. Instruction

In Engineering Exploration, the instructional staff includes a primary instructor and class aides. Class aides are current engineering students who are in their junior year or above. Class aides can also be graduate students. Prendergast (Author 1) was the primary instructor at the inception of this course. Even with the updated instructional strategies and project nature, the curriculum design of this course is one that is transferrable to others without much difficulty. There have been four instructors of Engineering Exploration to date. Table 3 lists the different instructors and their educational background at the time of instruction.

Table 3: *Instructional Staff*

Instructor	Highest Degree Held
Instructor 1	M.S. in Industrial Engineering
Instructor 2	M.S. in Industrial Engineering
Instructor 3	B.S. in Civil Eng'g
Instructor 4	Ph. D. in Chemical Engineering

The degrees held by the instructors vary from BS to PhD in Engineering. The conceptual content of Engineering Exploration is challenging enough for a first-year student. This in addition to the structure of the semi-defined projects provides a structure for a person with bachelor's level knowledge in engineering to be well prepared conceptually to teach Engineering Exploration. Grading is done by both class aides and by the primary instructor. Specific to the writing component, the class aides grade the rough draft, and the instructor grades the final draft. During the pilot phase, this grading structure works well. If the course expands, the grading structure may need modification in order asssess larger numbers of students effectively. During the pilot phase, Engineering Exploration is a voluntary course. In the next section, we will describe the student recruitment process.

VI. Student Recruitment

Out of approximately 700 new first-year students each year, only a small cohort of students are able to take Engineering Exploration during this pilot phase. In the engineering population, there are approximately 100 high achieving students who are in the Engineering Honors Program, and there are less than 100 students who place below calculus. During the pilot phase, we chose not to select students for Engineering Exploration from those two cohorts. These two factors, calculus placement and not being in the Honors Program, are the only academic criteria used in selecting the students. This cohort of ~500 'standard' first-year students is surveyed before they start school and asked if they want to take Engineering Exploration. The positive response rate within a 2 week period is 200-300. The factors used to select students from this cohort are: submission timestamp, gender, and ethnicity. Enrollment has ranged from 24-48 students. These 24-48 students are selected to take Engineering Exploration representing the demographics of the general student population, with a slightly higher representation of women and URM's, see Table 4.

Table 4: *Demographics - Engineering Exploration (EE) vs. School of Engineering (SOE)*

Cohorts	N(EE)=137	%age	N(SOE)=3249	%age
Female	55	40%	565	17%
Male	82	60%	2684	83%
White	54	40%	1488	46%
Asian	35	26%	1148	35%
URM	46	34%	456	15%
African-American	18	13%	166	5%
Latino	27	20%	286	9%
Native-American	1	<1%	4	<1%
Other	2	<1%	157	5%

Note: URM - African American, Latino, Native American

During the pilot phase of Engineering Exploration, participation in the course is voluntary. We reviewed SAT scores for the those who took the course vs those who did not to see if there was any correlation between students who took Engineering Exploration and SAT. The results are shown in Table 5.

Table 5: *Average SAT scores*

Cohort	Math SAT	Critical Reading	Total SAT
Engineering Exploration	664	568	1231
School of Engineering	666	578	1243
T-test*	0.88210	0.32194	0.54028

** Student T-test, two-tailed, p-value <.05 considered statistically significant.*

What is interesting is that there is no statistical difference between SAT scores for either of the groups. In fact, just by the numbers, the Engineering Exploration cohort has slightly lower SAT scores than the general student body. Even still, selecting students that already want to take the course could present some pre-existing motivational factors. Another selection option was to randomly select students to take the course and give them the option to switch out. However, with the full curriculum, project based nature, and group work format, it would be quite disruptive to have students moving about. Unfortunately, data from the group of students who wanted to take the course but were not selected has been maintained only since the fall 2012 semester. We have future plans to study the effects of the students who wanted to take the course, but were not selected, to see if there is any correlation between implemented reform, motivation, and retention.

VII. Findings: Traditional Course vs. Reformed Course

In this study, we conducted analyses to assess to what extent Engineering Exploration has on retention and student satisfaction. These areas will be explored in this section.

Retention: The One, Two, and Three Year retention figures for the entire School of Engineering were obtained from the Office of Institutional Research (OIR-the university's official data generation office). The school-wide figures measured students who started in engineering and remained in engineering after one, two, and three years. Correspondingly, we calculated the same 1, 2, and 3 yr retention figures for those students who took Engineering Exploration. As

mentioned earlier, Engineering Exploration students are chosen from the cohort of students who place into calculus and who are not a part of the Honors Program. The data from the OIR includes Honors students and student who placed remedially in upon entering RU-SOE. Retention of Honors students is tracked by the Honors Program Director at this institution. Average 1, 2, and 3yr retention of Honors students and for the entire student body is shown in Table 6.

Table 6: *Retention of School of Engineering and Honors students*

Retention	SOE (N=520 to750)	Honors (N =77 to 90)
1 yr	82.53%	>95%
2 yr	68.10%	>95%
3 yr	61.35%	>95%

Over the past decade, retention of Honors students has averaged from 96-98%. In Fall 2011, out of 665 incoming first-year students there were 90 Honors students. Retention of remedially placed students is unfortunately not tracked. Since we know retention of Honors students, the overall school retention rate, and the number of students placed remedially, we can see if honors students and remedially placed students skew the data in comparison to non-honors/calculus placed students (like those who take Engineering Exploration). The non-honors/calculus placed students will be called the 'standard' cohort. Using a simple weighted average calculation, where *x* is the retention of standard cohort, *y* is the retention of the remedially-placed cohort, and 98% honors retention, yields the following equation:

$$\frac{(90\times.98)+465x+110y}{665}=.60$$

The 3rd year retention rate of SOE is 61.35%, hence an estimated value of 60% was used above. For the sake of covering the case of a higher school retention rate, 70% was also considered as a second scenario. One might expect that the retention of a remedially placed student would be lower than the school average. In order to account for all scenarios, we will use *y* values of 40%, 50%, 60%, and 70%, which are values that are below, equal to, and above the school average retention. From the equation, the retention of non-honors/calculus-placed students (called the standard cohort) would be 57%, 55%, 53%, and 50% respectively. The retention rate calculation of the standard cohort (x_1, x_2) is shown in Table 7.

The calculated retention figures of the standard cohort suggest that regardless of the retention of remedially placed students, retention of the standard cohort is typically lower than the school average. In only one case (where remedially-placed retention is 40% and SOE retention is 70%), does the standard cohort retention rise above the school average. However in all other cases, the unknown retention of the remedially placed students will be offset by the much higher than average retention rate of the honors cohort. What can be drawn from this is that any positive shift in retention that is found for the Engineering Exploration cohort can be trusted as a positive shift.

Table 7: *Retention Calculation of Standard Cohort based on SOE retention.*

SOE Student Body	N 665	Remedial Retention 40%	Remedial Retention 50%	Remedial Retention 60%	Remedial Retention 70%
Honors	90	0.98	0.98	0.98	0.98
Remedial Retention (y)	110	0.40	0.50	0.60	0.70
Standard Retention (x_1) (SOE retention 60%)	465	0.57	0.55	0.53	0.50
Standard Retention (x_2): (SOE retention 70%)	465	0.72	0.69	0.67	0.65

Pre-existing motivational factors of the students who were interested in taking Engineering Exploration need further study. Additionally, any lower shift in retention will also need further study. The retention analysis was completed at the end of the spring 2012 semester. Table 8 shows course enrollment by semester.

Table 8: *Enrollment by semester (N 137)*

Semester	Enrollment
Fall 2009	1 section, 24 students
Fall 2010	2 sections, 48 students
Spring 2011	1 section, 17 students
Fall 2011	2 sections, 48 students
Fall 2012	1 section, 32 students

Gender and ethnicity sub-cohorts are also included in the retention analysis. In this study, URM, or under-represented minority, is defined as a grouping of African-American, Hispanic, Latin, and Native-American. The 3yr retention figures for Engineering Exploration are only based on one section (the fall 2009 course), as that was the first time the class was offered. A summary of the retention and gpa data is found in in Tables 9 through 13. Retention rates are defined as students who start in RU-SOE and remain in RU-SOE. SOE stands for School of Engineering. EE stands for Engineering Exploration.

Table 9: *Retention of SOE vs. EE*

Retention	SOE overall	EE overall	Percent Change
1 yr	82.53%	89.58%	+7.05%
2 yr	68.10%	86.36%	+18.26%
3 yr	61.35%	80.21%	+18.86%

Table 10: *Retention of SOE Female vs. EE Female*

Retention	SOE female	EE female	Change
1 yr	83.67%	91.70%	+8.03%
2 yr	69.28%	85.61%	+16.33%
3 yr	64.76%	82.58%	+17.82%

Table 11: *Retention of SOE URM vs. EE URM*

Retention	SOE minority	EE minority	Change
1 yr	80. 10%	80. 31%	+0. 02%
2 yr	66. 47%	74. 07%	+7. 60%
3 yr	57. 95%	55. 56%	-2. 40%

Table 12: *Retention of EE Male vs. EE Female*

Retention	EE male	EE female	Change
1 yr	87. 59%	91. 70%	+4. 11%
2 yr	83. 97%	85. 61%	+1. 64%
3 yr	77. 56%	82. 58%	+9. 02%

Table 13: *Retention of SOE Male vs. SOE Female*

Retention	SOE male	SOE female	Change
1 yr	82. 38%	83. 67%	+1. 29%
2 yr	67. 89%	69. 28%	+1. 39%
3 yr	60. 72%	64. 76%	+4. 04%

The retention rates indicate for the overall analysis that that retention of the Engineering Exploration retention was higher in all cases, with one exception. In Table 11, the 3rd year URM retention rate is lower than the school average. We are not certain if this is indicative of anything correlating to Engineering Exploration or if there is not enough URM data in the Fall 2009 cohort to be an accurate representation of URMs as a whole. Since Engineering Exploration appears to help most students, it is possible that reasons behind attrition for minority students may be different than non-minority students, and are possibly not addressed in this course. As there is more data available, we will continue to analyze all cohorts, in particular the URM cohort.

In addition to retention and project oriented courses, there are other areas in the first-year curriculum that are important to students. We also conducted student interviews to document their views concerning what worked well for them and what concerns they had in their first-year college experience. The results of these interviews will be explored next.

*Student Satisfaction and Concerns***:** The student interviews were conducted to find out some information about their experiences in the School of Engineering. The interviews were not associated with the course in any way. The interviewers had no connection to the course, to the School of Engineering, or to any of the course instructors. Students chose to be interviewed on a voluntary basis. Of those who volunteered, eight students took Engineering Exploration and four students took the standard course. A summary of four of the questions are shown in Table 14.

When students were asked which course was most valuable in their first year, 7 out of 8 (Engineering Exploration cohort) listed Engineering Exploration. For those who took the

standard course, none of them listed the standard intro course. When asked what skills they learned from the intro course, the Engineering Exploration cohort all listed one or more skills. The standard course cohort all listed that no skills were acquired. Lastly, when the students were asked about changes that they felt should be made to the first year curriculum, all of the standard course cohort indicated that the Intro to Orientation Lectures course should be updated to include more hands on activities and engaging instruction. The Engineering Exploration cohort noted that they wanted to reduce class sizes, move 2 courses to the sophomore year (in essence reduce the credit load), and to have even more hands on experience.

Table 14: *Interview Summary*

Question	Standard Intro Course cohort (n=4)	Engineering Exploration cohort (n=8)
Most valuable 1st yr course.	4 : Programming	7: Engineering Exploration 1: Programming and Calculus 2
Usefulness of the intro course in major selection	2: discouraging 1: not useful 1: helpful if lecturer was good	4: helpful 3: supported existing choice 1: n/a – question not asked
Skills learned from Intro course.	4: none	8: yes for one or more skill: math/science application to solve engineering problems, math/science concepts, work ethic, group work, time management, registration/scheduling, social/study network.
Changes should be made to the 1st yr curriculum?	4: revamp the intro to engineering course to include hands-on activities and better instruction	4: even more hands-on experience. 2: move two core courses to the 2nd year 1: smaller class sizes 1: scheduling exams differently

The retention analysis was reinforced by the results of the interviews. These results indicate that the existence of a dynamic first year experience produces beneficial outcomes throughout the engineering education. Our collaborative efforts between engineering and education and continued assessment have been a benefit to the quality of engineering education at this institution.

VIII. Discussion - Engineering Exploration vs. Other 1st Year Reform

The goals of this paper are to document the effects of the Engineering Exploration course on undergraduate engineering students and to understand to what extent and why the course affected student persistence in and satisfaction about engineering the way it did. We propose that the the curricular design of Engineering Exploration, the increased retention, and increased satisfaction of the students who took it are certainly correlated. The project and collaborative based nature of the course (as opposed to lecturing) requires maximum engagement on the part of the students. Additionally, requiring as a part of the project structure that students support their design decision with conceptual reasoning, as opposed to guess and check, requires the students to search for and obtain full conceptual understanding. Last, but not least, for a student to express (verbally or in writing) their conceptual knowledge and how it applied to the practical solution of the problem demonstrates the depth of understanding of the problem, concepts, and its solution

as a system of integrated parts. In addition to the reform analysis at RU-SOE, a retention comparison will also be made to three universities that have reformed their first year engineering course.

Other institutions have instituted first-year reform measures with increased retention results. We designed the curriculum of Engineering Exploration to include a combination of reform measures. The three institutions used in the comparison each have some elements of reform that are common to that of Engineering Exploration. At the University of Florida [25], their lecture course was converted into a laboratory format where students rotate to different labs/projects in the various majors. They reported 3 and 4 year retention increases from 34% (lecture course) to 51% (lab course). Their percentage increase is similar to that found in this study. However their overall retention rates are much lower than at RU-SOE, as our 3-yr retention rates are 61% (lecture) and 80% (Engineering Exploration). The new lab course at the University of Florida, while a marked improvement, still contained a fair amount of traditional instruction, leaving the students less engaged than they could have been. The minimal lecturing in the Engineering Exploration course could play an integral role in maximizing retention.

At the University of Denver, the Engineering and English departments collaborated and linked an Engineering Concepts course with a Critical Writing course in order to be in line with communication abilities that are noted in EC 2000.[18] This linkage is also a pedagogical element that we used in Engineering Exploration, where the two of the projects conclude with a comprehensive technical paper. At the University of Denver, this course linkage resulted in a huge 30% increase in 1st year retention from 53% to 83%. Two and three year rates were not given. Faculty at University of Denver noted the reasons behind huge retention increase to be student engagement and community development. Their results are remarkable for their institution. Their percentage increase in the first year is much higher than what was found in this study (30% vs. 7% increase). However their overall retention is still below our figures: 83% vs. 90%. It would be interesting to see their 2yr and 3yr retention rates for comparison. Engineering Exploration appeared to have a larger impact on retention in the 2nd and 3rd years.

At the University of Massachusetts at Dartmouth, their reform measure was to integrate the first year curriculum to include conceptual information, team-work, active learning, and a technology oriented space.[43] They experienced a 21% first year retention rate increase, from 62% to 83%. The results here are similar to the other universities mentioned in that the percent increase is higher than this study, but the actual retention rate is not as high as in this study at Rutgers University.

Institutions across the nation that have implemented reform measures to increase retention, success, and student satisfaction are commendable. In many cases, it is important to look past the first year in order to determine longer term effects. When comparing Engineering Exploration to these other institutions, it seems clear that the effects of Engineering Exploration spanning past the first year are substantial. It is unclear if the 2nd and 3rd year effect was similar at other institutions. We would attribute the marked increase in retention, especially in the 2nd and 3rd year, for students who took Engineering exploration to the design of the Engineering Exploration curriculum, in particular, the combination of active learning methods used. Engineering Exploration not only exposes students to the various fields, but also provides students with the

academic and professional skills needed to succeed in a rigorous engineering program. I will continue to work with the administration to foster a better future for engineering students at Rutgers University.

IX. Future Implications

Cornerstone courses like Engineering Exploration have proven to be an asset to an institution's retention, success, and satisfaction at other institutions, similarly to what has been found atRU-SOE.[4,25,26] We support and encourage expanding this course to all first year students. Prendergast, author 1, has recently begun efforts in this vein. We will continue to revise and enhance the curriculum to make the experience the most beneficial for the students. In addition, we plan to develop a video library of engineering related topics. One topic will be a virtual tour of each engineering department and of senior design courses. It is not feasible logistically to take all students on a tour of each department. However with a virtual video library, all students would have the opportunity to see each department. Another feature of the video library will be to create a portfolio of experiments and problems that elicit various concepts and components that relate to each engineering major. Etkina (author 2) has created such a library for Physics.[64] Creating these virtual experiments can also help the current situation of not having a real lab space. Experiments can be conducted and videotaped in labs where most students do not have access. Accompanying projects or problems can then be created and available for all students to use.

In order to continue to have a successful course curriculum in any subject, including an engineering project-based course, it is crucial to continue assessment, maintenance, and adaptation to fit the evolving needs of future engineers. Not surprisingly, this philosophy is consistent with ABETs' criteria for a successful and current engineering curriculum. Out of all of the theoretical and practical variables involved in creating and maintaining Engineering Exploration, it is the collaboration between education and engineering that has been the most essential and beneficial asset in this process. With such collaboration, this endeavor has undoubtedly been more successful, merging the breadth and depth in science education research with the vast field of engineering. We have learned a great deal from this experience and continue to assess the effectiveness of our reform measures in Engineering Exploration. The experiences that we have had through this process will help guide us in engineering education reform in other courses in the future.

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APPENDIX

Circuits project and activities – Electrical Engineering

- Demo-activity (*light a light bulb with 2 wires and a battery).

- Reconstruct the above set-up* and other listed below via an on-line simulation. Answer questions (http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc):
  - battery+bulb*
  - battery only
  - battery+resistor

  Questions:
  - Define electrical current, voltage, and resistance.
  - On the simulation, identify items on simulation: current, voltage, resistance.
  - Are there any similarities or differences between a light bulb and a resistor? Explain.
  - Why do balls go faster when there's no bulb/resistor?
  - What does a bulb/resistor do in the circuit?

- Find a diagram of simple series circuit and a simple parallel circuit (with only resistors). Draw each of them below.

- Using the on-line simulation, make 2 circuits: A. 2 resistors in series and battery. B. 2 resistors in parallel and battery.
  - What happens to voltage and current when they are in series vs. parallel?
  - Using bulbs instead of resistors, predict the brightness of the bulbs in these cases.
  - Construct the circuits with bulbs and test your prediction.

What happens to each part of the circuit when in:	Current	Voltage	Bulb brightness
Series			
Parallel			

- Based on your knowledge of the elements in a circuit, using an analogy, relate each element to the elements of people running on a track.

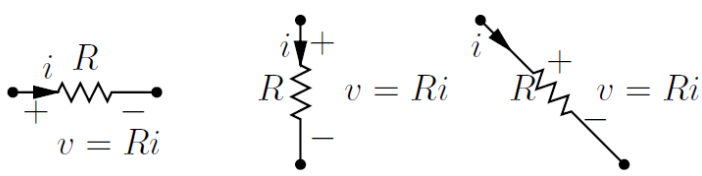
Parts of an electric circuit	**Parts of a system: people running on a track**
Moving Electrons	

Battery	
Connecting wires	
Light bulb	Hurdle
Light bulbs in series, bulb dimmer	
Light bulbs in parallel, bulb brighter	
Batteries in series, bulb brighter	
Batteries in parallel, bulb same brightness	

Conceptual Background

Our aim in this project is to design a simple interfacing circuit. Before we introduce the design project and a method of achieving our design goal, we need some background information. The needed background and the details of design are given below step by step. At first, we need to learn a property of a resistor, namely that it presents what is known as electrical resistance to a flow of current. For this reason, often the words 'resistor' and 'resistance' are used interchangeably. Once we learn about resistance, we proceed to learn how two resistances connected in series can be thought of as one equivalent resistance. Similarly, we will learn how two resistances connected in parallel can be thought of as one equivalent resistance. These concepts will then lead us to a simple design problem.

Step 1: (Concept of Resistance and Ohm's law) A resistor is a two terminal element used almost in every electrical circuit. It presents resistance to the flow of an electrical current. The value of resistance is measured in Ohms whose symbol is Greek letter Omega, Ω . Ohm's law states that v = Ri where v is the voltage in Volts across the resistance R and i is the current in Amperes through R. The figure below depicts a common representation of a resistance in a circuit.

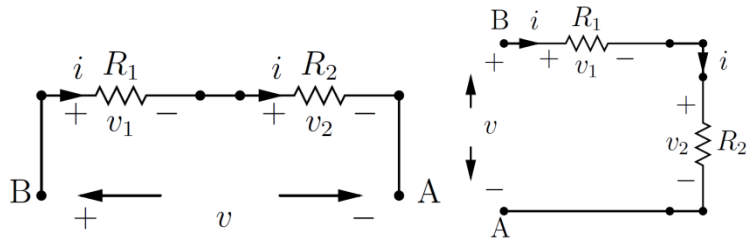


Resistance is akin to friction. Often friction is considered as an undesirable element. In automotive travel, friction presented by the road surface is the cause of loss of energy since it opposes the motion (or flow) of the vehicle. On the other hand, icy roads with no friction or reduced friction can be dangerous. You may have experienced that it is difficult to control the motion of a vehicle on icy roads. The lesson here is that a controlled amount of friction, and similarly resistance in electrical circuits or elsewhere is indeed desirable. An appropriately controlled flow of current is the goal of all circuit designers. Circuit elements including resistance values are designed properly to control the flow of various currents in a circuit.

Step 2: (Two resistances interconnected in series) Figure below shows the interconnection of two resistances in series. As seen in the figure, one terminal of the first resistance is connected to one terminal of the second resistance so that the current, i, flowing in both the resistances is the same. The other two terminals one from each resistance form the external terminals of the connection. One can view both the resistances interconnected together in series as one equivalent

resistance. Then, the equivalent resistance between the terminals A and B is given by: REq = R1 + R2. (Because v = iREq = v1 + v2 = i(R1 + R2).)

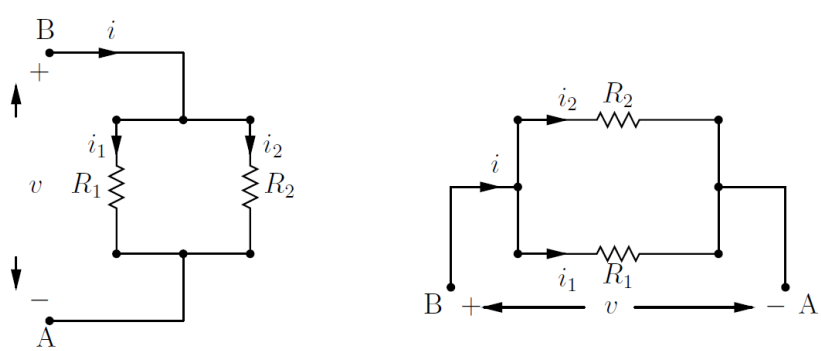
The above equation says that two resistances interconnected in series is equivalent to a single resistance having a value as the sum of two resistances, REq = R1 + R2. **Note that the equivalent resistance of two positive resistances in series is greater than either of the two resistances.**



Step 3: (Two resistances interconnected in parallel) Figure below shows the interconnection of two resistances in parallel. As seen in the figure, a pair of two terminals one from each resistance are connected together to form a node or a joint terminal, and similarly another pair of two terminals one from each resistance are again connected together to form another node. Both of these nodes form external terminals. In this case, the voltage v across each resistance is the same, however a current i flowing into a node divides itself into two parts i1 and i2. One can view both the resistances interconnected together in parallel as one equivalent resistance. Equivalent resistance of two resistances interconnected in parallel (that is, the resistance between the terminals A and B) is given by

$$\frac{1}{R_{Eq}} = \frac{1}{R_1} + \frac{1}{R_2} \quad \Rightarrow R_{Eq} = \frac{R_1 R_2}{R_1 + R_2}. \qquad \left(\text{Because } \; i = \frac{v}{R_{Eq}} = i_1 + i_2 = \frac{v}{R_1} + \frac{v}{R_2}.\right)$$

The above equation says that two resistances interconnected in parallel is equivalent to a single resistance having a value equal to the product of two resistances divided by their sum, as noted in the equation above. **Note that the equivalent resistance of two positive resistances in parallel is less than either of the two resistances.**

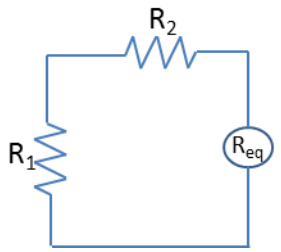


Two resistances interconnected in series as in Step 1 and similarly two resistances interconnected in parallel as in Step 2 form the basis of our design problem.

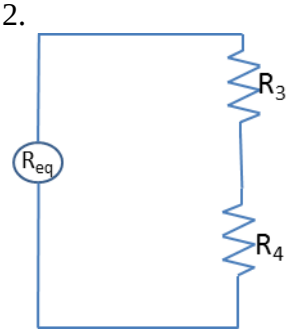
Guided Classroom problems:
Solve R_{eq} for these circuits where:

R_1= 50Ω	R_2= 2kΩ	R_3= 40Ω	R_4= 3kΩ
R_5=10Ω	R_6= 75Ω	R_7= 20kΩ	R_8= 15Ω
R_9= 35Ω	R_{10}= 100Ω	R_{11}= 95Ω	R_{12}= 20Ω

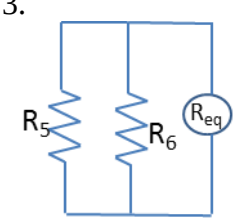
1.



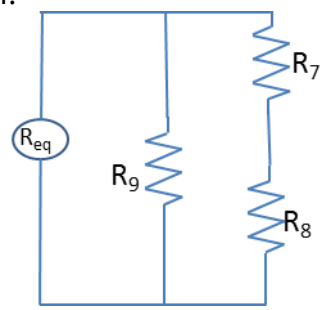
2.



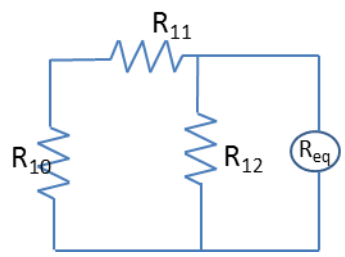
3.



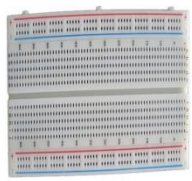
4.

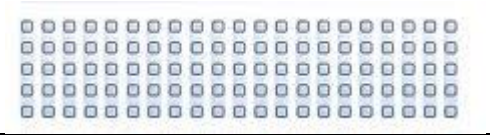


5.



- What is a solderless breadboard (pic below)? How is the breadboard constructed underneath the plastic covering with the holes (draw a picture or provide a picture)?



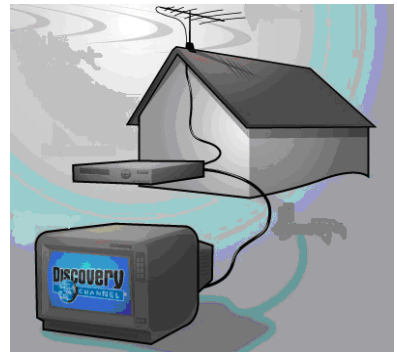
▪ Draw 2 resistors in series on a breadboard? 	▪ Draw 2 resistors in parallel on a breadboard? 

- Construct the following two scenarios on a breadboard with actual resistors and a multi-meter. (Note: you will not use a voltage source). Calculate the equivalent resistance of each circuit. Compare the calculated results with the measured results using the multi-meter.

Circuit configuration	**Circuit diagram (with R values shown)**	**Calculated R_{eq} (with calculations)**	**Measured R_{eq}**
Two resistors in series			
Two resistors in parallel			
A complex circuit (similar to #4 in the example problems)			

(the next page is the actual project)

What's Inside the Black Box?

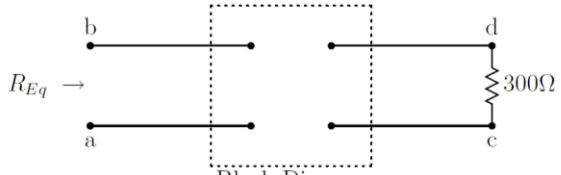


Background

Comvision is the largest cable company that supplies cable services to hospitals. In many hospitals, cable tv service is run from an outdoor antenna to several locations in the building. The standard cables used in the past were 300Ω cables. However, recent TVs have a 40Ω to70Ω cable connection, depending on the brand. If the resistance of incoming cable does not match what the TV cable connection requires, ghosts of previous images will linger on the TV screen making it impossible to watch the TV. One obvious solution to the problem is to replace all the 300Ω cables in the building cables that are 40Ω-70Ω. This is expensive. A smart solution is to design an interfacing circuit between the 300Ω cable and the TV. Comvision is hosting a competition for the best circuit design. The best design wins the contract and receives a permanent job offer from Comvision.

Design

Consider the figure given below where the dotted box represents the interface between the cable and the TV. It contains the interface circuit. The terminals 'a' and 'b' are to be connected to TV and the terminals 'c' and 'd' are to be connected to the cable coming from an outdoor antenna. Assuming that the interface box is already connected to the cable coming from an outdoor antenna, the resistance of 300Ω between the terminals c and d is the equivalent resistance of the cable.

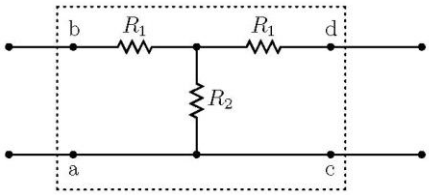


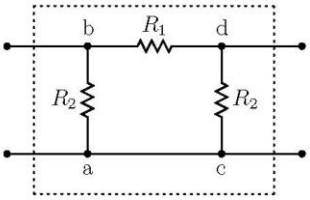
Block Diagram

The mathematical design problem can then be expressed as follows: Design the interface circuit that should be in the dotted box such that the equivalent resistance REq between the terminals 'a' and 'b' is between 40Ω and 60Ω (exact figure given by the instructor).

Constraints: The terminal b cannot be interconnected to terminal d, They need to be distinctly different. The terminals a and c can be interconnected. The circuit designed need to be symmetrical.

Below are two examples that satisfy the design constraints:





Assessment

Each project will be evaluated in terms of the circuit design, technical paper, and oral presentations. Each team member should keep record of project specifications, concepts, and conclusions.

Homework

Read 3 project papers and summarize main points (1 paragraph per paper). This assignment is to be included in the final draft of the technical paper and will not be collected separately.

Technical Writing Grading Rubric

Section (pp)	**Areas to be covered**	**Adequate**	**Needs improvement**	**Inadequate**	**Missing**
Abstract (¼-½ pg)	A condensed version of the main technical paper that highlights the major points covered (including the results), and reviews the writing's contents in abbreviated form. In the abstract, the reader should understand at a high level everything that is contained in the main body of the paper.	15	11	7.5	0
Introduction (½ to 1 pg)	A detailed description of the problem at hand.	10	7.5	5	0
Concepts (1 to 3 pgs)	Write your paper as if a high school student (stranger to Eng'g Expl) was reading it and you did not know their level of expertise in the subject at hand (ex. physics/electricity). Describe well the math and science concepts used.	15	11	7.5	0
Design and Constraints (½ to 2 pgs)	Detail of your plan or design to solve this problem. If there are any constraining factors as designated in the project write-up, include them in this section.	15	11	7.5	0
Results and Limitations (½ to 2 pgs)	Describe the results and any limiting factors encountered while carrying out the project.	15	11	7.5	0
Conclusions (½ to 1 pg)	Summary of the outcome of the project	10	7.5	5	0

Grammar and Mechanics					
Tense	Technical papers are written in the passive tense, meaning you **cannot** use the 1st, 2nd, or 3rd person (no I, we, the group, our, one, etc.) Acceptable: "the solar panel was tested" vs. Unacceptable: "the group tested the solar panel"	10	7.5	5	0
Font, format, and, cohesive-ness	12 font, double spaced. Figures, Diagrams, Charts labeled clearly and referenced in the text. Your paper should read fluidly. Each of the sections listed above should be addressed and should be connected in your text. When you transition from one section to another, you should have some text leading into the next section. Always reread your paper; check for grammar, spelling, and cohesiveness.	10	7.5	5	0
	TOTAL	***100***	***75***	***50***	***0***