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April 3 - 4, 2020

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Full Papers

An Undergraduate Experiment to Introduce Surface Science Fundamentals

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Abstract

The thermodynamic concepts relevant to surfactant adsorption, and their impact on surface tension, are introduced in a laboratory experiment designed for undergraduate students. Using a reliable and accessible method, students measure the surface tension of aqueous solutions at different concentrations of sodium dodecyl sulfate (SDS). Students collect data to estimate the critical micelle concentration (CMC) and quantitatively determine the maximum surface excess using the Gibbs adsorption equation. Students subsequently determine the surface area per molecule of this surfactant at the liquid-air interface and learn how to generate adsorption isotherm curves.

Introduction

The concepts of surface excess and the critical micellar concentration (CMC) are fundamental to the field of interfacial science and engineering. These concepts quantify the unique property of surfactants to adsorb at interfaces and to aggregate in surfactant solutions to form micelles. Experiments to determine the CMC and the surface excess as a function of bulk surfactant concentration are essential to student training. However, the measurement of these quantities often requires sensitive equipment and complex mathematical models. This can make it difficult to provide hands-on laboratory experiences for undergraduate students who are often taught in lab sections that have significant numbers of students. The availability of a sufficient number of duplicate experimental set-ups with sensitive equipment is often cost-prohibitive. Furthermore, the sensitive nature of such equipment often requires significant training time that may detract from the overall learning objectives that must be accomplished in the finite time allotted to a lab course. Thus, there is a need for laboratory experiments that are time-efficient, can be consistently duplicated so all students can participate, and produce results with sufficient accuracy that key concepts may be taught.

In this paper we disclose an experiment that is appropriate for large classes of undergraduate students since it eliminates the need for expensive equipment and is easily duplicated. This method to measure surface tension and surfactant adsorption properties can be accomplished easily by students with high-school level lab skills--yet the technique yields impressively accurate results. In addition, this experimental learning tool is designed so that the minimum number of data points is required to accomplish the intended objective, which is to obtain reasonable estimates for the CMC, surface excess, and surface area per adsorbed molecule.

Here, students measure the surface tension of solutions with different surfactant concentration by the "drop-weight" method, in which the mass of dispensed pendant droplets is measured and compared to the mass of similarly dispensed droplets of a standard liquid with known surface tension. Once the surface tension data is collected, ancillary surfactant adsorption properties are extracted from the data. The overarching goals of the experiment are to impart to students an understanding of the impact of adsorbed surfactant on surface tension, to quantify this effect through the collection and interpretation of data, and actively engage students in hands-on learning. The latter is important as it is well-understood that hands-on laboratory experiments enhance learning.[1] Details on the assessment and attainment of key learning outcomes of the experiment are provided as well.

Background

Derivation of the Drop-Weight Equations Used to Extract Surface Tension

The drop-weight method has been established as a convenient technique to determine the surface tension of liquids[2]. It is based on the postulate that at the time of detachment of a pendant drop being dispensed from an orifice with radius r, the surface tension force supporting the drop is equal to the weight of the released drop and is given by[2,3]:

$$mgf_c = 2\pi r\gamma \quad (1)$$

where m is the mass of the pendant drop at the time of detachment, g is the gravitational constant and γ is the surface tension of the liquid. In deriving Eq. (1), it is assumed that the dispenser orifice is in full contact with the liquid so that at the time of release the orifice diameter is equal to the cylindrical diameter of the top of the pendant drop (see experimental section below for confirmation of hypothesis).

In Eq. (1), f_c is a correction factor that accounts for the phenomenon that the full mass of a pendant drop does not all detach from the dispenser. Specifically, f_c corrects the mass measured during the experiments by increasing it to include the amount left behind on the dispenser. Consequently, the value of f_c must be larger than unity. If pendant drops from a standard liquid of known surface tension, γ_s, are carefully weighed, the correction factor can be found as:

$$f_c = \frac{2\pi r\gamma_s}{m_s g} \quad (2)$$

where m_s is the mass of a dispensed pendant drop of the standard solution[3,4]. This factor can then be used to find the surface tension of liquids with different surfactant concentrations from the mass of their drops and the radius of the dispenser orifice from Eq. (1). Alternatively, using the assumption of a constant correction factor, the surface tension can be calculated without the need to measure the orifice radius, r, if this radius is constant. For this special case, the surface tension, γ_i, of the liquid of interest having drop mass m_i, can be simply expressed as:

$$\gamma_i = \gamma_s \left(\frac{m_i}{m_s}\right) \quad (3)$$

In this paper, Eq. (3) is used to extract the dependence of surface tension on the concentration of the surfactant sodium dodecyl sulfate (SDS) in aqueous solutions.

The validity of the assumption of constant f_c is demonstrated by the measured dependence of surface tension on SDS concentration, as well as the extracted surface excess; both do agree well with the literature values (Table 2). Although a surface tension and geometry dependent correction factor is generally needed to extract properties suitable for academic studies, it is not needed here to within the desired accuracy of the experiments—which makes the experiment accessible to the target undergraduate audience.[5]

Experimental

Methods

The experiment reported here and experimental results to follow were performed by 48 students in a 2nd year undergraduate chemical engineering laboratory course entitled Chemical Engineering Principles Lab (CHME-391). This two semester-credit course was comprised of ten different modules covering key topics in Chemical Engineering. The duration of each module varies depending on the learning objectives. The Surface Science module consisted of four class periods lasting approximately 3 hours each with the following activities. The class of 48 students was divided into 17 groups of 2 to 3 students each, and was taught in two sections. In each section a detailed syllabus was provided to the students and an overview of the module was described. Prior to the lab portion of the module, six introductory lectures on surface tension, adsorption isotherms, surfactants, and other related topics were delivered to provide context. The lectures included lab demonstrations, video demonstrations, and "fun" experiments--these were presented during the first three classes. The experiment described herein was carried out during the last class (3 hours long). A detailed lab procedure was provided to the students, with time given for questions, and then the experiment proceeded as follows.

Each group was provided with a table of surface tension values for pure water as a function of temperature. The temperature in the room was noted, and the corresponding reference surface tension value was recorded. For the day of the experiment, the students used a standard surface tension value of 72 mN/m for a recorded room temperature of 25°C. The average drop mass for solutions of SDS was determined as described below. Pure distilled water (18.3 milliohm) was used as the standard liquid of reference. Students prepared stock solutions of 0.05 M and 0.01 M from a concentrated SDS solution provided (0.1 M). Then they diluted them to make a series of concentrations between 0.0001 M and 0.05 M. Note that the dilutions were made by volume, and not mass, which introduced little error since the concentrations of the solutions were low.

The mass of several empty vials with their caps was measured and recorded, and the vials were individually labeled to denote the solution/reference standard that would be collected. A pipette was used to dispense multiple drops of each solution into the corresponding vials, and the number of drops per vial was recorded (for details regarding the pipette used see discussion below). Vials were capped immediately after drop dispensing to minimize the effects of evaporation. The mass of each vial was then re-measured, and the mass of the liquid determined by subtracting off the masses for each empty vial. The average drop mass was calculated by dividing the liquid mass in each vial by the corresponding number of drops used to fill them. The average drop masses (obtained for surfactant and standard solutions) were substituted into Eq. (3) to obtain surface tension values for each solution. Note that the procedure to pre-weigh and label the vials was adopted in order to accommodate multiple groups of students with the two available analytical balances in the lab (Mettler Toledo New Balance MS scales with a precision to 0.001g).

To minimize the contribution to variability attributed to drop detachment, a standardized drop-formation procedure was adopted. The samples were measured by one individual per experimental group. The same disposable pipette was used for all the experimental measurements to eliminate variability in the pipette radius. Plastic pipettes (Fisherbrand, disposable, polyethylene transfer pipettes – cat# 13-711-9AM from Fisher Scientific) were used to prevent wetting of the outside edge of the pipette. Preliminary experiments with thin glass pipettes revealed significant wetting on their outer surface which led to increased variability in drop masses. Visual observation (no magnification) of the drop detachment from the Polyethylene transfer pipettes confirmed this non-wetting behavior; and these pipettes had the added benefit of being safer to use. The radius of the drops was observed to be that of the dispenser orifice, as it was assumed in the equations above. Additionally, it was observed that the drops detached when their tangents were vertical and parallel to the centerline axis of the pipette (the pipette was held vertically as discussed below). Since the same pipette was used for all samples, the measurements progressed in the order of increasing concentration--starting from the reference sample--to minimize contamination error.

Students were instructed to form pendant drops slowly, so as to provide enough time for surfactant to fully adsorb to the air-liquid interface before dispensing. If dispensed too quickly, the extracted measurements would not be the true static surface tension, as the interface would not achieve an equilibrium with its bulk concentration. Once formed, students were told to hold the pendant drop for a few seconds in its critical configuration prior to detachment; previous studies,[6,7] suggest that a few seconds is sufficient to achieve equilibrium. With the manual dispensing method used, students did find it difficult to maintain pendant drops at the final critical configuration for longer times. As discussed further in the Results and Discussion section, this limitation may have caused some minor errors in the final results. Nevertheless, the results obtained demonstrate that the magnitude of such errors was not sufficient to invalidate the simplified experiment within the scope of our educational objectives.

It was also suggested that students begin each sample with "practice drops" and discard the first droplets that were formed from the pipette. Such initial droplets were often observed to include air bubbles that would introduce error in the drop mass.

Another experimental concern was to minimize variations in the orientation of the axis of the pipette—which could invalidate the assumption of constant correction factor underlying Eq. (3). Drops needed to be consistently dispensed with the axis of the pipette perpendicular to the bottom of the vial. According to experiments done by Gans and Harkin the effect on drop mass from an axis angle deviation under 2 degrees is negligible.[8] They argue that because a tilt of such magnitude is noticeable to the human eye, the drop masses used to measure surface tension are accurate if no tilt is perceived without magnification. The students were indeed instructed to keep the pipette axis vertical, and if necessary, to find a reference edge on the lab bench (such as the wall of a beaker) to look at while aligning the pipette before dispensing a drop.

Materials

The SDS was purchased from Sigma-Aldrich (cat. #436143-100G with ACS reagent grade purity of 99% or higher). It is widely accepted that when SDS is used, purification such as by recrystallization may increase the surface tension values obtained.[9] In such cases, the impurity responsible for the surface tension decrease is believed to be dodecanol. In the presence of this impurity a minimum in the surface tension as a function of concentration is observed around the CMC. When dodecanol contamination is present, it is believed that it decreases the surface tension at concentrations below the CMC. However, for concentrations higher than CMC, the dodecanol is solubilized by the micelles thus eliminating its effect, increasing the surface tension, and creating the minimum. No such minimum was observed with the SDS used in these experiments, so no purification of the purchased SDS was deemed necessary. In addition, all the SDS solutions used were fresh to avoid the hydrolysis of any SDS to dodecanol.

Results and Discussion

Student groups determined the surface tensions of seven solutions containing SDS using Eq. (3). Typical data from one student group is provided in Table 1; students subsequently plotted this data as illustrated in Figure 1. The students examined this plot and applied the learnings from the lecture portion of this lab module to determine the CMC for this surfactant and then estimate the maximum surface excess. Based on these learnings the CMC was determined by students as the lowest concentration at which the lowest surface tension was measured on a surface tension plot as indicated by the open plot symbol in Figure 1. Furthermore, a quantitative value of the maximum surface excess was extracted from Figure 1 by noting that it occurs in the linearly sloped region of the plot just below the CMC. In accordance with Gibb's adsorption equation for an ionic surfactant, the surface excess, $\mathit{\Gamma}_i$, is given by:

$$\mathit{\Gamma}_i = -\frac{1}{4.605RT}\frac{d\gamma}{d\,[log_{10}(c)]} \tag{4}$$

where R is the ideal gas constant in units of [erg K^{-1} mol^{-1}], T is the absolute temperature in Kelvin, γ is the surface tension in [mN/m], and c is the concentration in mol/L.[10] Each student group replotted the linear portion of Figure 1 as shown in Figure 2 and determined the best-fit slope $d\gamma/d[log_{10}(c)]$ of that curve.

Table 1. Typical Student Results for Surface Tension

Concentration (M)	Average Mass of 20 drops (g)	Surface Tension* (mN/m)
$1.0X10^{-4}$	0.833	73.68
$5.0x10^{-4}$	0.785	69.43
$1.0x10^{-3}$	0.775	68.55
$2.5x10^{-3}$	0.739	62.60
$5.0x10^{-3}$	0.592	52.36
$1.0x10^{-2}$	0.485	42.90
$5.0x10^{-2}$	0.491	43.43

*Average mass of 20 drops and calculated surface tension using Eq. (3).

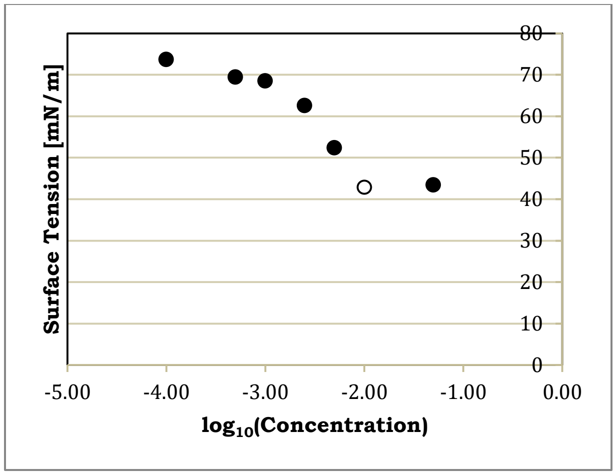

Figure 1: Typical student generated surface tension plot. The open plot symbol in the figure provides an estimate of the critical micellar concentration at 10^{-2} M.

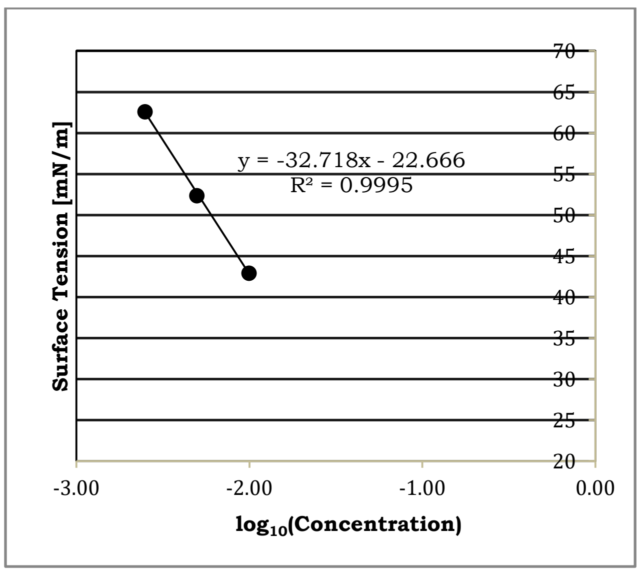

Figure 2: Typical determination of $d\gamma/d\log_{10}[c]$ in Eq. (4), which is the slope of the indicated line. Here, its value is -32.718 mN/m.

Once the surface excess was determined from Eq. (4), each group also extracted the area per molecule through the relationship:

$$A^{\Gamma} = \frac{1}{\Gamma_i N_{Av}} \quad (5)$$

where N_{Av} is Avogadro's number. Figure 3 compiles all the surface tension vs concentration data collected from the groups in this experiment. As evidenced in Figure 3, the average surface tension data collected by the students follows the literature values for the surfactant with reasonable accuracy.[11]

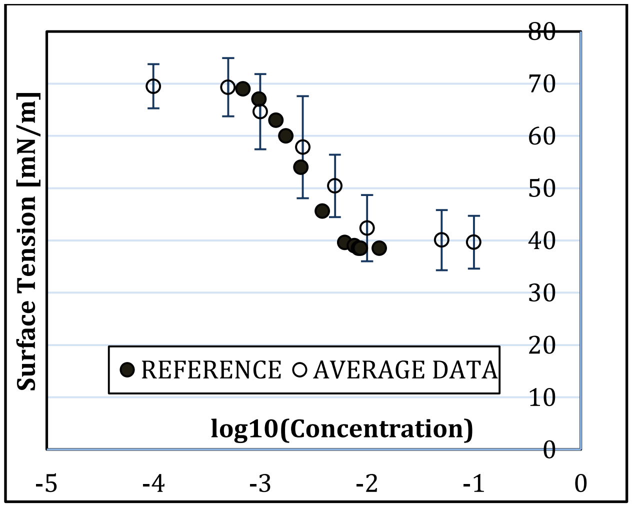

Figure 3: The average surface tension for both lab sections as compared to reference literature values[11]. Error bars represent a confidence interval of 1 standard deviation of the experimental values.

The extracted results for surface excess and surface area per molecule (Eq. (4) and Eq. (5)) obtained by the students are summarized in Table 2 and compared with accepted values provided by Rosen.[10]

Table 2. Values of Surface Excess in moles/cm^2 and Molecular Surface Area in A^2/molecule for SDS at 25^{o}C

Source	Surface Excess (moles/cm^2)	Molecular Surface Area (A^2/molecule)
Literature[10]	***3.1 E-10***	***53***
Section 1	2.74E-10 ± 0.75E-10	62.7 ± 20.1
Section 2	2.67E-10 ± 0.80E-10	67.8 ± 22.4

Values were determined by averaging the values obtained from each group. The variability in the measurements is expressed as 1 standard deviation from the average value.

The underlying student data contributing to the averages in Table 2 are provided in Figures 4 and 5, respectively. The data indicates a systematic error by both lab sections as evidenced by the non-random distribution of the data around accepted values. The origin of this error is apparent by inspection of Figure 3, where the slope of the student data just below the CMC is not as steep as the corresponding slope exhibited by the literature data.[11] This deviation produces a decrease in the surface excess value and an equivalent increase in the surface area per molecule value as seen in Figures 4(a) and 4(b). A possible explanation for this result is that surfactant is not fully adsorbed to the air-drop interface. To dispense a drop, students apply pressure to the bulb of a pipette via their fingers. It is difficult to maintain a drop in its critical configuration before detachment for a significant length of time using manual pressure. Thus, drops likely detach before an equilibrium surface adsorption is achieved, and this could explain the observed deviation.[12]

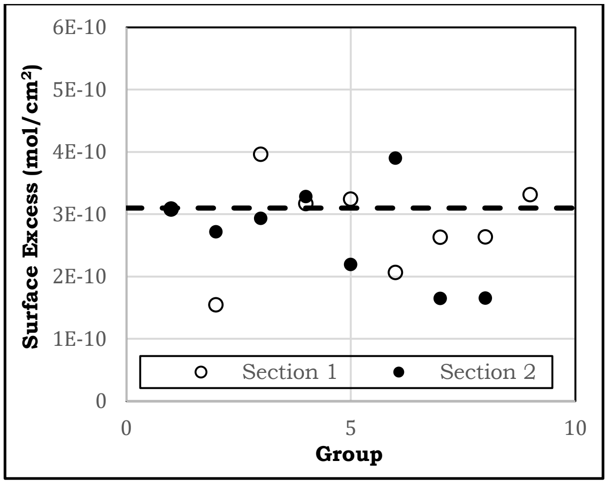

Figure 4(a): The surface excess (mol/cm^2) calculated by each student group compared with its literature value at 25°C, represented by the dashed line.[10]

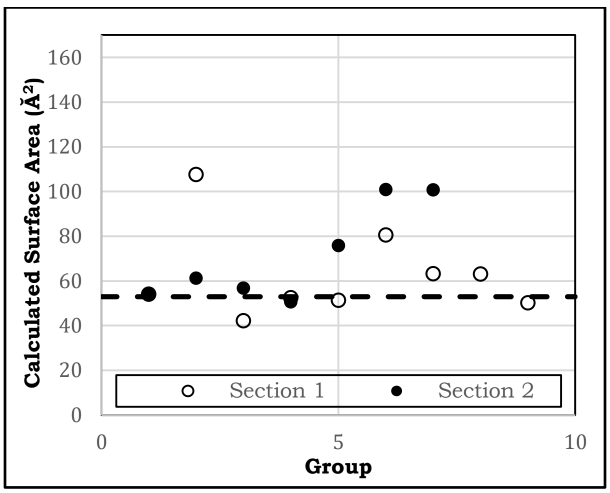

Figure 4(b): The surface area per molecule ($Ă^2$) calculated by each student group compared with its literature value at 25°C, represented by the dashed line.[10]

Additionally, a general discussion regarding the origin of the surface tension vs concentration curve – including the micellar region – was provided to students during the lab as auxiliary instructional material. The students were shown how to use Eq. (4), along with the surface tension vs. $\log_{10}$ of concentration curve shown in Figure 1, to generate an adsorption isotherm in the form of surface excess vs concentration. This could be done by extracting the local slope of the curve in Figure 1 at various concentrations. However, as the number of concentrations studied was small in order to make the experiment fit within time allotted for the lab, there was not enough resolution in the Figure 1 curve to obtain reasonably accurate slopes except in the linear region as shown in Figure 2. Thus, only the maximum surface excess, which corresponds to that linear region, was extracted in the experiment.

At the end of the experiment, each group of three students was required to submit a Microsoft Excel file with all their data, calculations, and observational comments. These results were summarized in the form of a short technical report submitted for the team. Each student was also graded individually on key concepts taught in the module via three quizzes. The final grade for the surface science portion of the laboratory course was obtained as a weighted average of these component grades.

The success of this experiment and the supporting lectures in achieving the learning objectives of the Surface Science portion of the lab course was assessed by three criteria: 1) the accuracy of the reported values of the CMC, the maximum surface excess just below the CMC, and the area per molecule of the adsorbed surfactant at this bulk surfactant concentration; 2) the understanding of the concepts of surfactant adsorption, micelle formation, surface excess, and adsorption isotherms as reflected by the submitted technical reports; and 3) the level of understanding of these same concepts as reflected by the answers to three quizzes related to these concepts.

Student performance indicated that the learning objectives were achieved based on both the final grade for the lab as well as the individual criteria grades above--the average final grade of all students was 88%. Thus, it is concluded that the experiment described herein is a good instructional tool for teaching fundamental surface science concepts to second year students in the Chemical Engineering program. In addition, student evaluations for the Surface Science portion of this course were quite positive, and this indicated that the students were receptive to the experiment and analysis of their data. It is worth noting that a recent article[13] has confirmed that the Gibbs adsorption method used in this experiment (see Eq. (4)) does estimate accurately the surface excess for surfactant concentrations that are lower than the CMC. This demonstration further confirms the soundness of this educational experiment.

Conclusions

The experiment described in this paper provides a simple means to introduce the thermodynamic concepts relevant to surfactant adsorption, and their impact on surface tension, to undergraduate students. Results were generated for an SDS-water solution by undergraduate students as part of a Surface Science Module in a second year laboratory course. In spite of its simplicity, the experiment yielded surface tension vs. SDS concentration curves, as well as extracted surface excess and area per surfactant molecule, close to those reported in the literature. The experiment itself was imbedded in an overall lab module that included lectures, quizzes, and an experimental lab report. Learning objectives were met based on student performance on these evaluation components. It was thus concluded that this experiment, and the module as a whole, is an effective introduction to key elements of surface science.

Acknowledgements

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We thank the chemical engineering student class of 2021 of the Rochester Institute of Technology (RIT) for the data they provided for this paper. Without their diligence and

enthusiasm, this paper would not have been possible. The Surface Science lab module, in which this experiment was conducted, is one of eight lab modules featured in the Chemical Engineering Principles Lab (CHME-391) course that is required for 2nd year students majoring in chemical engineering at RIT.

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Compressive Mechanical Properties of Three-Dimensional (3D) Printed Thermoplastics

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1. Introduction

Impact and adoption rate of 3-dimensional (3D) printing in manufacturing will increase dramatically over the next few years. The market for 3D printing technology itself is expected to grow to $5.2 billion by 2020 [1]. One example is General Electric (GE)'s decision to deploy 3D printers to manufacture nozzles for its LEAP engines. GE Aviation projects have printed more than 30,000 fuel nozzle tips in 2018 [2] and GE expects to print more than 100,000 additive parts by 2020 [3]. Engineering components printed by 3-dimensional printers are employed as mechanical structures in an assembly. In order for the printed components to be useful for engineering applications, mechanical properties of printed parts must be known for structural design. The properties provide answers to the strength of the material, the types of stresses a component can endure before failure, and the size of a component based on the loads it experiences. 3D printed materials have recently been studied for their mechanical properties [4, 5, 6]. This study was undertaken to further understand the compressive mechanical properties of thermoplastic materials printed by 3D printers and provide the fundamental mechanical compression data of thermoplastic for structural design by students. This project also provided training in mechanical engineering research to two students in addition to their regular coursework in Mechanical Engineering Technology.

2. Experiment

Acrylonitrile butadiene styrene (ABS), a common type of thermoplastic material for three-dimensional (3D) printing, was the material used in the construction of the specimens for compression testing. The material was printed by three 3D printers including Stratasys Fortus 450mc Printer (Figure 1), Stratasys Mojo Printer (Figure 2), and Stratasys uPrint SE Plus Printer (Figure 3). The printers employed the 3D deposition technology of fused deposition modeling (FDM) process. Fused deposition modeling process extrudes molten thermoplastic material through a nozzle, deposits the molten material as a cylindrical layer on a planar substrate initially or on a previously deposited thermoplastic layer at subsequent depositions, and solidified in situ. The process repeated itself until a three-dimensional structure was formed. The manufacturing process is known as 3D printing or additive manufacturing.

Specimens of cylindrical shape were printed at nominal dimensions of 13 mm in diameter and 20 mm in height. They were printed at a combination of raster angles of 0 degree, 45 degrees, and 90 degrees, and orientations of flat and upright. Figure 4 shows the print orientations of each set of specimens printed by a printer. Two specimens were each printed at flat-0 degree, flat-45 degrees, flat-90 degrees, and upright print orientations. The specimens were identified as “0”, “45”, “90”, and “UP” on the top surface to represent printing orientation of flat at 0 degree, flat at 45 degrees, flat at 90 degrees, and upright, respectively. Two specimens were printed at each combination of raster angle and orientation for testing repeatability. All eight specimens were printed at the same time in a run. Each set of specimens was further printed in both solid and sparse internal structure. The solid internal structure was formed by direct deposition of one layer on top of another layer, while the sparse internal structure was created by deposition of a porous interior network structure enclosed by an exterior envelope of solid layer. A specimen printed by a 3D printer before compression test is showed in Figure 5. Specimen identifications with print orientation and sample number are listed in Table 1.

Table 1: Specimen Identification

Specimen Identification	Print Orientation	Sample Number
0-1	Flat-0 degree	1
0-2	Flat-0 degree	2
45-1	Flat-45 degrees	1
45-2	Flat-45 degrees	2
90-1	Flat-90 degrees	1
90-2	Flat-90 degrees	2
UP-1	Upright	1
UP-2	Upright	2

A universal testing machine, PASCO model ME-8244 Comprehensive Materials Testing System with 7100 Newton capacity (Figure 6), was employed to measured mechanical properties of thermoplastic. A specimen was mounted on the machine and subjected to a compression test. The specimen was pressed by a compression force until failure or ultimate compressive strength was attained. Applied force and specimen length were continuously measured and converted respectively to engineering stress and engineering strain during the test. The data were recorded at 0.2 second intervals. Typical compression test graph of solid structure and sparse structure are showed in Figure 7 and 8, respectively. A smooth curve was recorded in the stress-strain curve of solid specimens. A jagged stress-strain curve was however found in sparse specimens. The jagged appearance was caused by the low resolution in sampling at 0.2-second intervals and the crumbling of the internal network system of the sparse structure under compression.

Figure 1. Stratasys Fortus 450mc Printer

Figure 2. Stratasys Mojo Printer


Figure 3. Stratasys uPrint SE Plus Printer

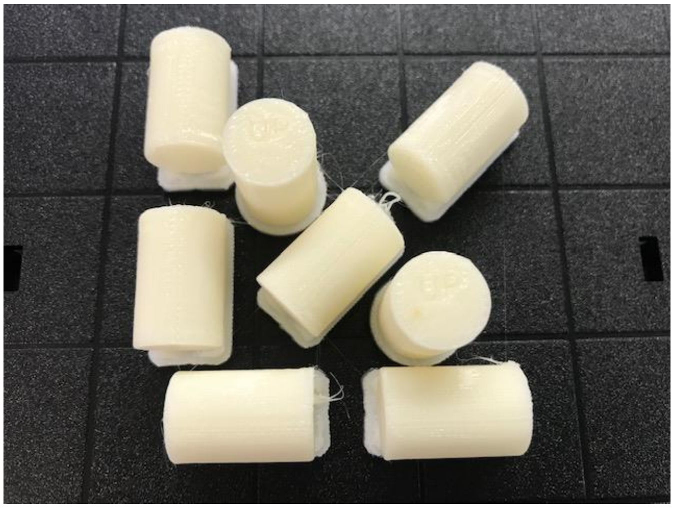

Figure 4. Orientations of Specimens at 3D Printing

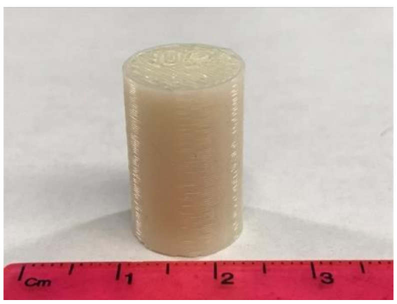

Figure 5. Specimen in Sparse Structure printed by Fortus Before Compression Test

Figure 6. PASCO ME-8244 Comprehensive Materials Testing System

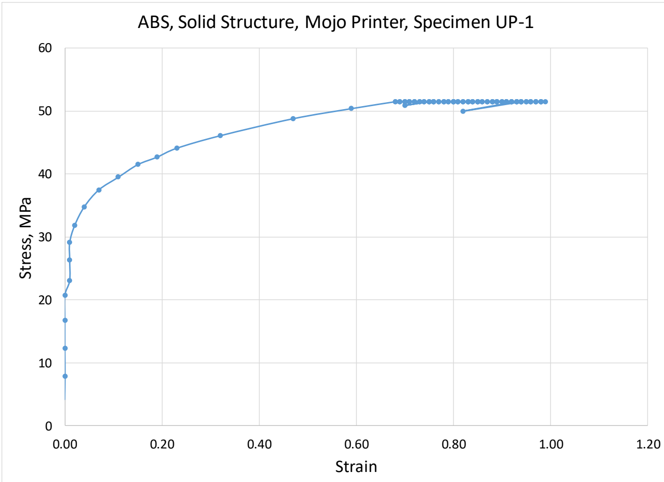

Figure 7. Compression Test Data of ABS, Solid Structure, Mojo Printer, Specimen UP-1

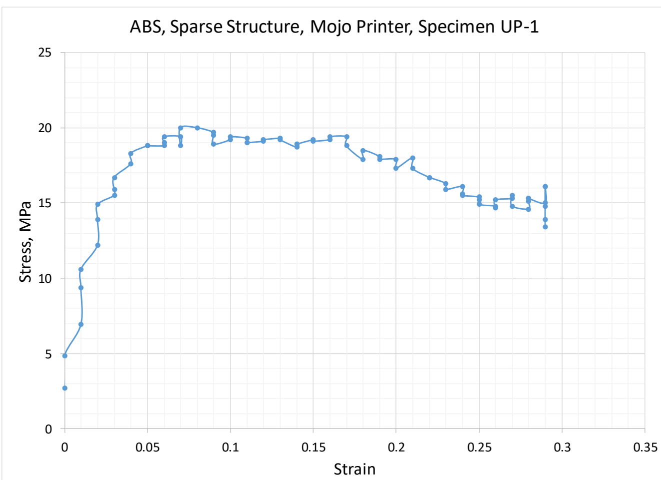

Figure 8. Compression Test Data of ABS, Sparse Structure, Mojo Printer, Specimen UP-1

3. Results and Discussion

3.1 Stress and Strain of Solid and Sparse Specimens

ABS thermoplastic in solid structure was stronger than that in sparse structure in compression. Stress experimental data as a function of time of solid and sparse specimens at flat-45º printed by Mojo printer are compared in Figure 9, while strain of the two structures at flat-45º printed by Mojo printer are compared in Figure 10. The ultimate compression strengths and strains of solid structures were more than double of those of sparse structures.

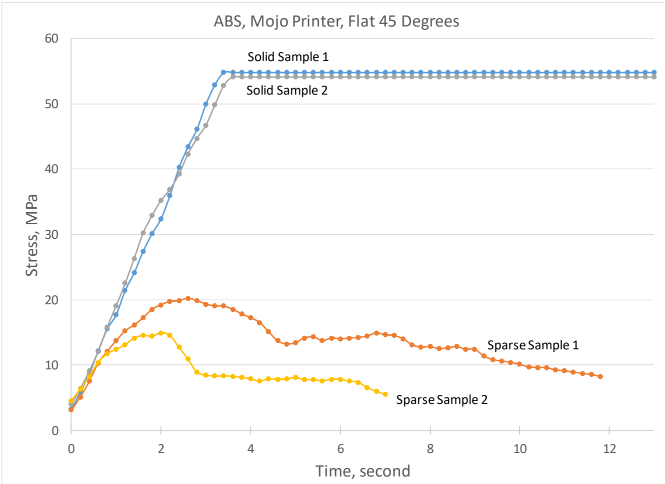

Figure 9. Comparison of Stress of Solid and Sparse Structure of Flat 45 Degrees by Mojo Printer

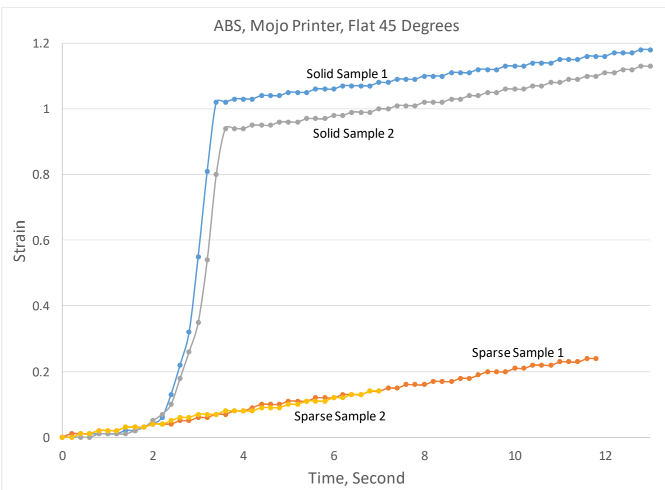

Figure 10. Comparison of Strain of Solid and Sparse Structure of Flat 45 Degrees by Mojo Printer

3.2 Ultimate Compressive Strength

Ultimate compressive strength of ABS thermoplastic, which is the highest stress on the stress-strain curve, is depicted in Figure 11. Ultimate compressive strengths of solid structure printed by Fortus, Mojo, and uPrint, ranged from 49.6 MPa to 55.3 MPa, 51.5 MPa to 55.3 MPa, and 49.9 MPa to 55.3 MPa, respectively. Ultimate compressive strengths of sparse structure printed by Fortus, Mojo, and uPrint varied from 22.4 MPa to 29.5 MPa, 14.9 to 20.3 MPa, and 18.6 MPa to 22.4 MPa, respectively. Overall, ultimate compressive strengths of solid structure ranged from 49.6 MPa to 55.3 MPa, and those of sparse structure varied from 14.9 MPa to 29.5 MPa. Ultimate compressive strength of solid structure was approximately twice that of sparse structure.

In view of orientation effect, distinctive pattern in ultimate compressive strength among print orientations of flat-0°, flat-45°, flat-90°, and upright was not observed in Figure 11. Ultimate compressive strength remained relative constant among all print orientations in the same internal structure printed by a particular printer.

In comparison of the data among specimens produced by various printers, ultimate compressive strengths of solid structure printed by Mojo were slightly higher than those printed by the other two printers. Maximum variations in ultimate compressive strength of solid structure among printers ranged from 0.1 MPa to 5.7 MPa (Figure 12). The variations were relatively insignificant. Effect of printer on ultimate compressive strength of solid structure was therefore not found. Ultimate compressive strengths of sparse structure demonstrated larger variations among printers (Figure 11). The ultimate compressive strengths of sparse structure printed by Fortus printer were predominately higher than those printed by the other two printers with values exceeding from 3.5 MPa to 10.1 MPa (Figure 12). The sparse structure produced by Fortus printer was therefore stronger than those manufactured by Mojo and uPrint.

Specific ultimate compressive strength, which is the strength per unit density, is depicted in Figure 13. Density of solid structure by Fortus, sparse structure by Fortus, solid structure by Mojo, sparse structure by Mojo, solid structure by uPrint, and sparse structure by uPrint were 0.982 g/cm^3, 0.598 g/cm^3, 1.06 g/cm^3, 0.694 g/cm^3, 1.01 g/cm^3, and 0.598 g/cm^3, respectively. The specific compressive strengths of solid structures among all printers were comparable. In view of the specific compressive strength of sparse structures, samples printed by Fortus were consistently stronger than those by uPrint and, in turn, samples printer by uPrint were stronger than those printed by Mojo.

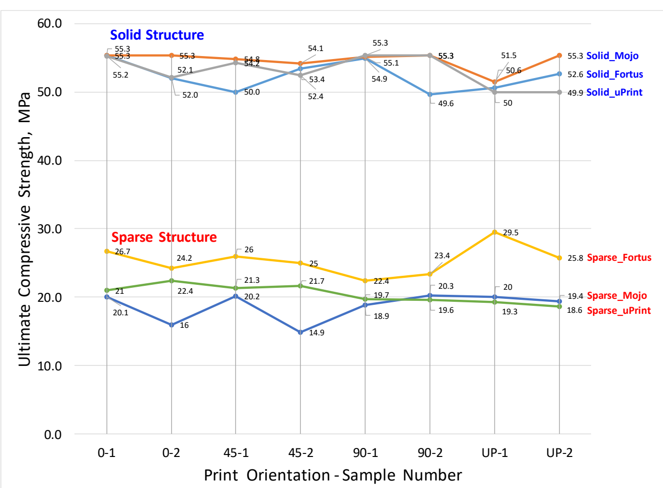

Figure 11. Ultimate Compressive Strength of ABS Thermoplastic

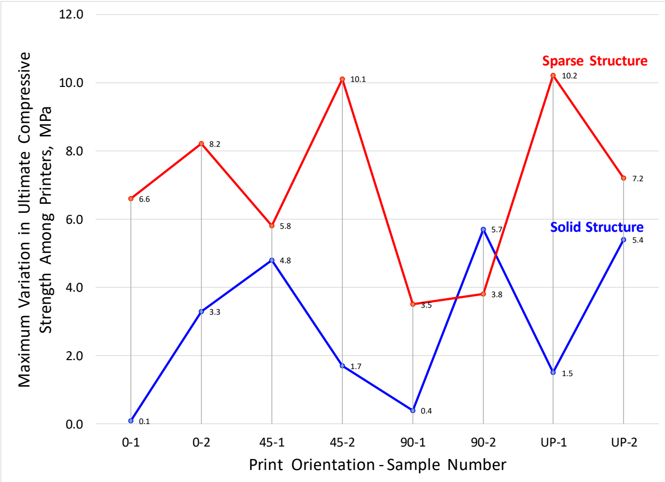

Figure 12. Maximum Variation in Ultimate Compressive Strength among Printers

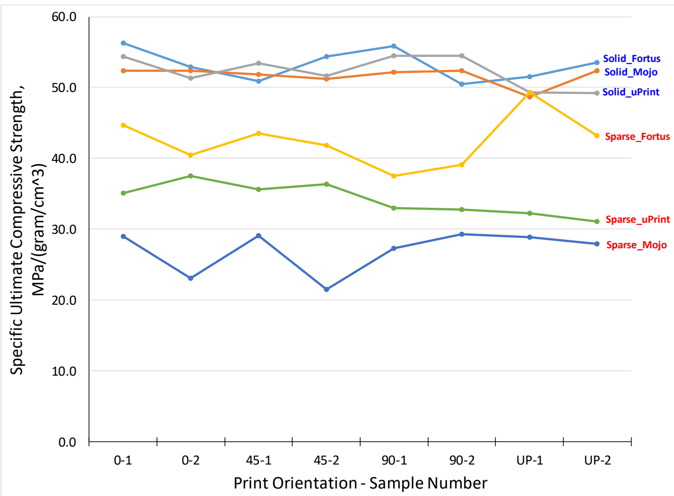

Figure 13. Specific Ultimate Compressive Strength of ABS Thermoplastic

3.3 Ultimate Compressive Strain

Figure 14 presents ultimate compressive strain that is the strain at which ultimate compressive strength is reached. Ultimate compressive strains of solid structure varied from 0.60 to 1.2; while those of sparse structure ranged from 0.04 to 0.15. ABS thermoplastic could therefore sustain minor degrees of deformation before the highest stress level was attained. Ultimate compressive strains of solid structures were significantly higher than those of sparse structures. Sparse structures were weak and they can be easily compressed with a reduced amount of deformation to reach their ultimate compressive strengths.

Effect of print orientation on ultimate compressive strain was not apparent as showed in Figure 14. Data of solid structures were so scattered that effect of print orientation in solid structures on ultimate compressive strain was inconclusive. Ultimate compressive strains of upright print orientation in sparse structure exhibited slightly higher ultimate compressive strains than those of flat print orientations. The ultimate compressive strains of upright print orientation ranged from 0.06 to 0.15, while those of the three flat print orientations varied from 0.04 to 0.07. This implied that the sparse structure in upright print orientation demonstrated a higher degree of compression deformation than those of flat print orientations, exceeding by approximately 3 times.

Printer effect on ultimate compressive strain was not found. In reference to the ultimate compressive strain in Figure 14, sparse structure produced by Fortus printer exhibited higher compressive strengths in all print orientations and generally higher compressive strains in the upright orientation in comparison with sparse structures printed by Mojo and uPrint.

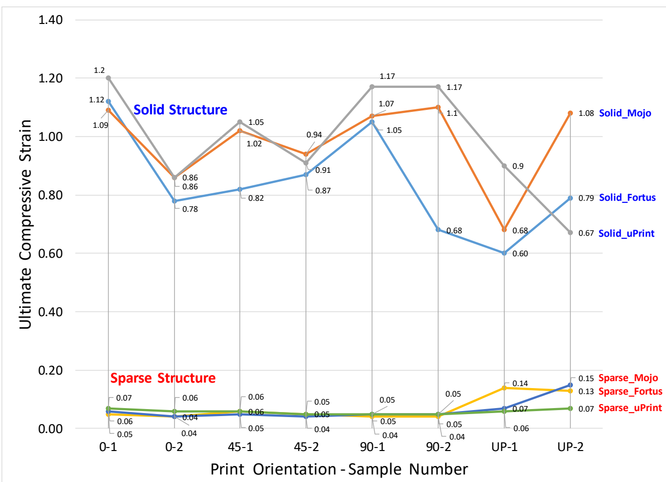

Figure 14. Ultimate Compressive Strain of ABS Thermoplastic

3.4 Modulus of Elasticity

Figure 15 shows modulus of elasticity that is the slope of the stress-strain curve of elastic deformation. The slope was determined by using the data points in the linear section of the stress-strain curve. The modulus of elasticity of ABS overall varied from 305 MPa to 1046 MPa. No distinct pattern of change in modulus of elasticity in reference to print orientation was found. Effect of print orientation on modulus of elasticity was therefore not observed.

Modulus of elasticity of solid structures printed by Fortus, Mojo, and uPrint ranged from 305 MPa to 725 MPa, 555 MPa to 1046 MPa, and 585 MPa to 776 MPa, respectively. Modulus of elasticity of sparse structures printed by Fortus, Mojo, and uPrint varied from 524 MPa to 685 MPa, 306 MPa to 484 MPa, and 337 MPa to 531 MPa, respectively. Values of modulus of elasticity of solid structures were generally greater than those of sparse structures. Greater stress was thus required to compress solid structures to the same amount of strain than that to sparse structures in elastic deformation. Solid structures are therefore stronger than sparse structures.

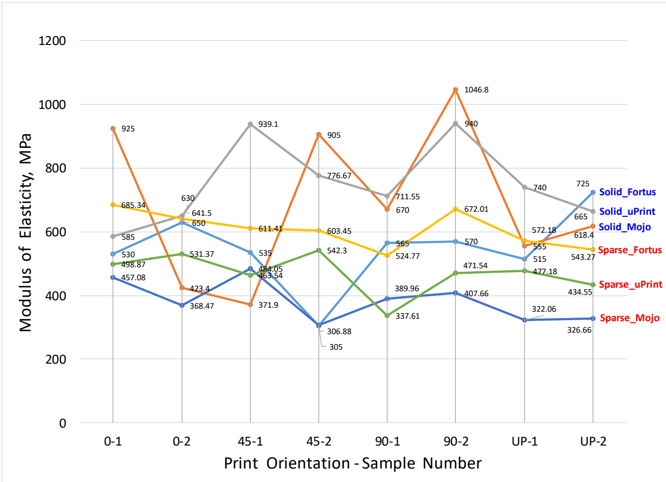

Figure 15. Modulus of Elasticity of ABS Thermoplastic

3.5 Yield Strength

Figure 16 depicts yield strength that is the transition point from elastic deformation to plastic deformation. The yield strength is the endpoint of linear part of the stress-strain curve. The 0.2% offset rule was not employed. Yield strength of solid structures varied from 33.6 MPa to 39.3 MPa, while yield strength of sparse structure ranged from 14.5 MPa to 27.9 MPa. Yield strengths of solid structures were approximately two times those of sparse structures.

Yield strength of each orientation printed by a printer were found to have similar values. Effect of print orientation on yield strength was therefore not observed.

Yield strength of solid structures printed by Fortus, Mojo, and uPrint was measured to be 33.6 MPa to 37.2 MPa, 34.8 MPa to 36.9 MPa, and 34.1 MPa to 39.3 MPa, respectively. Yield strength of sparse structures printed by Fortus, Mojo, and uPrint varied from 22.1 MPa to 27.9 MPa, 14.5 MPa to 19.8 MPa, and 18.1 MPa to 22.1 MPa, respectively.

Yield strengths of solid structures printed by the three printers were similar to each other. Maximum variations in yield strength ranged from 0.6 MPa to 2.7 MPa (Figure 17). These variations were insignificant in specimens produced by the three printers.

Yield strengths of sparse structure printed by Fortus exhibited values higher than those of sparse structures printed by Mojo and uPrint. The yield strength values of Fortus exceeded those of the two other printer by 3.1 MPa to 10.1 MPa (Figure 17). The sparse structure manufactured by Fortus was thus stronger than those sparse structures produced by Mojo and uPrint.

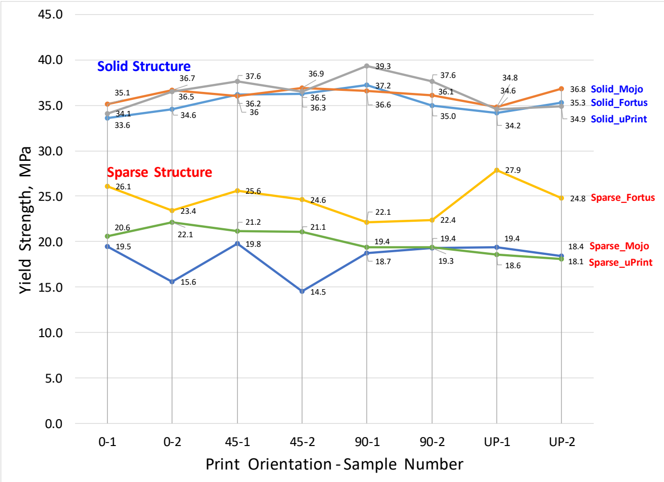

Figure 16. Yield Strength of ABS Thermoplastic

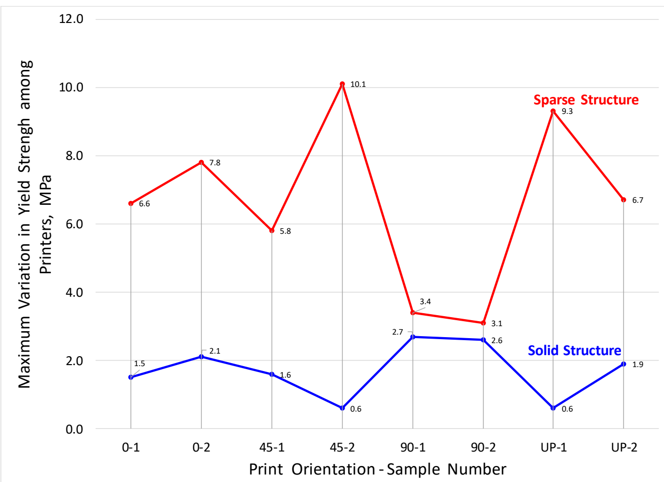

Figure 17. Maximum Variation in Yield Strength among Printers

3.6 Yield Strain

Figure 18 depicts yield strain that is the strain when yield strength occurs. Yield strain of ABS thermoplastic varied from 0.03 to 0.12. ABS could be deformed at a small degree before the deformation was transformed from elastic mode to plastic mode. Effects of print orientation and printer on yield strain were not observed.

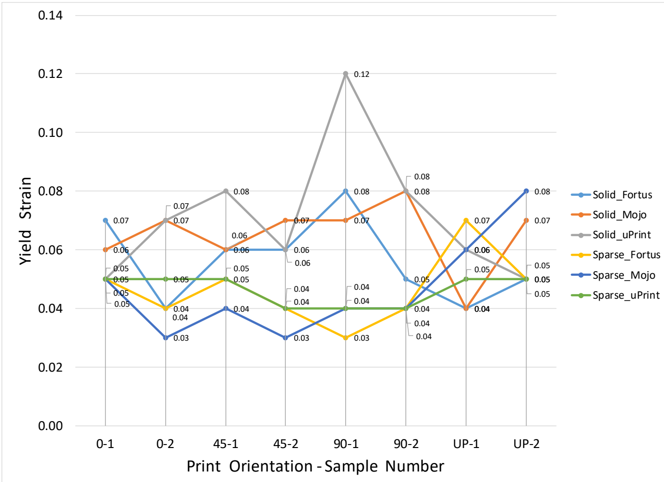

Figure 18. Yield Strain of ABS Thermoplastic

3.7 Failure Mode

Solid structures at flat-90° print orientation and upright orientation printed by Mojo after compression test are respectively showed in Figure 19 and 21. Compression force was sustained by the entire solid body of the specimen. Compressive plastic deformation transformed an initial cylindrical shape into a barrel shape as the highest deformation occurred at the middle portion of the cylinder.

Sparse structures printed by Mojo at flat-90° print orientation after compression test is depicted in Figure 20. Exterior layer that enclosed the sparse structure was the load bearing component of the structure. The exterior layer sustained compression force until the exterior layer failed by buckling, at the same time the interior network of porous structure collapsed under the force. The exterior layer was formed by deposition of layers in the direction parallel to the longitudinal axis of the specimen cylinder when the specimen was printed flat. As the exterior layer buckled, the layer folded perpendicular to the direction of 3D layer deposition and away from the centerline of the cylinder. Meanwhile, the interior porous structure was reduced in size in longitudinal direction. The folding of the exterior layer at buckling extended the outer diameter of the layer and contributed to the large increase in lateral strain. This type of exterior layer buckling failure was also observed in the other two print orientations of flat-0° and flat-45°.

Due to the fact that higher values in specific ultimate compressive strength (Figure 13) of the sparse structure printed by Fortus in comparison with the sparse structures printed by Mojo and uPrint, the exterior layer produced by Fortus was stronger than those produced by the other two printers. The exterior layer printed by Fortus failed by buckling in a catastrophic manner and the layers separated and folded extensively (Figure 23).

Figure 22 depicts specimens with sparse structures at upright orientation printed by Mojo after compression test. Specimens in the upright orientation was produced by 3D deposition of layers perpendicular to the longitudinal axis of specimen cylinder. The exterior solid layer in sparse structure was also the load bearing component in compression. As the exterior layer buckled and the interior porous layer collapsed, the exterior layer folded in the same direction of 3D layer deposition. The buckling occurred along the joint between deposition layers, the exterior layer were easily folded with little extension outside its outer diameter. The lateral strain of sparse structure in upright print orientation was therefore not as high as those at flat-0°, flat-45°, and flat-90°.

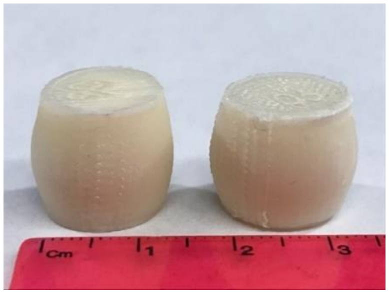

Figure 19. ABS Specimens of Solid Structure Printed by Mojo at flat-90° Print Orientation After Compression Test.

Figure 20. ABS Specimens of Sparse Structure Printed by Mojo at flat-90° Print Orientation After Compression Test.

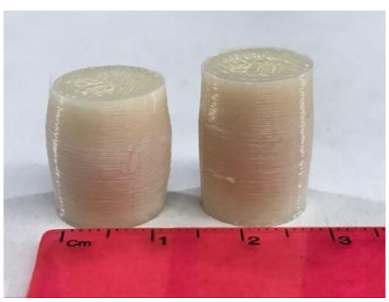

Figure 21. ABS Specimens of Solid Structure Printed by Mojo at Upright Orientation After Compression Test.

Figure 22. ABS Specimens of Sparse Structure Printed by Mojo at Upright Orientation After Compression Test.

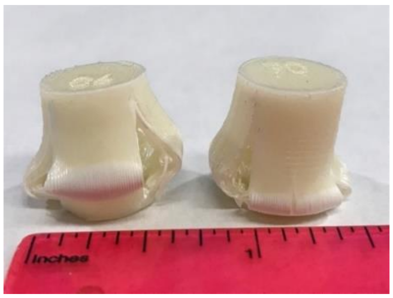

Figure 23. ABS Specimens of Sparse Structure Printed by Fortus at flat-90° Print Orientation After Compression Test.

4. Conclusion

Ultimate compressive strength, ultimate compressive strain, modulus of elasticity, yield strength, yield strain, Poisson's ratio, and failure mode of acrylonitrile butadiene styrene (ABS) thermoplastic printed by Fortus, Mojo, and uPrint printers at print orientations of flat-0°, flat-45°, flat-90°, and upright with solid and sparse structures under compression were examined in this study.

Solid structures were significantly stronger than sparse structures. Ultimate compressive strength and yield strength of solid structures were larger than those of sparse structure by approximately two times. Solid structures were more difficult to deform in the elastic region than sparse structures, as the moduli of elasticity of solid structures were generally higher than those of sparse structures.

ABS thermoplastic both in solid structure and sparse structure exhibited very limited elastic deformation before transition from elastic to plastic deformation. Yield strain of ABS thermoplastic varied from 0.03 to 0.12. Plastic deformation was therefore limited before ultimate compressive strength occurred. Ultimate compressive strains of solid structures varied from 0.60 to 1.2; while those of sparse structures ranged from 0.04 to 0.15. Plastic deformation at ultimate compressive strength of solid structure was 8 to 15 times that of sparse structure.

Effects of flat print orientations on mechanical properties of ultimate compressive strength, ultimate compressive strain, yield strength, yield strain, and modulus of elasticity were not observed.

Solid structures at all print orientations failed in the classical way by forming a barrel shape from a cylindrical shape, as high degrees of deformation occurred at the mid-section of the cylinder. Exterior layer of sparse structure was the main load bearing component in compression. Buckling of the exterior layer in sparse structure was the failure mode as the interior porous network structure collapsed under compression. The buckling in sparse specimens with flat-0°, flat-45°, and flat-90° print orientations occurred perpendicular to the 3D printing deposition direction, while the buckling in sparse specimens with upright print orientation occurred parallel to the 3D printing deposition direction. The buckling in flat oriented specimens in sparse structure was more extensive than that of upright oriented specimens.

Based on the data of ultimate compressive strength and yield strength, sparse structures produced by Fortus demonstrated higher strength and greater degree of brittle buckling with catastrophic failure than those of sparse structures produced by Mojo and uPrint.

The specific compressive strengths of solid structures among all printers were comparable. In view of the specific compressive strength of sparse structures, samples of sparse structures printed by Fortus were consistently stronger than those by uPrint and, in turn, those samples printed by uPrint were stronger than those by Mojo.

5. Acknowledgement

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A Scholarship Program for Students Transferring from Two-Year Colleges

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Abstract: This paper provides a mid-project report on a scholarship program funded by the National Science Foundation that focuses on students who transfer at the 3rd year level from 2-year schools to the engineering and engineering technology BS programs at our university. The goals of the program are: (i) to expand and diversify the engineering/technology workforce of the future, (ii) to develop linkages and articulations with 2-year schools and their S-STEM programs, (iii) to recruit, retain, and graduate 78 low-income students, and place them in industry or graduate schools, (iv) to generate knowledge about the program elements that can help other universities, and (v) to serve as a model for other universities to provide vertical transfer students access to the baccalaureate degree.

The project is in its fourth year, and has met its recruitment goal of a total of 78 scholars divided in three cohorts. Our goal is to retain and graduate at least 95% of these scholars.

Three key programs that have contributed to our success are: (i) the co-op program facilitated by the Office of Cooperative Education and Career Services, (ii) a newly developed zero-credit VTAB Orientation Program course, and (iii) our academic advising system.

Our external evaluator was involved in the development, implementation, and analysis of two surveys and focus group interviews, and is satisfied with the progress we have made. Survey #S1 was developed in year one for incoming scholars, and has been administered to all three cohorts. Survey #S2 was developed last semester for scholars in the middle of the program, and has been administered to the first cohort. The focus group interview protocol was developed in year one, and has been administered to all three cohorts.

We faced two major challenges so far: (i) obtaining the complete list of incoming scholars from the Office of the Financial Aid and Scholarships (OFAS) before the Fall semester began, and (ii) setting up the zero-credit VTAB Orientation course. First challenge was overcome by working with OFAS to get the name of the scholar as soon as the student accepted our admission and scholarship offer instead of waiting until all scholarships had been awarded. The second challenge was overcome by having a specific course code assigned to the Orientation course by the Registrar with time/day/location so that each scholar could adjust their academic schedule to accommodate the course, and register for it before the Fall semester began.

We are on schedule with no major changes from our original timeline. This paper will provide an overview of the scholarship program, and the progress we have made so far.

Introduction: This paper discusses the VTAB (**V**ertical **T**ransfers' **A**ccess to the **B**accalaureate) project that focuses on students who transfer at the 3rd year level from 2-year schools to the engineering and engineering technology BS programs at RIT. The objectives of this project are:

1. Recruit a total of 78 low-income vertical transfer students from 2-year colleges into RIT's engineering and Engineering Technology BS degree programs,
2. Retain and graduate at least 95% of the recruited scholars,
3. Prepare scholars with the necessary skills, education, and work experience to enter the high technology workforce upon completion of BS degree, and place them in industry or graduate schools,
4. Design and develop program elements to achieve objectives #1, #2, and #3, and
5. Generate knowledge about each program element that will be essential to the success of a vertical transfer program at any 4-year private institution.

The VTAB project is funded by a five-year grant from the National Science Foundation (NSF) that began in September 2017. In its program solicitation [1], NSF stated its goals to be: (i) to increase the number of low-income academically talented students in STEM, (ii) to improve the education of these STEM students, and (iii) to generate knowledge to advance understanding of factors that lead to the success of these students. VTAB is leveraging the lessons learned from an earlier TiPi (Transfer Pipeline) project to achieve the first two goals [2]. The third goal is addressed later in the section that describes the online surveys and focus group interviews [3].

The VTAB project is a collaborative effort of eight academic departments from two colleges, the Enrollment Management and Career Services Division, and the Office of Financial Aid and Scholarships. Table 1 lists the participating departments in column 2, and their BS degree offerings in column 3.

Table 1: Participating Colleges, Academic Departments, and Degree Programs

College*	Academic Department	BS Program in
CET	Civil Engineering Technology and Environmental Management and Safety (CET-EMS)	Civil Engineering Technology
		Environmental Sustainability, Health, and Safety
CET	Electrical, Computer, and Telecommunication Engineering Technology (ECTET)	Electrical Engineering Technology
		Computer Engineering Technology
		Telecommunication Engineering Technology
CET	Manufacturing/Mechanical Engineering Technology (MMET)	Manufacturing Engineering Technology
		Mechanical Engineering Technology
CET	Packaging Science (PS)	Packaging Science
COE	Electrical and Microelectronic Engineering (EME)	Electrical Engineering
		Microelectronic Engineering
COE	Mechanical Engineering (ME)	Mechanical Engineering
COE	Industrial & Systems Engineering (ISE)	Industrial Engineering
COE	Computer Engineering (CE)	Computer Engineering

*CET ≡ College of Engineering Technology; *COE ≡ College of Engineering

Collectively, the eight departments listed in Table 1 offer thirteen BS degree programs that are five-year programs with a mandatory cooperative education component wherein students attend classes in Fall and Spring semesters in their first two years. During the third and fourth years, students alternate between on-campus study and off-campus co-op employment in industry. All students must complete at least 48 weeks of paid co-op employment. Each student finds co-op employment with help from an assigned co-op coordinator in the Office of Cooperative Education and Career Services.

Recruitment: The project is in its fourth year. Its goal was to recruit 26 low-income transfer students from 2-year schools in three yearly cohorts for a total of 78 scholars. Figure 1 shows each year's recruitment goal, and the resulting cohort size. The project has met its goal of recruiting 78 scholars.

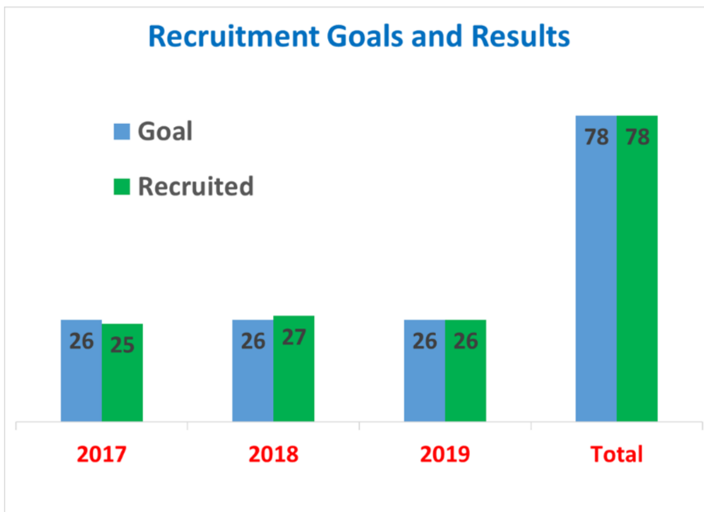

Figure 1: Number of transfer students recruited from 2-year schools in Fall of 2017, 2018, and 2019

64 scholars are male, and 14 are female. Under NSF classification for race, 58 reported White, 10 Asian, 4 black or African American, and remaining 6 did not answer. Table 2 shows the departmental distribution (see Table 1 for departmental abbreviations):

Table 2: Number of scholars in each department

CET	ECTET	MMET	PS	EME	ME	ISE	CE	**Total**
11	1	19	1	15	21	4	6	**78**

Each scholar will receive a scholarship of $2,500 per semester for four semesters for a total of $10,000. This scholarship is in addition to other grants and aid consistently awarded by RIT. After the grant expires, RIT will ensure that continuing VTAB scholars have adequate financial support to complete their degree.

Retention: The second goal is to retain and graduate at least 95% of these scholars. Figure 2 shows the retention statistics in each academic term beginning the Fall of 2017. The five bars for each term indicate the number of scholars (i) on campus, (ii) on coop employment, (iii) on official leave of absence, (iv) graduated, and (v) left RIT. One scholar graduated at the end of the Summer of 2019. Only one scholar left RIT resulting in 98% retention so far.

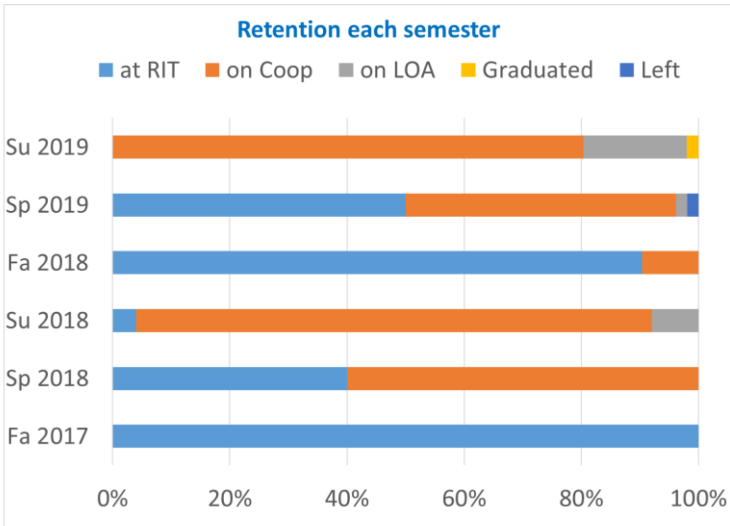

Figure 2: Number of scholars (i) on campus, (ii) on coop, (iii) on leave of absence, (iv) graduated, and (v) left RIT in each academic term beginning the Fall of 2017

Paid Co-op Employment: RIT's degree requirements require that each scholar must complete at least 48 weeks of paid co-op employment. A scholar will be in either on-campus study or paid coop employment. At the end of each co-op session, students submit a report of their experience along with evaluations from their employers. Figure 3 shows the percentage of scholars who are not on-campus with paid co-op employment in each academic term based on student co-op reports. The slightly lower 82% reported for Summer 2019 may not include a few co-op reports that need to be completed.

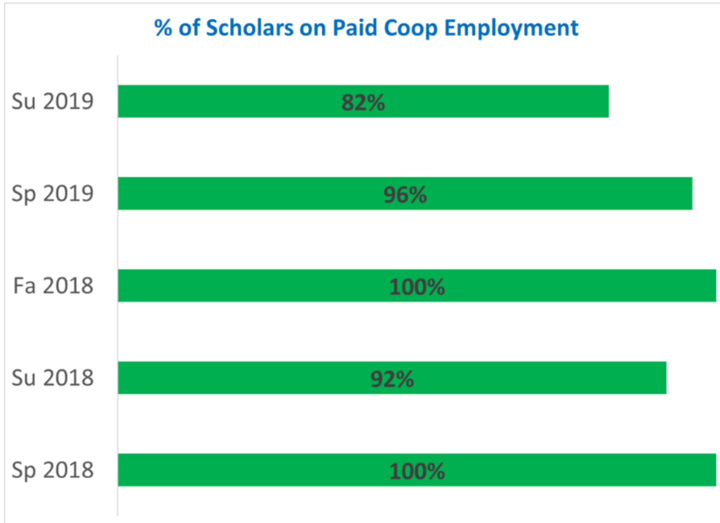

Figure 3: Percentage of scholars (not on campus) who are in paid coop employment

Support Programs and Challenges: To help VTAB scholars succeed, several new program elements were developed such as a six-week zero-credit VTAB Orientation course for all incoming scholars, individualized diagnostics and intervention for underperforming scholars, providing special mentoring and scholarly opportunities, and a lunch get-together each semester hosted by a participating department [3]. The project has had excellent support from the Offices of Financial Aid and Scholarships, Cooperative Education and Career Services, and Transfer Admissions.

We faced two major challenges so far: (i) obtaining the complete list of incoming scholars from the Office of the Financial Aid and Scholarships (OFAS) before the Fall semester began, and (ii) setting up the six-week zero-credit VTAB Orientation course for all incoming scholars. The first challenge was overcome by working with OFAS to get the name of the scholar as soon as the student accepted our admission and scholarship offer instead of waiting until all scholarships had been awarded. The second challenge was overcome by having a specific course code assigned to the Orientation course by the Registrar with time/day/location so that each scholar could adjust their academic schedule to accommodate the course, and register for it before the Fall semester began.

Knowledge Generation: An external evaluator is involved in the development, implementation, and analysis of three online surveys and two focus group interviews. The first survey developed in year one has been administered to all three cohorts. The survey was organized to examine the scholars' experiences at their 2-year schools, their experiences during the transfer process, as well as their experiences while enrolling RIT and their expectations academically, financially, personally, and socially for RIT. The first focus group interview at end of the six-week orientation course has also been conducted for all three cohorts. The focus-group questions were built on their responses to the survey and the orientation course, and to determine how scholars were acclimatizing to RIT. The survey and focus group results will be reported in an upcoming paper in the 2020 ASEE Annual Conference Proceedings.

The second online survey for each cohort during their third semester will focus on their experiences at RIT and during coop employment. It will connect back to their preconceptions from the first survey. It has only been administered to the first cohort so far.

The third online survey for each cohort will be administered before graduation and will focus on their career preparation at RIT. The second focus group interview will build on the third survey, and have questions about scholars' experiences at RIT and on coop. These are currently under development as the first cohort will graduate this coming Spring.

The external evaluator is satisfied with the progress the project has made, and suggests that the project should now shift its attention from recruitment to retention and graduation. The project is on schedule with the original timeline with no major changes.

Conclusions: The VTAB project has met its goal of recruiting 78 low-income highly talented transfer students from 2-year schools to BS degree programs in engineering and engineering technology at RIT. The goal is to retain and graduate at least 95% of these scholars. Only one scholar has left RIT, and one scholar has graduated. Results from the first online survey and focus group interview of all three cohorts will be published in the 2020 ASEE Annual Conference Proceedings.

Acknowledgements

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Active Learning in Dynamics: Hands-on Shake Table Testing

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Abstract:

Dynamics is one of the core courses in Civil Engineering Technology. The principles of dynamics apply to civil engineering practices in the areas of roadway design, bridge design, building design and seismic retrofit and rehabilitation. Students should have a functional understanding of the course materials rather than substitute numbers into the given equations. Active learning promotes hands-on learning, and has been proven to increase critical thinking and problem-solving abilities. It gets students more involved in their classes and students enjoy their classes more. In this paper, we present a hands-on active learning module using shake table testing to supplement the traditional lectures of Dynamics in order to enhance teaching and learning effectiveness. The learning outcomes include understanding basic vibrations and dynamics terminology, and modeling structural systems using single-degree-of-freedom models. Students design, build, analyze and test their scaled balsa wood building models. The shake table input motions include sinusoidal waves and four scaled earthquakes. The real-time motions of the models are recorded by a video camera. The final exam grades of the students were compared before and after the hands-on active learning module was implemented. The results show significant enhancement of students' grades as well as teaching and learning effectiveness. Feedback about the hands-on shake table testing module was also collected and analyzed, and students' feedback shows the active learning module advances their understanding of the course materials and enhances their interest in Dynamics.

Keywords: active learning, dynamics, hands-on, t-test

1. Introduction:

Active learning is a process which engages students in various activities that help advance their understanding and knowledge of a particular subject. Over the years, this process has become more technology-based, especially for the newest generation. Active learning promotes hands-on learning, and has been proven to increase critical thinking and problem-solving abilities. It gets students more involved in their classes and students enjoy their classes more. Active learning strategies have been adopted in STEM higher education for years and have been proven to be effective in many different disciplines such as Mathematics, Physics, Computer Science and Mechanical Engineering (Freeman et al. 2014, 8413; Michael. 2006, 160). Many studies have demonstrated active learning can have positive impact on students' learning effectiveness. Anderson et al. found that active learning "increased content knowledge, critical thinking and problem-solving abilities, and positive attitudes towards learning in comparison to traditional lecture-based delivery" (Anderson et al. 2005, 390-391). Thaman et al. pointed out active learning "increased enthusiasm for learning in both students and instructors" (Thaman et al. 2013, 33). Other benefits of active learning include development of graduate capabilities such as critical and creative thinking, problem-solving, adaptability, communication and interpersonal skills (Kember & Leung. 2005, 167), and improving students' perceptions and attitudes towards information literacy (Deltor et al. 2012). Active learning strategies need to be well planned in order to engage students' participation inside and outside classrooms. Our teaching innovation is built upon the successful teaching pedagogy, and will extend the application to a new sub-discipline within Civil Engineering Technology.

Structural Dynamics is a class typically taken by the fourth- or fifth-year Civil Engineering Technology students at Rochester Institute of Technology and involves kinematics and kinetics as well as vibrations of a structure. Dynamics lectures are typically theoretical and math-intensive, and provide some initial struggles to Civil Engineering Technology students who have not taken Calculus courses since their first year. In our teaching innovation, earthquake engineering is introduced at the end of the course with a new hands-on shake table testing active learning module to improve students' understanding of vibrations on structures.

Shake table is an earthquake simulator ideal for teaching structural dynamics, vibration isolation, feedback control, and other control topics related to earthquake, aerospace and mechanical engineering. Users can generate sinusoidal loading, chirp loading as well as pre-loaded acceleration profiles of real earthquakes, to study their effects on buildings, bridge and other types of structures. Additionally, earthquake vibration data can be downloaded from an online Ground Motion Database.

2. Hands-on Shake Table Testing Active Learning Module:

A new active learning hands-on lab module of shake table testing was developed in 2018 and has been implemented into the course CVET-437 Principles of Dynamics in Civil Engineering Technology at Rochester Institute of Technology ever since. The module includes both class demo and small group project and testing.

The intended learning outcomes for the hands-on active learning module are:

1) Observe the effects of different stiffness and mass on the frequency of structures.
2) Observe resonance of the building.
3) Calculate the natural frequency and stiffness of the building.

The class demo project uses a 6-story comprehensive balsa wood building model simulating the real-world building as shown in Figure 1, and the building details include mini-figures and furniture on each floor to representing real loads, adjustable mass on each floor and adjustable lateral stiffness of the building. The input motions are simulated earthquake loads from the shake table. Students can change the loads and adjust the building stiffness to observe different dynamic responses of the building model. The demo model allows students to change design configurations, add bracings to enhance the building performance under earthquakes as well as developing strategies of seismic retrofit and remedial options. The building has a strong axis and a weak axis, and the two axes are orthogonal. The cross-sectional dimensions of the balsa wood column are ½-inch by ¼-inch. Therefore, the moment inertia of the strong-axis is 4 times of that of the weak axis. By changing the directions of the model on the shake table, students can observe the effect of stiffness on the building's dynamic responses to vibration and different shaking modes.

Figure 1: Demo Building Model

For the small group project, students design, build, analyze and test their building models in a group of 4 students. Students apply the vibration theories that they learn from dynamics lectures and combine their engineering knowledge to design a 2-story building that can survive the given earthquake loadings. Students are encouraged to form their groups. The story height should be between 22 cm and 25 cm, and total height of the building should be between 44 cm and 50 cm with a flat roof. The building plan dimensions are 20.3 cm (8 inches) by 20.3 cm (8 inches) with column spacing of 10.15 cm (4 inches) as shown in Figure 2. The total mass including dead load and live load should be between 0.8 kg and 1.2 kg. The entire class have about 15 models with different designs to test each year as shown in Figure 3. The students can observe and compare different dynamic behaviors of all the models. After the tests, students can discuss the lessons they have learned from seismic failures, and summarize the effective strategies for seismic design and retrofit. The new active learning module is substantial enhancement to the traditional lecture-type instruction of the course. Figure 4 shows the shake table testing setup.

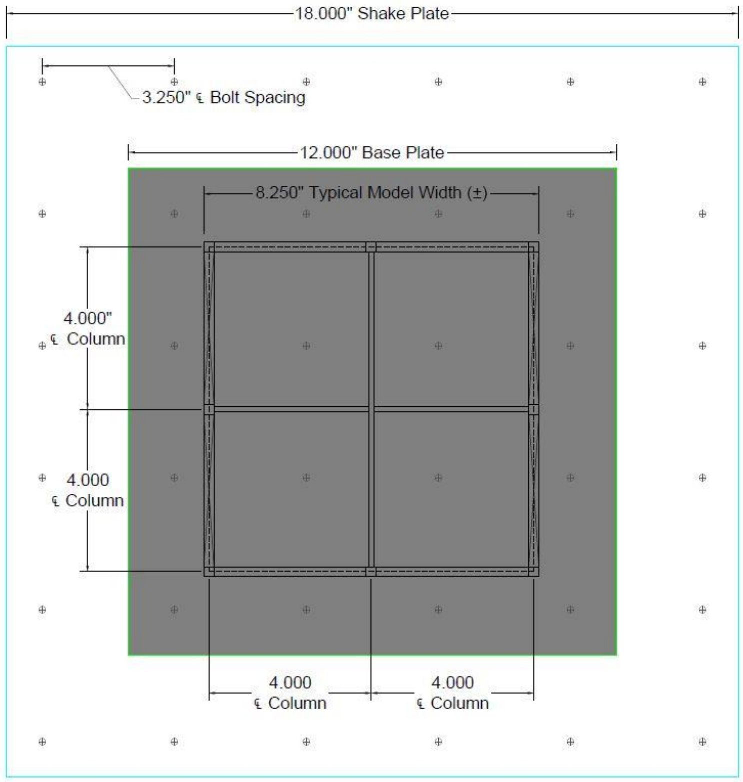

Figure 2: Base Plate and Building Plan

Figure 3: 2-Story Balsa Wood Models Built by Students

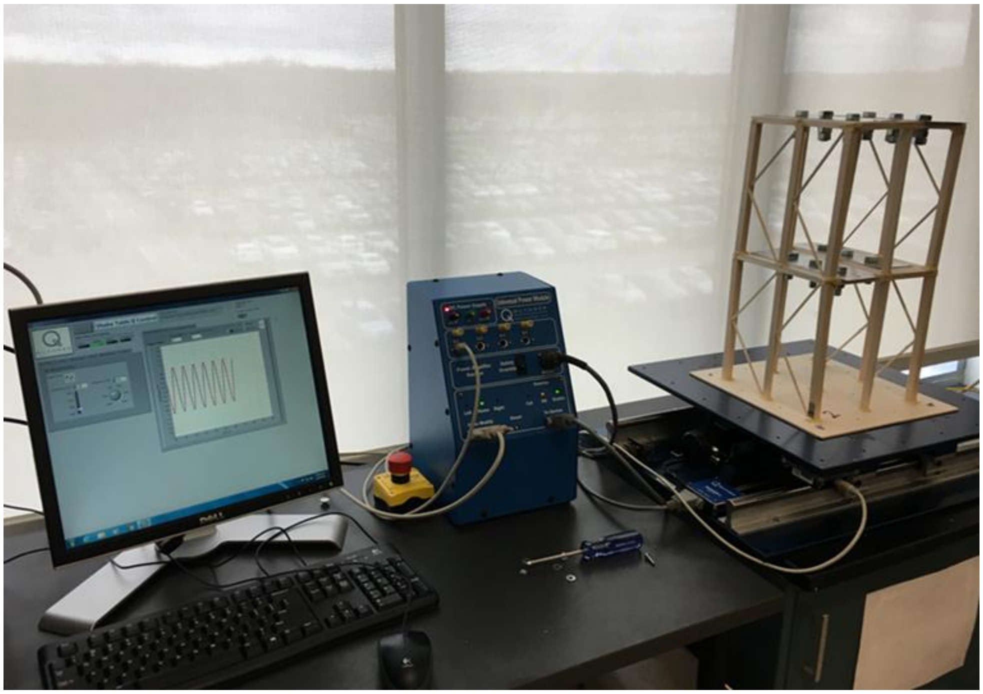

Figure 4: Shake Table Testing Setup

The input motions can be controlled by the shake table manufacturer's software, which include sinusoidal waves, chirp loading and four historical seismic events. The amplitude and frequency of the sinusoidal motion can be adjusted from 1cm to 5cm and from 1Hz to 5 Hz, respectively. Chirp loading increases its frequency from 1 Hz to 10 Hz in 10 seconds, therefore, the resonance behavior can be caught if the natural frequency of the building model falls between 1Hz and 10Hz. Four scaled seismic events including 1994 Northridge earthquake (6.7 Magnitude), 1995 Kobe earthquake (6.9 Magnitude), 1992 Mendocino earthquake (7.2 Magnitude) and 1940 El Centro earthquake (6.9 Magnitude), are the preloaded earthquake motions.

The dead load and live load on the building model is simulated by using aluminum plates with bolts and nuts on the floors and the roof as shown in Figure 1 and Figure 4. The mass at each floor and roof can be adjusted by changing the number of bolts and nuts. Students can observe different dynamic responses with various mass on their building models.

The hands-on shake table active learning module consists of design, construction, testing, data collection and analysis, and provides students with opportunities of applying theories into practice and solving engineering problems. Figure 5 shows a group of students test their building model on the shake table. Students are required to complete a lab report after the test. The lab report includes data collection and analysis as well as developing the Single-Degree-of-Freedom Model of the building. Figure 6 shows the sample data collection on the lab report.

Figure 5: Students Mounting Building Model to Shake Table

Number of Columns =

Total mass of the building including base = g = kg

Base plate mass = 180 g = 0.180 kg

Effective seismic mass = kg

Observed frequency based on resonance behavior during chirp loading, f = Hz

Natural frequency of the building, ω_n = rad/s

What is the total stiffness of the building in the lateral direction, $\sum k$ = N/m?

What is the stiffness of each column in the lateral direction, k = N/m?

The coefficient of damping c = N*s/m

Figure 6: Sample Data Collection of the Shake Table Test

3. Results:

The hands-on shake table testing module started being implemented in Spring 2018. Direct assessment of the teaching effectiveness is students' final exam grades before and after implementing the active learning module. The problems on final exams were kept the same every year from 2016 to 2019 in order to allow for appropriate comparisons. The final exams were not returned to the students and the contents were kept confidential. To minimize the impact of subjectivity in grading, the grading criteria were kept consistent over the four years. Detailed and itemized grading sheets were developed, and the points were assigned to each step of every problem. Figure 7 shows the average final exam grades of the students from Year 2016 to Year 2019 for the course CVET-437 Principles of Dynamics in Civil Engineering Technology. The grades are all out of the full points of 100.

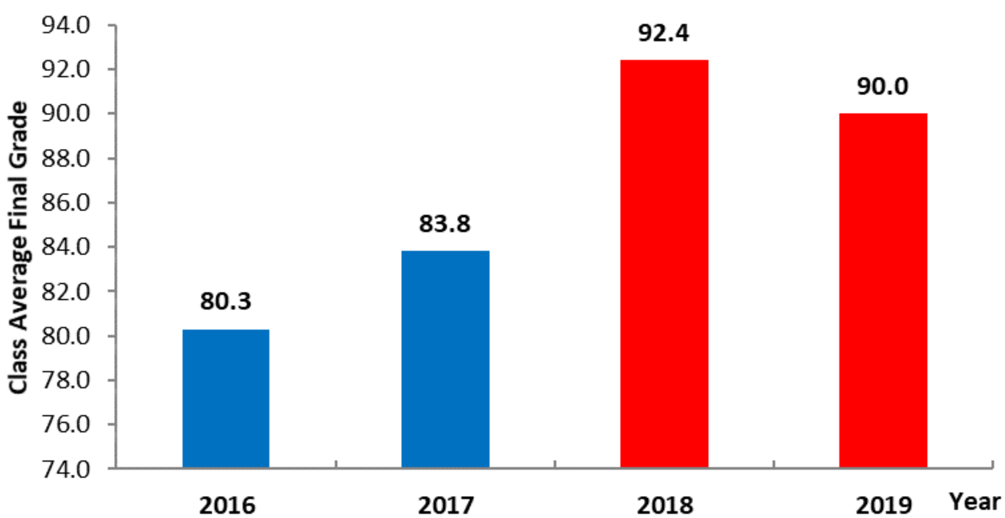

Figure 7: Class Average Final Exam Grade

Statistical analyses using unpaired t-test were performed to verify the statistical significance of the grade differences before and after implementing the hands-on active learning module. Table 1 lists the t-test results of the course "CVET-437 Principles of Dynamics in Civil Engineering Technology" before and after the hands-on shake table testing module was introduced. Average grades, standard deviations, t-values and p-values are compared from 2016 to 2019. The statistical significance of the grades before and after the active learning module was implemented are evaluated.

In a t-test, the common cutoff p-value is 0.05. If p-value is greater than 0.05, it means that the two comparison groups are not statistically significant. The differences between the two comparison groups are statistically significant when p-value is no greater than 0.05.

Table 1: Statistical Analyses for CVET-437 Final Exam Grades: Unpaired t-test Results

t-test Number	Comparison Years	Number of Students	Average Grade	Standard Deviation	t-value	p-value	Significant Different?
1	2016	64	80.30	10.719	1.7660	0.0879	No.
	2017	58	83.79	11.098			
2	2016	64	80.30	10.719	7.7082	<0.0001	Yes.
	2018	54	92.46	4.791			
3	2016	64	80.30	10.719	5.8476	<0.0001	Yes.
	2019	61	90.03	7.525			
4	2017	58	83.79	11.098	5.2983	<0.0001	Yes.
	2018	54	92.46	4.791			
5	2017	58	83.79	11.098	3.6057	<0.0001	Yes.
	2019	61	90.03	7.525			

From Table 1, in the t-test number 1, we found that before the hands-on learning modules was introduced in the course of CVET-437, the p-value between the Year 2016 and the Year 2017 is 0.0879, which is higher than the cutoff value of 0.05. It means the grade differences between the Year 2016 and the Year 2017 are not at all significant. In the t-test number 2 and 3, the grades of the Year 2016 are compared with those of the Year 2018 and the Year 2019, respectively. Both of the p-values between the Year 2016 and the Year 2018 and between the Year 2016 and the Year 2019 are less than 0.0001, which means the grade differences before and after the hands-on active learning module was implemented are significant. Consistently, in the t-test number 4 and 5, the grades of the Year 2017 are compared with those of the Year 2018 and the Year 2019, respectively. The p-values between the Year 2017 and the Year 2018 and between the Year 2016 and the Year 2019 are both less than 0.0001, which again indicates the final exam grades after the hands-on active learning module was implemented are significantly improved.

The students' online teaching evaluations related to teaching effectiveness in the course "CVET-437 Principles of Dynamics in Civil Engineering Technology" from 2016 to 2019 were collected and analyzed. The rating number 1 through 5 represents "strongly disagree", "disagree", "neutral", "agree" and "strongly agree", respectively.

The online teaching evaluation web link was sent to students by email near the end of each semester, and students were given a few weeks window to complete the online survey based on their learning experience. The online teaching evaluation questions were consistent over the four years, and students took the survey voluntarily and anonymously. Figure 8 shows students' feedback about "Advanced Student Understanding" in the course "CVET-437 Principles of Dynamics in Civil Engineering Technology" from 2016 to 2019. Students' feedback about "Enhanced Interest" in CVET-437 from 2016 to 2019 is illustrated in Figure 9.

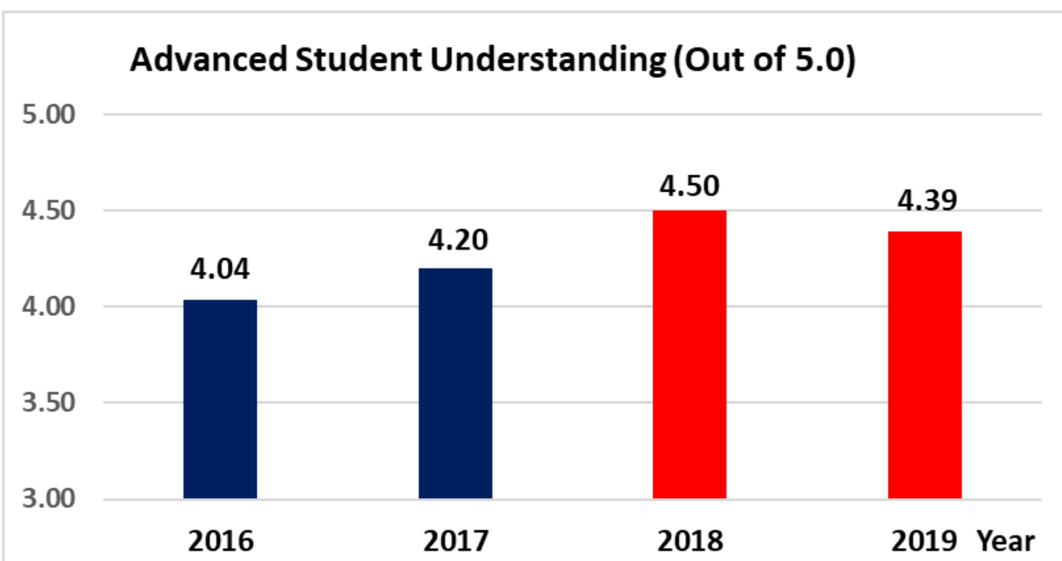

Figure 8: Teaching Evaluation of "Advanced Student Understanding"

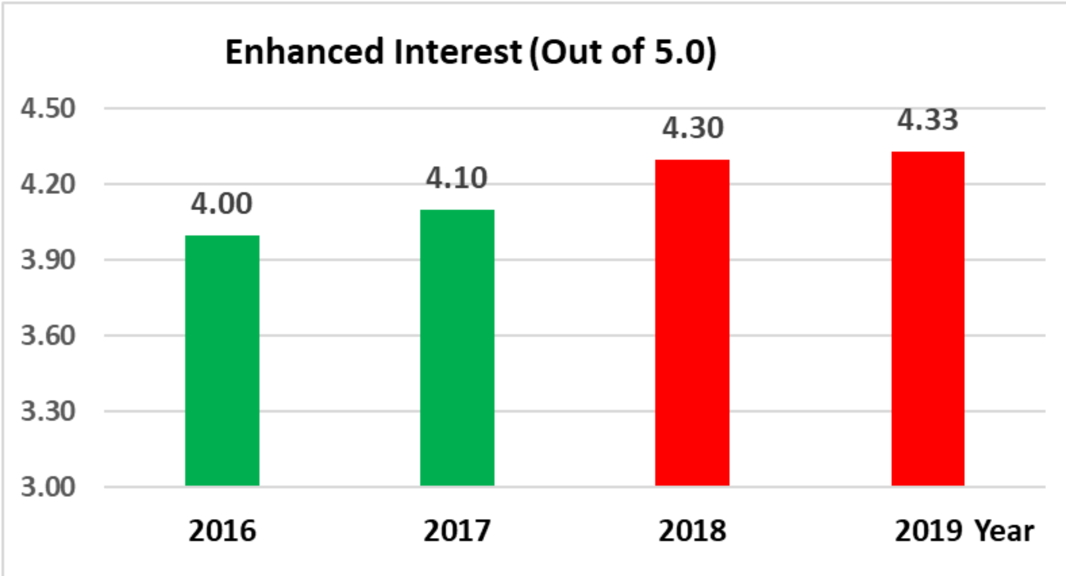

Figure 9: Teaching Evaluation of "Enhanced Interest"

4. Conclusions:

A new hands-on shake table testing active learning module has been developed and adopted in a Civil Engineering Technology Dynamics course at Rochester Institute of Technology since 2018. Both direct measurement of students' final exam grades and feedback from students' teaching evaluations show the new hands-on active learning module advances students' understanding of the course materials as well as enhances their interest in learning Dynamics.

From the results and evidence shown in Table 1 and Figures 7 through 9, we can conclude that:

1) The students' grades in Dynamics are significantly improved after the hands-on shake table testing active learning module is implemented into the course CVET-437 "Principles of Dynamics in Civil Engineering Technology".
2) The trend of students' feedback about "Advanced Student Understanding" from the teaching evaluation is consistent with that of the direct assessment of students' final exam grades. The hands-on active learning module has proven to effective to advance students' understanding of Dynamics course materials.

3) The ratings of "Enhanced Interest" get higher after the hands-on shake table testing was adopted to supplement the traditional Dynamics lectures. Students are more interested in the course materials and learn better under the active learning environment.

Some factors remained beyond the author's control, such as class enrollment numbers, students' previous academic background, the subjectivity of students' online teaching evaluations, and the like. These variables may affect the results.

5. **Acknowledgement:**

This study was supported by Rochester Institute of Technology 2018 Provost's Learning Innovation Grant (PLIG). Rochester Institute of Technology Civil Engineering Technology Students: Andrew Walker, Christopher Powell, Emilio Moran, Marquis Mark and Deondre Roseboro, helped build the 6-story class demo building model.

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Curriculum Enhancement to the Mechanical Engineering Graduate Program and Undergraduate Aerospace Option by Including Contemporary Issues of Integrating Unmanned Aircraft Systems into the National Airspace System

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In this paper, curriculum modifications to enhance and support Unmanned Aircraft Systems (UAS) integration into the National Airspace System (NAS) (along with other related UAS and unmanned system missions such as technologies that reduce environmental noise and emissions; increased aircraft and traffic safety; advanced sensor UAS sensor development; etc.) as well as the formation of a regional student UAS competition to be held at the Rochester Institute of Technology's (RIT's) is outlined. The curriculum modifications focus on RIT's Mechanical Engineering (ME) department related to the ME Aerospace Option and ME Graduate program. The proposed curriculum enhancements include the development of a new UAS related course; updates to two undergraduate aerospace courses transitioning the course as dual-listed undergraduate/graduate courses; the formation of a new ME Graduate Focus area in UAS; the development of an Advanced Certificate in the UAS; and updates to our Graduate Seminar series for inclusion of UAS related concepts. The new UAS course has direct benefits to students exposing them to UASs where a new pool of potential undergraduate/graduate students can be recruited for research related activities in UAS. Two RIT courses (Flight Dynamics and Orbital Mechanics) are to be updated and offered as both a terminal undergraduate course and an introductory graduate course for increasing enrollment in the ME's aerospace undergraduate option and newly developed Graduate Focus area. The updated courses will give higher exposure to a greater number of students for related subjects to UASs. The new Aerospace Graduate Focus area benefits students directly by allowing them to focus on an up-and-coming area, i.e., UAS that may be included in resume building and future projects related to UASs. We also outline a foundation for a regional UAS student competition to be housed at RIT's existing outdoor UAS netted closure facility and, in the future, a student UAS related conference. In particular, we consider the development of a final capstone requirement for the new proposed UAS related dual-listed course for mandatory participation in the proposed UAS student competition and student conference as part of the curriculum enhancement effort. A new lecture for presentation to RIT's graduate seminar series was developed in the topic of commercial applications and societal benefits of UASs. This will be a valuable recruiting tool for new graduate research students by exposing new graduates to new and exciting UAS research possibilities. RIT will also benefit since regional industry leaders will be recruited to attend the seminar and will be able to converse with faculty and students for possible research collaborations. The Engineering Education efforts presented here were funded by a NASA/New York Space Consortium STEM Curriculum Higher Education Curriculum Enhancement grant.

In this work, a curriculum enhancement to the Rochester Institute of Technology's Mechanical Engineering department's undergraduate and graduate program was completed. The curriculum enhancement included incorporating, within our current curriculum, a NASA priority area, i.e., integrating unmanned aircraft systems into the national airspace system that had direct benefit to the RIT faculty and students. In particular, several enhancements to our current curriculum were completed including:

1. the development of a new undergraduate/graduate dual-listed course related to unmanned aircraft systems. The new course has direct benefits to students exposing them to UASs and to RIT faculty where a new pool of potential graduate students can be recruited for research related activities RIT faculty who have area of expertise in UAS along with a benefit to the RIT for recruiting new students and soliciting external grants related to one of RIT's signature research area, UASs.
2. updates to two existing undergraduate courses to be offered as dual-listed courses. Two RIT courses (Flight Dynamics and Orbital Mechanics) were updated to be offered as both an terminal undergraduate course and an introductory graduate course. The updated courses will give higher exposure to a greater number of students for related subjects to UASs. This will also benefit RIT by the ability to recruit more graduate students and for a higher enrollment in our aerospace undergraduate option and newly developed Graduate Focus area.
3. the development of a new Graduate Focus and undergraduate aerospace option area related to unmanned aircraft systems. The new Aerospace Graduate Focus area benefits students directly by allowing them to focus on an up-and-coming area, i.e., UAS that may be included in resume building and future projects related to UASs. Again, this will also benefit RIT and RIT facultyby the ability to recruit more graduate students and for a higher enrollment in our aerospace undergraduate option.
4. updates to the; development of a new lecture presentation for the graduate seminar series. A new lecture for presentation to RIT's graduate seminar series was developed in topic of commercial applications and societal benefits of UASs. This will be a valuable recruiting tool for new graduate research students for the RIT along with getting new graduates excited about UAS research possibilities. RIT will also benefit since regional industry leaders will be recruited to attend the seminar and will be able to converse with RIT faculty and students for possible research collaborations.
5. the researching of developing an advanced certificate program related to unmanned aircraft systems. The benefits of the new advanced certificate to the RIT faculty, RIT, and the students are the same as developing the new UAS course, graduate focus area, and graduate seminar.
6. the formation of a unmanned aircraft systems student competition (first at a regional level then at a national and international level) to be used for the student capstone project of the new proposed course. This will give students exposure to UASs and get them excited about UASs moving forward in a real-world type application that can be used for resume building and other future projects. RIT faculty and RIT will benefit by placing them in the forefront of this new technology first at a regional level then on an international level.

1.1 Development of a New UAS Course

A new UAS course (MECE-5xx/6xx Unmanned Aircraft Systems) related to educational outcomes for integrating UASs into the NAS was developed as part of the curriculum development. The new course is an enhancement to RIT's MECE-411 Flight Dynamics basis course by focusing solely on UAS. The overall goal of this course is to provide students a fundamental understanding of unmanned aircraft systems with sufficient knowledge to design, construct, and perform flight testing of a small unmanned aircraft system. The students will obtain knowledge to develop a complete end-to-end flight unmanned aircraft flight simulator including full nonlinear flight dynamics, sensor models, autopilot integration, and path planning methods. In addition, students will be exposed to contemporary issues related to unmanned aircraft systems such as current FAA regulations, societal benefits of unmanned aircraft systems, commercial applications, etc. A capstone project was developed for participation in a UAS Regional Student competition (to be described later). The capstone project is team based and we expect teams of 5 students to work on the capstone project for the course. The new dual-listed course was fully developed and completed, i.e., course outline, learning and educational outcomes, course notes, class book selection, pre-requisite requirements, homework and project problems, etc. The intended **course learning outcomes** and associated assessment methods are shown below:

Course Learning Outcome	Assessment Method
Fundamental understanding of UAS system architecture and design models	Homework
Introduction to system coordinate frames including differences in UAS velocity components	Homework, Test
Full understanding of UAS rigid-body kinematics and dynamics equations of motion	Homework, Project, Test
Full understanding of UAS of applied forces and moments including atmospheric disturbance models	Homework, Project, Test
Full understanding of linear design models including transfer functions and linearized state-space models	Homework, Test
Introduction to UAS autopilot design including lateral-directional and longitudinal autonomous control	Homework, Project, Test
Introduction to sensors typically used in UAS flight	Homework
Introduction to state estimation theory with applications to attitude estimation and GPS smoothing	Homework, Test
Full understanding of UAS guidance design and straight-line and orbit following algorithms	Homework, Test
Full understanding of path planning design and management	Homework, Project, Test
Introduction to vision-guided navigation with applications to UAS precision landing and target motion estimation	Homework, Project, Test
Introduction to UAS contemporary issues	Homework

The **program outcomes** and **goals** supported by the new UAS course are as follows:

Program Outcome	**Instructional Level**
an ability to apply knowledge of mathematics, science, and engineering	●
an ability to design and conduct experiments, as well as to analyze and interpret data	◕
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	◔
an ability to function on multidisciplinary teams	◔
an ability to identify, formulate, and solve engineering problems	●
an understanding of professional and ethical responsibility	◔
an ability to communicate effectively	◔
the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	◑
a recognition of the need for, and an ability to engage in life-long learning	◑
a knowledge of contemporary issues	◕
an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	●

1.2 Updates for MECE-410 Flight Dynamics and MECE-411 Orbital Mechanics

Two undergraduate courses (MECE-410 Flight Dynamics and MECE-411 Orbital Mechanics) that are being taught by the authors were updated to meet requirements for the Mechanical Engineering Graduate program. The original new course proposal forms for each of these courses were modified to update these courses for listing them as dual-listed courses (undergraduate/ graduate courses). The new course names and numbers are: MECE-510/610 Flight Dynamics and MECE-511/611 Orbital. The course content for each course was modified and updated to an appropriate level required for use as dual-listed courses including aspects of UASs. For example, additional homework was developed for each course along with an additional test. Also, an additional project was developed for each course to include newly develop graduate level topics such as Lagrange's approach in developing kinematical equations of motions, quaternion models, orbital perturbations, Gibbs method of orbital determination from three position vectors, Gauss method of preliminary orbit determination, linearization of flight dynamics equations-of-motion and comparison to full nonlinear simulation models, etc. For example, a newly developed computer project was developed for the updated Flight Dynamics course related to linearization of nonlinear equations-of-motions and comparison to full nonlinear models. The updated courses were used to form a cluster for the new proposed Graduate UAS Focus area outlined in the next subtask.

1.3 New ME Graduate Focus Area and Updates to the ME UG Aerospace Option

The authoes investigated the formation of a new Mechanical Engineering Graduate Curriculum Focus area and updates to the Mechanical Engineering Undergraduate Aerospace Option as part of the curriculum enhancement effort was performed. The Aerospace Engineering Option allows for specialized study in the engineering aspects of air- and space-borne vehicles and starts with a course introducing students to the aerospace field. The sequence starts in the third year with students taking a variety of electives focused on aerospace. In addition, students choosing this option are expected to work on an aerospace engineering design project in Senior Design I and II capstone courses and to pursue co-op employment in a related field. The Mechanical Engineering undergraduate Aerospace Option was updated to include the new proposed UAS course and the updated Flight Dynamics and Orbital Mechanics courses as shown below:

Extended Core	
REQUIRED COURSES - pick 1 from this list	
MECE-350	Strengths of Materials II
MECE-360	Advanced Computational Techniques
Applied Electives	
REQUIRED COURSES - pick 2 from this list	
MECE-403	Propulsion
MECE-409	Aerodynamics
MECE-412	Aerostructures
MECE-510/610	Flight Dynamics
MECE-511/611	Orbital Mechanics
MECE-512/612	Unmanned Aircraft Systems
MECE-543/643	Continuous Control Systems
MECE-544/644	Intro to Composite Materials
MECE-558/658	Introduction to Engineering Vibrations

All students in the Mechanical Engineering Graduate Program are required to develop a concentration/focus area by completing 9 credits of study in an area. Current Focus Areas include: automotive systems, business, controls, manufacturing, mechanics-design/materials, product development, sustainability, thermo/fluids engineering, vibrations engineering. Also, students with a specific career interest may develop an individually customized concentration based on mutual agreement between the student and the department. The current Graduate Focus areas consist of 9 sub-disciplines but none related to aerospace systems and UAS. In this curriculum update, the relevant courses required to complete the three course sequence for the new Aerospace/UAS Graduate Focus area was finalized and is shown below:

Aerospace/UAS (choose 1 of 4)		**9**
MECE-610	Flight Dynamics-X	3
MECE-611	Orbital Mechanics-X	3
MECE-612	Unmanned Aircraft Systems-X	3
MECE-643	Classical Controls-X	3

“X” indicated dual-listed undergraduate/graduate course

The necessary proposal paperwork required for updating the undergraduate Aerospace Option and Graduate Focus area (including the new UAS course and updates to Flight Dynamics and Orbital Mechanics) was completed. The updated Aerospace Option and new Graduate

Aerospace/UAS Focus Area received ME faculty and Mechanical Engineering curriculum committee approval and will be incorporated into the 2020-2021 RIT Course Bulletin. In addition, updates to the ABET and Middle States learning outcomes and corresponding documentation were performed and documented.

1.4 Graduate Seminar Lecture

A lecture for the Mechanical Engineering and college wide Graduate Seminar series was fully developed for exposing the general population Masters and Ph.D. students to the topic of integrating UASs into the NAS thus giving students a direct benefit. The seminar series presents topics of contemporary interest to graduate students enrolled in the program and is ideal for introducing contemporary issues of UAS. The seminar also benefits the RIT faculty as a possible recruiting tool for Masters and Ph.D. students for research opportunities related to the RIT faculty who have research interest in UASs.

1.5 Advanced Certificate in Unmanned Aircraft Systems

The authors have worked with other departments in RIT performing UAS research and course offerings to investigate the possibility of developing an Advanced Certificate in UAS. The certificate could be made more attractive by allowing students to take courses from a broader selection of courses and explicitly to allow them to take advantage of directly applying the courses required for the Advanced Certificate degree program towards course work completion of either the two Master's programs within Mechanical Engineering. This will make the Advanced Certificate attractive to a broader audience of students interested in not only a certificate in unmanned aircraft systems but working towards a Master's degree in Mechanical Engineering. The new Advanced Certificate will thus be a better feeder for the Master's program for students who are not ready at the onset to commit to complete Master of Science degree. Furthermore, students who complete the Aerospace/UAS Graduate Focus area part of the Master's program may be directly eligible for the Advanced Certificate in Unmanned Aircraft Systems. It is expected that the majority of students will be practicing engineers from the Rochester and surrounding communities, or students ultimately interested in obtaining a Master of Science or Master of Engineering degree. Students seeking to earn a Master's degree can use the courses taken within the proposed new Advanced Certificate program towards degree requirements for the Master of Science or Master of Engineering degree and thus has a direct benefit to students and the RIT community for attracting higher graduate level student cohorts. The initial stages of the new Advanced Certificate program were developed. The courses required for the Advanced Certificate program have been selected and are shown below:

Proposed UAS Advanced Certificate		**15**
MECE-707	Engineering Analysis	3
MECE-709	Advanced Engineering Mathematics	3
MECE-610	Flight Dynamics -X	3
MECE-612	Unmanned Aircraft Systems-X	3
MECE-643	Classical Controls-X	3

"X" indicated dual-listed undergraduate/graduate course

The Advanced Certificate will also benefit RIT faculty in attracting possible graduate research students for research related to UAS. A proposal to RIT was completed for RIT governance approval of the Advanced Certificate program. The new MECE-612 Unmanned Aircraft Systems course must be approved prior to the approval process for an Advanced Certificate in Unmanned Aircraft Systems. Once the new course is approved the authors will seek RIT governance approval for Advanced Certificate in Unmanned Aircraft Systems after which all necessary documents (i.e., NYSED New Program Form, Table 1, Table 3, and Outcome Form) will be sent to NYSED for NYS approval with the goal of offering the Advanced Certificate during the 2021-2022 Academic Year.

1.6 UAS Student Competition

A new team-based UAS student competition is proposed to be researched in this curriculum development project. The student competition focuses on FAA and NASA priority areas such as technologies related to integrating UAS into the NAS and design of UAS with reduced emissions and noise. For example, the student teams are required to implement autonomous sense and avoid and technologies used to detect and avoid obstacles of various sizes while integrating autonomous navigation and control technologies; design for minimal fuel consumption and reduced noise output; overall cost; aesthetics of the UAS design; etc. The competition utilizes RIT's existing outdoor UAS research netted enclosure for showcasing operation in outdoor environments. A plan for implementing the student-based team UAS completion was investigated and finalized in this curriculum update project. Items completed in this task include:

RIT's Netted Enclosure

1. the development of an outline of the competition emphasizing FAS and NASA related priority areas; the rules for the competition; competition scoring; time frame; etc.
2. The authors will coordinate with Monroe Community College (MCC) to combine MCC's UAS student competition with the competition proposed here.
3. Students enrolled in the new UAS course are required to participate in the UAS student completion as part of the culminating effort for the course.

We envision opening the student competition to all RIT and MCC students in the first year then opening the competition to all universities (and outreach high schools). The first competition will be held during the first week of June, 2021 at RIT's UAS Netted Enclosure site. The solicitation will be distributed to regional universities (through NUAIR's University Partnership) including schools in New York, Massachusetts, and Michigan. NUAIR manages one of seven FAA UAS Test Sites in the United States consisting of a highly instrumented UAS test ecosystem with functionality. NUAIR is also responsible for the continued development and advancement of New York's 50-mile UAS corridor between Syracuse and Rome, facilitating beyond visual line of sight testing, commercial operations, and the safe integration of UAS into the national airspace. Dr. Crassidis is a the Academic Director for NUAIR and has contacted several participating universities though email and phone conversations, within the NUAIR alliance, and local high schools to solicit interest for the competition and future framework of the competition in the following years. All universities and high school responded that they would be sending students to the competition. The authors have also contacted several potential sponsors for the planned UAS student competition.

Monroe Community College

Drone Design Team

2019 AUVSI SUAS Technical Design Paper

Authors:

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Abstract

This paper will outline the engineering design and development process undertaken by the Monroe Community College Drone Design team to create an Unmanned Aerial System (UAS) for the 2019 AUVSI SUAS competition. After having a major system failure at the 2018 competition, the MCC Drone Design team created a new system that is more capable and flexible for future competitions than our legacy systems. This new platform is named "Big Flying Lilac" (BFL). Detailed in this paper is the systems engineering approach taken to initiate the development of our UAS, detailed system design information of each individual system on our UAS, and the methods taken to minimize potential risks to ensure overall safety. Being the only community college at competition, we look forward to representing our college, and to competing with many of the big-name schools from around the country.

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1 Systems Engineering Approach

1.1 Mission Requirement Analysis

Big Flying Lilac (BFL) was designed and developed to perform a safe and reliable package delivery mission for the 2019 AUVSI SUAS competition. BFL is capable of autonomous flight, obstacle avoidance, manual object DLC, UGV airdrop and delivery. **Figure 1** outlines the mission tasks, scoring breakdown, and the system requirements placed on the UAS

Mission Tasks	Description	System Requirements
Timeline (10%)	***Mission Time (80%) -*** conduct a simulated package delivery mission within 30 minutes ***Timeout (20%) -*** Avoid taking timeout	• UAS capable of efficient autonomous flight, take off, and landing • Structured and experienced team
Autonomous Flight (20%)	***Autonomous Flight (40%)*** - UAS flies completely autonomously, -10% for every manual takeover ***Waypoint Capture (10%)*** - Capture multiple waypoints along a maximum 4 mile long path ***Waypoint Accuracy (50%)*** - Capture waypoints within a 100ft radius or less	• Autonomous flight system that is reliable and capable of accurate waypoint capture • Must be able to fly longer than maximum flight time
Obstacle Avoidance (20%)	***Telemetry Prerequisite*** - Upload correct telemetry data via the interoperability system at a rate of 1 Hz ***Stationary Obstacle Avoidance (100%) -*** avoid up to 30 stationary obstacles shaped as cylinders	• Ground station capable of correctly uploading telemetry data • Autonomous flight system capable of altering UAV path during flight
Object Detection, Classification, Localization (20%)	***Characteristics (20%) -*** Capture up to 20 objects and identify each objects characteristics ***Geolocation (30%) -*** Determine the GPS location of the objects within 150ft, ***Actionable (30%) -*** Submit object information via the interoperability system during the first flight ***Autonomy (20%) -*** Submit all object information autonomously	• Imaging system capable of producing high quality images of ground targets from a minimum height of 100ft • Communication system to transfer images from UAV to ground station • Manual image processing system capable of object DLC
Airdrop and Delivery (20%)	***Prerequisite -*** Unmanned Ground Vehicle (UGV) weighing under 48oz ***Drop Accuracy (50%) -*** Drop the UGV within 5ft of a given GPS Coordinate ***Drive to Location (50%) -*** Autonomously deliver package via UGV within 10ft of a GPS Coordinate	• UGV weighing under 48oz that is able to drive autonomously and carry an 8oz water bottle • Drop mechanism that safely secures and drops UGV from the UAV
Operation Excellence (10%)	***Professionalism -*** operate system with confidence and maintain strong communication between team members ***Safety -*** Stay aware of surroundings and be safe	• Professional attitude on and off the flight field • Well trained personnel capable of operating UAS safely and effectively

Figure 1. Mission Requirement Analysis

After analyzing the requirements placed on the UAS in **Figure 1**, our team determined that an autonomous flight system, imaging system, object DLC system, propulsion system, communications system, air delivery system and obstacle avoidance system are needed to complete the mission tasks. Subsequently, each task was analyzed further to determine the specific requirements placed on each system. Our team determined that the autonomous flight tasks require a light, durable, and maneuverable airframe, a highly efficient propulsion system, and a reliable autopilot. The Air Delivery tasks require a lightweight autonomous UGV and an accurate drop mechanism that is capable of safely securing the UGV to the UAV while in flight, and delivering the UGV from at least 100ft AGL. The Object DLC tasks require a high speed, high resolution camera, a gimbal, a manual DLC system, and a high speed communication system to properly capture, transmit, identify, and submit objects. The Obstacle Avoidance tasks require an algorithm that will identify multiple stationary obstacles and plot the best flightpath for the UAV.

During the design and development phase, design limitations were presented that forced tradeoffs between systems. Due to the addition of the UGV airdrop in this year's competition, our team chose to develop a large multirotor aircraft, over a fixed wing aircraft. A multirotor has the main advantage of being able to hover in place, allowing our team to design a mechanical system to slowly lower the UGV down to the ground. Compared to most fixed wing aircraft, a multirotor also has major disadvantages in power consumption, efficiency, flight time, and air speed. To address these disadvantages, a new propulsion system was designed using high efficiency motors and large diameter propellers. This used a large portion of our supply budget, leaving insufficient funds to upgrade the imaging system. Throughout the design process many tradeoffs were addressed when designing each individual system. The tradeoffs described above are the most significant pertaining to the development of BFL.

1.2 Design Rationale

BFL is the third iteration of our "Lilac" UAS systems, this system incorporates some aspects from our legacy systems "Lilac" and "Lilac Heavy", and introduces new systems and redesigns to increase mission performance. BFL is designed to perform complete autonomous flight, image capture, manual object DLC, and payload air delivery. Obstacle Avoidance will be attempted at this year's competition and is expected to achieve a maximum 75% success rate. Prior to starting the design phase for BFL, our team assigned a priority rating to each system based on a system's necessity to overall functionality, and how difficult the system is to design. These prioritization ratings were used to guide the overall flow of decisions when designing BFL.

System	Functional Necessity	Design Difficulty	Priority Ranking
Aircraft	High	Low	2 (Highest)
Autopilot	High	Medium	3 (High)
Air Delivery	High	Medium	3 (High)
Imaging and Object DLC	Medium	Medium	4 (Medium)
Obstacle Avoidance	Low	High	5 (Low)

Figure 2. Mission Requirement Analysis

1.2.1 Environmental Factors

During development there were several constraining environmental factors that influenced the design and creation of our UAS. Some of these constraints include time, budget, team experience, and weather. This year the MCC Drone Design Team is made up of 12 students, including 4 returning members and 8 true freshman. As a community college design team, one of our main constraints is the student graduation rate. Students graduate at double the rate compared to a 4 year institution, forcing team leaders to quickly educate and prepare freshman students for competition. A limited budget is also a constraining factor that most teams face when creating a new system. Our team developed the BFL system with parts from legacy systems, $3800 from internal university sources, and 3 business sponsorships. Without these resources, our team would not have been able to create this new system and sustain the AUVSI-SUAS design team.

One of the biggest restrictions on development and testing is the prolonged winter climate in Rochester, NY. From October 24th to April 1st Rochester has seen 83 inches of snow, with an average temperature of 29.2 degrees Fahrenheit. Although the college does have a large indoor facility, it does not allow for autonomous flight or any high altitude testing. These circumstances prevented our team from safely conducting most system tests outdoors, due to the extreme cold at higher altitudes and precipitation on the ground. To compensate for the weather, our team extended the design and development phase of our build to perfect designs, and prepared heavily for a compressed testing phase before competition.

1.2.2 Air frame and Propulsion

The first decision to creating BFL was the design of the airframe and propulsion system. Our team determined that another multirotor design will be the best option for this year's competition due to our familiarity to the platform and our starting inventory. The multirotor platform will also allow the UAS to use a mechanical winch air delivery system to safely and accurately deliver the UGV. Following this decision, multiple requirements were placed on the aircraft to determine the best multirotor platform to design around. These requirements include: a high thrust to weight ratio for maneuverability and power efficiency, a light and rigid airframe to carry the loaded weight of the aircraft, and the ability to fly at least 8 miles within a 30 minute flight time. After researching and analyzing various types of multirotor designs, our team determined that an X-H combination quadcopter frame paired with a highly efficient and powerful propulsion system will be the best platform for meeting our aircraft requirements. Following this decision, research was conducted on the propulsion system to determine the best option for meeting our requirements. Our team determined that the BFL system needs a propulsions system that includes a high capacity battery, low KV motors, and large diameter propellers. Upgrading this year's UAS with a new airframe and propulsion system used a substantial amount of our budget, and left inadequate funds to upgrade our onboard camera, but will allow more time for the imaging system to capture images of the targets. Overall, the new aircraft design is a large upgrade compared to our previous competition builds and will enable our team to be more competitive at competition.

1.2.3 Autopilot and Obstacle Avoidance

Following the Aircraft and Propulsion systems, our team prioritized the autopilot system. Our team stated that the autopilot system must be capable of safe, reliable, and accurate takeoff, landing, and waypoint point capture. The autopilot system must also be capable of interfacing with custom software to properly implement an obstacle avoidance system. Our team chose the Pixhawk 2.1 autopilot system, Odroid-XU4, and our own custom mission planning software, named "Commander", to fulfill the set requirements. The Pixhawk 2.1 was chosen due to its high number of redundant sensors, capability to replace sensors in the case of failures, open source firmware, and the team's familiarity to the Pixhawk platform. Commander was chosen over readily available mission planning softwares to better incorporate custom scripts for obstacle avoidance, and provide a centralized system for manual object DLC.

1.2.4 Air Delivery

The third design decision was choosing an approach to creating a UGV and air delivery system. Our team chose to create a custom UGV using a similar autopilot system as our UAV, and a winch air delivery system to lower the UGV down to the ground. A delivery system was created to incorporate multiple subsystems onto the chassis to ensure stability during flight, and a disconnect from the UAV while staying under the required 48 oz weight limit. A winch air delivery system was chosen to deliver the UGV due to its high accuracy and reliability when used on a multirotor. Combining these systems will ensure a safe, accurate, and autonomous air delivery.

1.2.5 Imaging and Object DLC

The fourth design decision was choosing an imaging and object DLC system. Our team chose to use the Sony A6000 camera with a Sony E PZ 16-50mm lens, paired with a custom 2-axis gimbal. This system will take stable, high resolution images while interfacing with the Odroid XU4 onboard computer and Ubiquiti M5 bullet to transmit images to the ground station. The 2-axis gimbal will also allow the team to locate the off-axis target by autonomously altering the camera's angle relative to the ground. The imaging system will fit on one half of the aircraft's baseplate, and will have a similar weight to the airdrop system. This will keep the center of gravity close to the center of the aircraft while under full load. For the Object DLC system, our team chose to use a manual object detection system similar to legacy object DLC systems. This decision was made to allocate more development time for our limited software personnel to focus on the obstacle avoidance algorithm.

2 System Design

2.1 Aircraft

To accommodate the new propulsion system for the 2019 competition, the team created a completely new airframe layout. A quad H-X hybrid frame was determined to be the best option as it could accommodate the large propellers while maintaining a relatively small midsection. The midsection was then constructed in a tiered configuration which allowed all on board systems to be mounted without increasing the frame's surface area and maintaining aerodynamic integrity. The first two tiers, fabricated from carbon fiber, were designed to hold the batteries, imaging, and air delivery systems. The top two tiers were designed to hold the radios, onboard computers, GPS, and flight controller. These layers were made from acrylic and wrapped in magnetic shielding to minimize the magnetic interference from the power wires. To increase portability and ease of repair of the frame, the quadcopter's arms were designed to be easily removed and replaced.

Before beginning the construction of the airframe, our team conducted a series of finite element analysis tests on the frame design to determine whether several structural components will withstand the force of the motors under max load. Using Autodesk Nastran In-CAD, our team simulated the response of different structural components when subjected to the maximum load each might experience. Our team first used FEA to determine the maximum stress in the connection point between the arms and the midsection. Under max load it was shown that the stress was 6270 psi, which was well below the yield stress of the Delrin connectors. This gave us a safety factor of 1.6:1. Our team also simulated a comparison of the bearing stress on a motor arm when the motor mount was bolted to it and tightened to 75% of it's proof load. From the simulation shown below, it was determined that sleeve bearings were necessary to reduce the bearing load experienced by the motor arms.

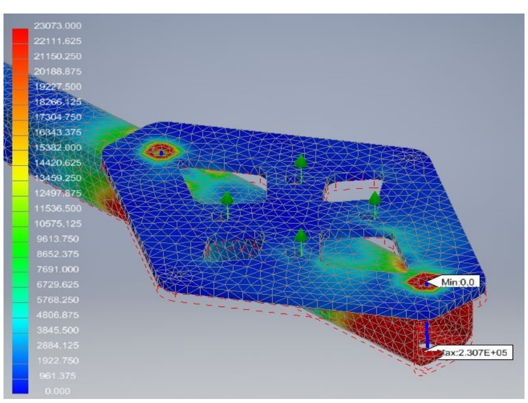

Figure 3. Bearing stress without sleeve bearing

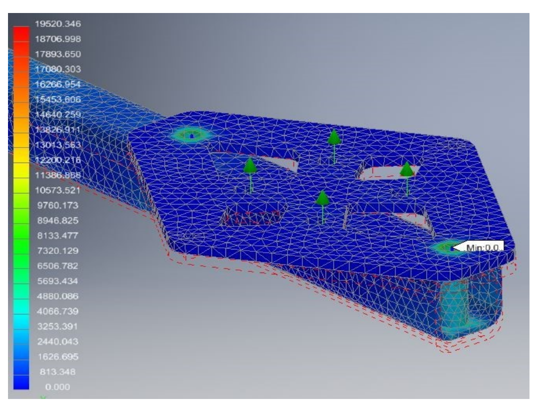

Figure 4. Bearing stress with sleeve bear-

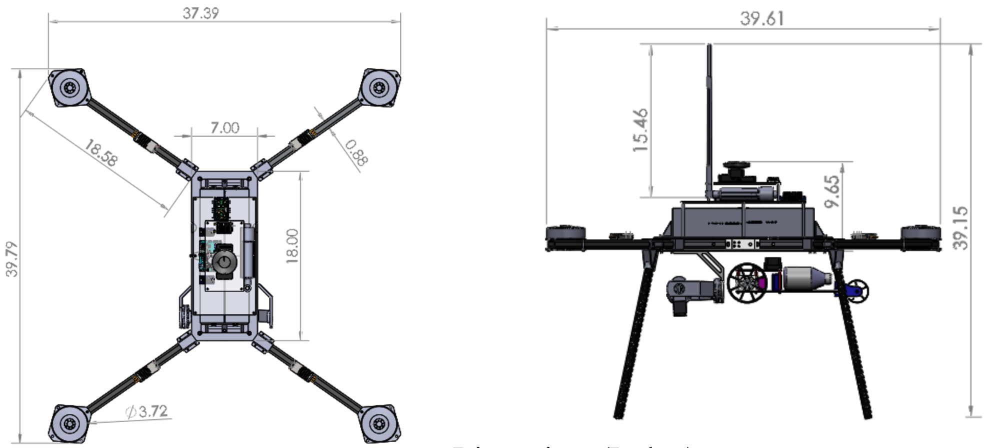

Figure 5. BFL Dimensions (Inches)

Standard modulus carbon fiber was chosen as the primary material for the frame construction due to its high rigidity, high yield strength, and low weight. Delrin acetal plastic was used to create connectors from the arms to the midsection. The combination of these materials allows for the quadcopter to be extremely durable while having a weight of only 1.71kg. To connect the arms to the midsection our team chose to use black oxide alloy steel shoulder screws because of their incredible strength, and minimal weight. These shoulder screws are used in conjunction with nylon washers and lock nuts for a precise and secure fit.

To cut the carbon fiber for the frame, our team used solid carbide endmills and drill bits to reduce delamination of the material. To further minimize delamination, the carbon fiber plates were sandwiched between thin sheets of basswood as they were milled. This kept the individual fibers from deflecting away from the endmill which resulted in a cleaner cut. To cut the acrylic plates, our team used a laser cutter to reduce machining time while maintaining quality and precision.

Thrust to Weight Ratio	2.42 : 1
Length	39.8 in
Width	37.4 in
Height	39.2 in
Max Thrust	93.5 lbs
Weight	38.6 lbs
Useful Thrust	54.9 lbs
Max Flight Time	45.3 mins
Max Flight Range	10.9 miles
Cruise Speed	17.6 knots

Figure 6. BFL Relevant Metrics

Due to the increased flight distance requirements for this year's competition, our team decided to allocate a large amount of our budget to sourcing and purchasing a new propulsion system. To achieve an optimal T/W ratio and maximize flight time, our team chose to use 4 T-motor U10II 100KV motors with 30"x10.5" propellers. This allowed the copter to sustain a max thrust of 93.5 lbs while only drawing 32.4 amps per motor.

In order to achieve the flight time necessary to attempt all mission tasks, our team analyzed multiple batteries of different sizes and compared each battery's capacity, weight, physical size, and cost. From the comparison data, our team determined that four Tattu 6S 16Ah batteries were the optimal choice. These batteries will be connected in a two parallel, two series configuration for a final output of 32Ah at 44.4V. **Figure 7** shows the theoretical distance our UAS will travel at different speeds. From this, our team determined that our UAS is capable of flying for 10.9 miles at 20 mph while operating at maximum efficiency.

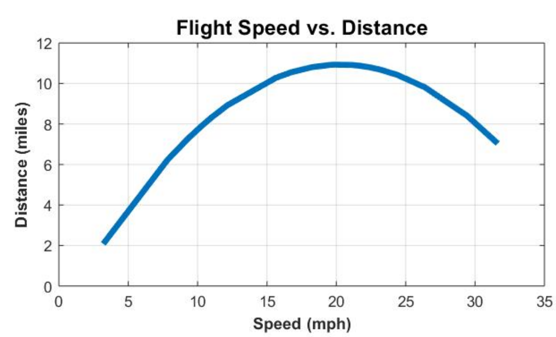

Figure 7. Flight Efficiency Calculations

2.2 Autopilot

Autonomous flight is one of the most important mission tasks to complete when competing in this competition, making up 20% of mission demonstration points. To complete the autonomous flight section of the competition an autopilot system is needed with the following requirements:

- Capable of safe, reliable, and accurate autonomous flight (including take offs and landings)
- Ability to interface with an external on board computer to manipulate flight path for obstacle avoidance
- Compatible with external sensors (gps, telemetry radio, ect…)
- Ability to set autonomous Return To Home (RTH) and flight termination failsafes
- Easy to use and troubleshoot

With these requirements in mind, our team analyzed several commercial market solutions for flight controllers and determined that a Pixhawk flight controller will work best for our UAS. Research was then conducted on the Pixhawk 1, Pixhawk 2.1, and Pixhawk 4, to determine the one that best fits our needs. A comparison table is displayed in **Figure 8**.

Flight Controller	Processor (Frequency)	Cost	Sensors
Pixhawk 4	STM32F765 (216 MHz)	$270	x2 Accelerometer, x2 Gyroscope, x1 Magnetometer, x1 Barometer
Pixhawk 2.1 (Cube)	STM32F427 (168 MHz)	$240	x3 Accelerometer, x3 Gyroscope, x1 Magnetometer, x1 Barometer, x1 Altimeter
Pixhawk 1	STM32F427 (168 MHz)	$130	x2 Accelerometer, x2 Gyroscope, x1 Magnetometer, x1 Barometer

Figure 8. Pixhawk Autopilot Compari-

After analyzing the information above, our team chose to use the Pixhawk 2.1 (Cube) on BFL. The Pixhawk 2.1 meets all requirements set by the team, and has proven to be reliable on our legacy systems. Other reasons the Pixhawk 2.1 was chosen include its relatively low cost, excess amount of redundant sensors for safe flight in case of sensor failure(s), and ability to replace sensor hub when sensors fail. The Pixhawk 2.1 will also be paired with a HERE GNSS GPS to gather data on BFL's location relative to a maximum of 3 Global Navigation Satellite Systems (GNSS) to ensure waypoint capture within 6 feet.

The Pixhawk 2.1 will be running Arducopter V3.2.1 firmware to control the processes of the flight controller. ArduCopter is a well known and trusted opensource firmware that is created and used by the hobbyist UAV community. The firmware has premade functions to control the autonomous flight of the aircraft, including waypoint capture, autonomous take off, autonomous landing, autonomous RTH, and autonomous flight termination. The last two functions are crucial for the safe operation of the aircraft, as they are needed to meet failsafe safety requirements for competition. To ensure accurate waypoint capture, certain parameters in ArduCopter are restricted to force our aircraft to hover at waypoints until it gets within at least 6ft of the given GPS coordinate.

At the base station, our team will be running a custom made mission planning application named Commander, as seen in **Figure 9**. The application consists of a frontend backend design, where the python framework Django runs the backend, JavaScript framework Vue runs the frontend, and REST API's perform communication between both ends. Commander is capable of displaying all of the necessary mission elements, communicating with the competition interoperability server, and operating manual object DLC. Our team decided to create our own mission planning software, instead of using premade mission planning software, to incorporate every component of the base station into one easy to use application.

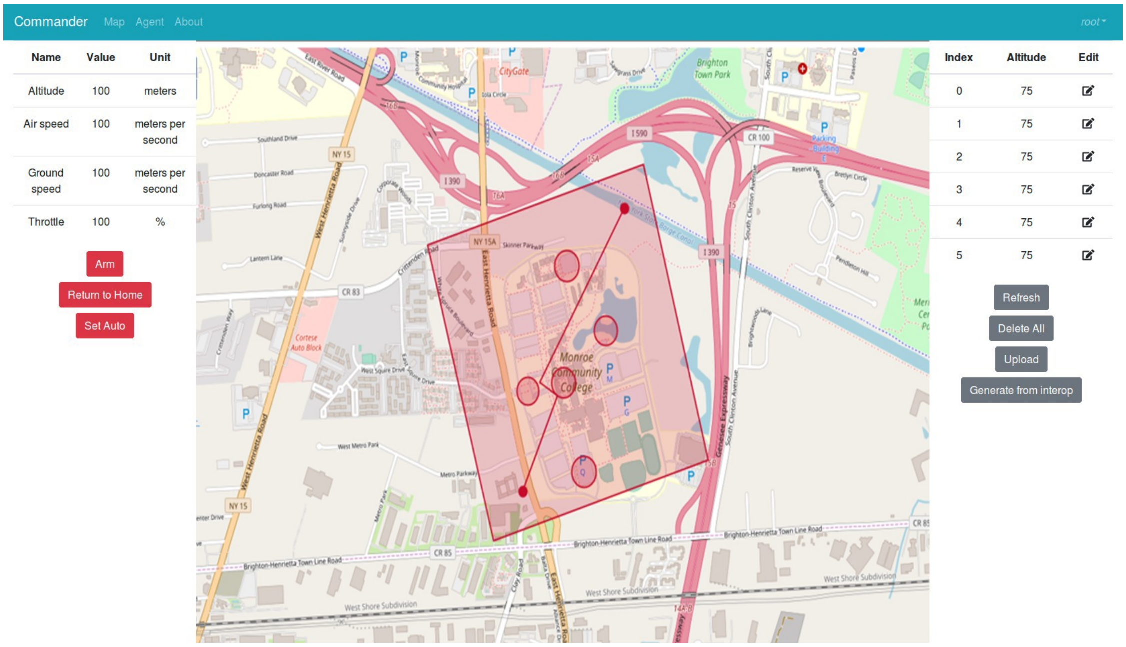

Figure 9. Commander Ground Control Station (GCS)

Following the completion of the autopilot system, complex autonomous navigation missions were conducted on a test aircraft, Maverick, to test the autonomous flight capabilities and waypoint accuracy of the system. Data was collected on the average distance the aircraft gets to each waypoint, and if a successful autonomous landing and take off occurred. Before each mission, the propulsion system, airframe, GPS, and Pixhawk internal sensors were tested to ensure personnel safety and that no bad data was collected. **Figure 10** shows the resulting data from the tests.

Mission Conducted	18
Waypoints Hit	968
Average Distance to Waypoint	4.3ft
Autonomous Takeoffs	18
Autonomous Landings	16

Figure 10. Autopilot Testing Da-

2.3 Obstacle Avoidance

To achieve the obstacle avoidance portion of the mission, the team created a custom obstacle avoidance algorithm (OAA) to identify obstacles and create an path to avoid them. The algorithm is fed a prewritten mission through MavLink and obstacle information through the interop server. It then identifies obstacles that lie in the current path of the UAS and creates a new waypoint path to circumvent the obstacles as efficiently as possible using ray tracing methods.

The algorithm first breaks down the flight path into a discrete set of points. It then tests to determine whether any of the points on the flight path exist inside of an obstacle. If so, the algorithm first checks if the UAV can fly over the obstacle while staying within the altitude limit as seen in **Figure 11**. This will allow for the UAV to scan for objects on the ground under the obstacle while still avoiding the obstacle. For all other cases, the software creates a new waypoint that lies on a line through the center of the obstacle and is orthogonal to the flight path. This new waypoint is offset from the center of the obstacle by that obstacle's radius plus an additional distance relative to the radius to ensure clearance as seen in **Figure 12**. Once the new waypoint is plotted, the process is repeated for the new flight path to confirm that no obstacles exist on the new flight trajectory.

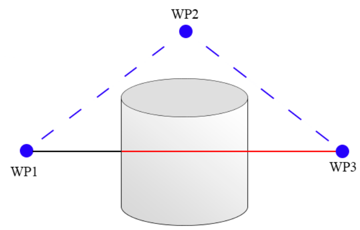

Figure 11. Fly Over Algorithm

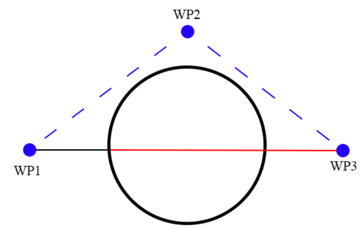

Figure 12. Fly Around Algo-

During development, the OAA was tested extensively using software test cases. Once the team was confident in the capabilities of the OAA, a series of manual waypoint tests were performed using our Commander autopilot system. Our team created multiple missions in Commander with different configurations of obstacles scattered throughout the flight path. Once the OAA had been executed, the new flight path was manually inspected by a team member to determine whether the new flight path intersected any of the obstacles. The new missions avoided obstacles with an average success rate of 70%.

2.4 Imaging System

2.4.1 Camera

The camera used on this year's system is the Sony A6000 mirrorless camera paired with a Sony E PZ 16-50mm lens. As described previously in the design rationale section, upgrading the propulsion system and creating a new airframe left inadequate funds to purchase a better camera. Images from last year's competition were analyzed to determine the minimum number of pixels/ft needed for our manual object DLC system to work. It was determined that a minimum of 18 pixels/ft were needed for a person to properly detect and characterize a ground target. Research was conducted on multiple cameras comparing the capabilities of the Sony A6000 to newer cameras on the market, as seen in **Figure 13**. The cameras researched all met the basic requirements of having a minimum of 18 pixels/ft and an Application Program Interface (API) to transfer images while in operation.

Specification	Sony A7RII	Sony A6000	Nikon Z6
Resolution	42.4MP	24.3MP	25MP
Weight	625g	468g	675g
Price	$1800	$800	$2000
Sensor	CMOS	APS-C	CMOS
Pixels / Foot (at 150ft)	23.6	27.3	18.0

Figure 13. Camera Comparison Data

After analyzing the information in **Figure 13**, the Sony A6000 was shown to still be a very capable camera, having a high image resolution, and 27.3 pixels/ft at an altitude of 150ft. The Sony A6000 also has fast autofocus features, a wide field of view when using the 16mm focal length, and a relatively low price if replacement is necessary. These characteristics make the Sony A6000 a good choice for our imaging system.

2.4.2 Gimbal

The camera will be mounted onto a custom 2-axis gimbal, using a Storm32 control board and an Inertial Measurement Unit (IMU) to control the orientation of the camera. The gimbal will point the camera directly at the ground and will compensate for any changes in the aircraft's pitch and roll axes. The gimbal itself is made out of ABS+ plastic, and is mounted to an aluminum connector to attach to the bottom of the UAV. To minimize vibrations from the UAV to the camera, vibration dampeners were added to the aluminum connector.

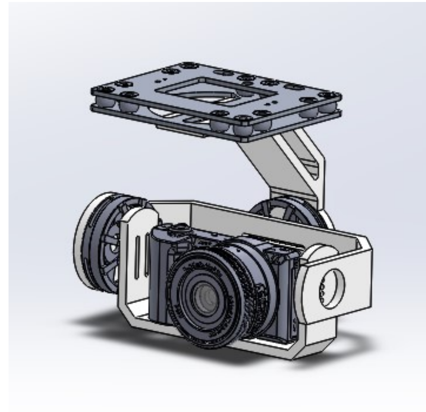

Figure 14. Custom 2-axis Gimbal

2.5 Object DLC

Due to a limited amount of time and software personnel, our team decided to only implement a manual Object DLC system. The system, named "Spotter", receives images from the UAV and displays them to multiple users through the Commander web app. The users then scan through the images to identify potential objects. When an object is identified, the user will crop the image to include just the object, and select characteristics of the object manually using the drop down lists in the Spotter interface shown in **Figure 15**. Once images have been cropped and classified they are manually submitted to the judges server.

To simplify the localization portion of Object DLC, our team decided to point the imaging system directly at the ground for the duration of the mission. With the imaging system fixed, the localization algorithm already knows the orientation of the camera and can easily determine the location of objects. Our team then created a localization algorithm to work with the fixed imaging system. The process for determining the latitude and longitude of an object is detailed in **Figure 16**.

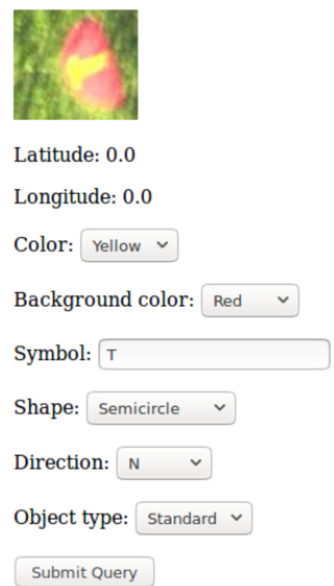

Figure 15. Spotter User Interface

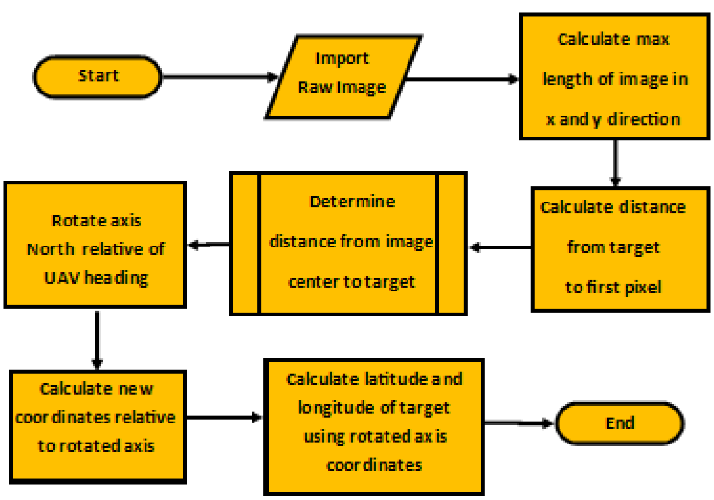

Figure 16. Localization Algorithm

To ensure that the localization algorithm was able to consistently and accurately localize objects, the team conducted multiple tests using raw images and geolocation data from previous competition missions. In testing, the algorithm successfully localized all objects that were feed to it with an average error of less than 25 feet.

2.6 Communications

BFL has three wireless connections from the UAV to the ground station, and two wireless connections from the UGV to the ground station. **Figure 17** outlines all wireless connections between the UAV and UGV to the ground station. The wireless connections include a 5.8 GHz WIFI link, two 2.4 GHz ACCST (Advanced Continuous Channel Shifting Technology) links, and two 900 MHz telemetry data signals.

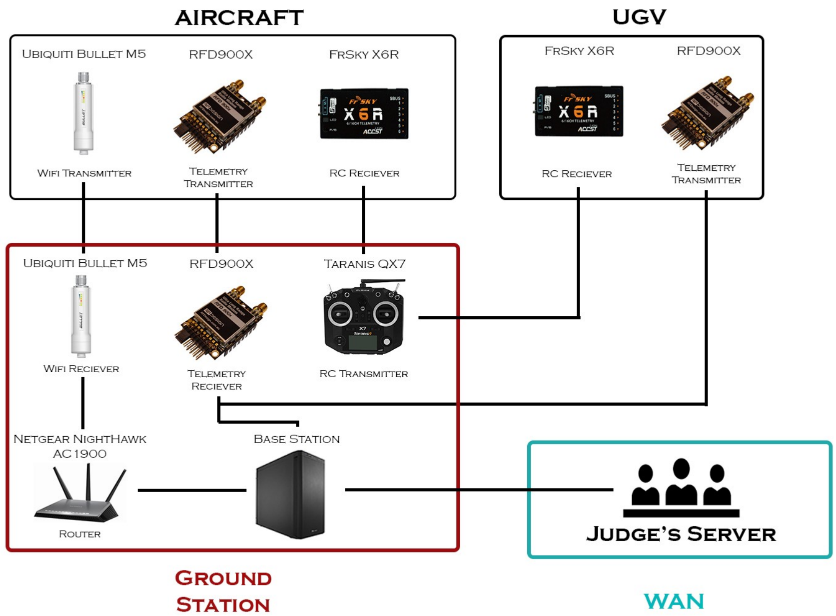

Figure 17. Communications Block Diagram

The 5.8GHz WIFI link is used to transfer images from the UAV down to the GCS using an onboard Ubiquiti M5 Bullet paired with a 9 dBi dipole antenna, and another Ubiquiti M5 Bullet at the ground station using a 24 dBi directional antenna. This link is then passed through a Nighthawk AC1900 router to communicate images to the base station and the Object DLC system. To ensure all images are transferred to the base station, one team member is assigned to manually track the UAV with the base station Ubiquiti M5 Bullet. The two 2.4 GHz ACCST links are used as safety pilot overrides, using FrSky X6R receivers and Taranis QX7 transmitters with a tested range of 1.2 miles line of sight. The two 900 MHz links are used to upload telemetry from the UAV and UGV to the base station, using one onboard UGV RFD900x, one onboard UAV RFD900x, and a base station RFD900x.

2.7 Air Drop

In order to successfully complete the payload delivery the team created several models to compare different rover designs. From the initial designs, the team chose a three wheeled UGV with a differential steering system and a rear pivot wheel to allow for precise turning. This design was chosen because the team found differential steering to be more reliable than servo or skid steering and because the lack of a fourth wheel allowed for a reduction in weight. The combination of precise turning and a lightweight design increases the likelihood of a successful drive to the delivery destination.

To control the UGV, the team decided to again use the Pixhawk 2.1 based on previous flight controller comparison data **(See Figure 8)**. To control the motors through the Pixhawk, our team researched several different speed controller setups before determining that a Polulu Dual Motor Driver was optimal for our design. Using a motor driver instead of two ESCs further reduced the weight of the power system without sacrificing on system performance.

A main objective of the air delivery task for the SUAS 2019 competition is to land the UGV accurately and softly enough as to not damage the payload. To achieve both these objectives the team chose to use a controlled dropping system. The system was built off of last years system which used a resisted gravity system in order to increase the accuracy of the drop. This year, the team chose to use a powered winch system to lower the UGV and payload. The system uses a brushed motor and a gear reduction box to allow for a speed controlled drop and a soft landing to maximize payload survivability.

Once a controlled drop prototype was created our team tested the system extensively to collect data on gear ratio, drop time, payload survivability, and force upon impact. From the data collected, our team determined that a 12V, 1100RPM, 10:1 gear reduced motor used in conjunction with a 3:1 gearbox would offer the best compromise between drop time and payload survivability.

After designing and prototyping the UGV and winch systems, our team decided that a mechanism must be designed to ensure a secure attachment from the UAS to the UGV. Based on these requirements, our team created a trapeze harness to connect the two systems. This mechanism ensures that the UGV remains stationary relative to the UAS while in flight, and also makes sure the UGV lands parallel to the ground by using a three point connection.

To release the trapeze from the UAS and subsequently from the UGV, a single high torque servo is used on each vehicle. When activated, the servo simultaneously releases the trapeze from all three connection points on both the UAS and UGV. The use of a single high torque servo allows our team to save weight on the UGV while still creating a reliable release.

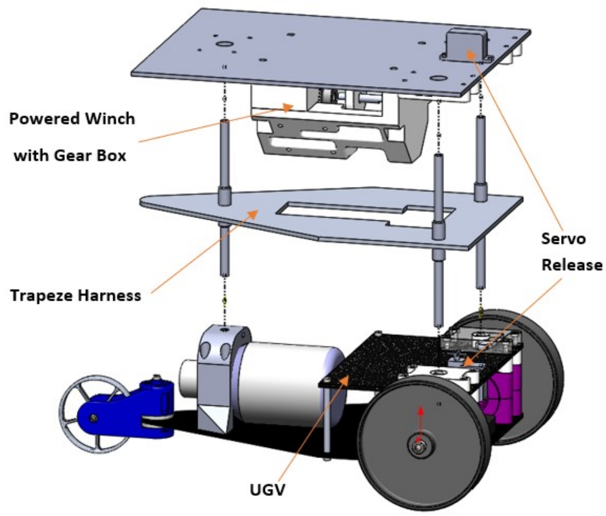

Figure 18. Air Delivery System

To ensure payload survivability while maintaining time efficiency, the optimal time to drop the payload was determined to be 33 seconds. Our team then conducted several drop tests with the complete system to test the trapeze release from the UAS, the trapeze release from the UGV, and the survivability rate of the payload. **Figure 19** displays the results of the tests.

Number of Tests	Payload Survived	Released from UAS	Released from UGV
16	15	15	13

Figure 19. Results from Payload Delivery Test-

2.8 Cyber Security

During the development of our UAS, a whitelist approach was taken to ensure the security of our systems. Our team determined that the majority of potential threats would target the wireless communications of our UAS. Technology built into our communication equipment was utilized to prevent a variety of cyber security threats. In the event of a network breach, multiple firewalls have been setup to restrict access to important services. Lastly, to ensure an airtight system, the Odroid, base station, and virtual machines within the base station have been encrypted with a public key. The private key is always securely stored away from potential threats, making the chance of unauthorized access low. **Figures 20 and 21** outline the methods used to protect our system from potential cyber security threats.

Link / Component	Hardening	Reasoning
5GHz Wireless Link	WPA2—AES	Prevents data sniffing and unauthorized access
	Channel Hopping	Channel Jamming
	MAC Filtering	Only allows a single line of communication

Figure 20. Cyber Security Break-

Link / Component	Hardening	Reasoning
900MHz Telemetry	AES Encryption	Prevents data sniffing and unauthorized access
RC Link	ACCST	Prevents Jamming
Base Station Router	Strict Firewall Rules	Prevents Unauthorized Access
Base Station Server	Hypervisor / Containerization	Prevents full system takeover
Spotter (Imaging WebApp)	User Authentication	Only allows operator access
Odroid XU4	Strict firewall rules	Only allows communication between base station and interop server
SSH/Management Connections	Public Key Authentication	Only allows system administrators to make changes

Figure 21. Cyber Security Breakdown Contin-

3 Safety, Risks, and Mitigations

Safety was the number one priority when working to develop and test our UAS. Before starting any work on the UAS, our team evaluated and improved previous safety protocols and implemented new strict safety guidelines to minimize risk and ensure the safety of all personnel. Possible risks were listed and grouped into two categories, developmental risks, and mission risks. Following this, each risk was analyzed and given a rating for consequence severity, and accident probability to better determine the risk mitigation method.

3.1 Developmental Risks and Mitigations

Throughout the development process of creating our UAS there were multiple risks that posed a possible safety hazard to personnel. Each risk is identified in Figure 21 along with the corresponding mitigation method. Every member is responsible for knowing these mitigation methods and enforcing them between every member.

Risks	Severity of Consequences	Event Probability	Mitigation Method
Machine Shop Related Injury / Equipment Failure	High	Medium	• Attend faculty lead safety training every semester • Wear protective equipment (Safety glasses, closed toe shows, ect…) • Follow shop guidelines (no long-sleeve shirts, necklaces / jewelry, ect…)
Electrical Related Injury / Fire	High	Low	• Implemented battery charge/discharge training and guidelines • Store all batteries in lipo bags and fireproof ammo boxes • Have sandbags nearby to smother batteries in case of fire
Misuse of Equipment / Tools	Medium	Low	• Have first aid kits nearby at all times • Train members on general equipment safety

Figure 22. Developmental Risks and Mitigation Meth-

3.2 Mission Risks and Mitigations

During mission testing and the mission demonstration section of competition, there are multiple risks attributed with operating the UAS that pose possible safety hazards to team personnel and others. Each risk is identified in **Figure 23** along with the corresponding mitigation method. To ensure the procedures are followed, a dedicated safety director role is assigned to one member when operating the UAS to enforce all safety procedures.

Risks	Severity of Consequences	Event Probability	Mitigation Method
Pilot Error / Autopilot Failure	High	Medium	• Extensive pilot training on legacy crafts • Fly only in good weather conditions (low wind, no precipitation, ect…) • Kill switch failsafe incase of an uncontrollable flyaway
Electrical System Failure	High	Low	• Check battery voltages before each flight • Monitor battery voltage during flight • Always RTL with a minimum of 25% power reserve
Communication System Failure / Interference	Medium	Medium	• Monitor electrical interference before flight • RTL failsafe in case of RC link drop out
Environment	Medium	Low	• Use bug spray and sunscreen when necessary • Always have a case of water on hand to keep team hydrated • Have a vehicle with working AC

Figure 23. Mission Risks and Mitigation Methods

4 Conclusion

Throughout the last year our team worked hard to develop and test a system that would be capable of competing in the SUAS 2019 competition. Our team has achieved our goal for this year which was to create a system that is able to complete a simulated package delivery mission safely and effectively. Our team is confident in our system, and we look forward to competing at this years mission demonstration in June.

A Hands-on Activity to Assist Students in Making Connections between Topics in Heat Transfer

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Abstract

The preliminary work presented here consists of an educational module designed for a course in thermal fluid sciences focused on fundamental thermodynamic and heat transfer principles. The hands-on, project-based activity promotes entrepreneurially-minded learning by encouraging students to connect information across topics in both courses to solve a real-world problem. This was accomplished using a project-based approach where students conducted an experiment to investigate the cooling of pizza. Students had to apply the 1st Law of Thermodynamics and fundamental heat transfer principles, such as conduction and convection, to determine the optimal temperature to eat the pizza and an estimated delivery time. To do this students were required to go beyond basic problem-solving and forced to apply theory from multiple courses to solve an ill-defined problem. The author has delivered the course Thermal Fluid Sciences II five times and implemented the module in two of the five deliveries. After the most recent execution in fall 2019, a preliminary study was conducted via student surveys to determine if students considered the module a valuable addition to the course. These preliminary findings aimed at not only determining if the module should be continued in the future, but also at evaluating if the module resulted in: (1) increased student engagement and interest in thermal fluids, (2) increased learning effectiveness compared to traditional teaching methods, and (3) increased understanding of how topics within thermal fluids are connected. Exam scores between course sections that completed the module and those that did not were also compared to provide quantitative data regarding increased learning effectiveness. Preliminary findings conclude that students perceive this module to be a great tool for not only improving learning effectiveness and engagement, but also helping them connect information across topics. A comparison of exams scores and class averages between the two semesters the module was delivered and the three semesters the module was not, showed an improvement in scores in two of the three semesters. Future work will include improving the module to enhance the understanding of transient conduction and collecting more data to obtain a statistically significant data set.

Introduction

There are numerous articles in the literature describing the widespread poor learning of basic concepts and principles within thermal fluids courses, i.e. fluid mechanics, thermodynamics, and heat transfer[1, 2, 3]. These are concept heavy courses that students often struggle with due to their abstract nature[4]. Thus, students simply memorize equations and never truly understand what those equations mean or how to apply them[4]. In addition, when students are asked to provide explanations or reasoning while problem solving, they often struggle and fail. Finally, these courses usually require coverage of a wide breadth of topics in a short period of time, making them especially challenging to teach effectively[1,2,3].

In response, educators have developed real-life examples, hands-on experiments, and projects to tackle difficult concepts, helping students connect abstract ideas to actual hardware[1]. However, these activities tend to focus on a single concept in one course, for example head loss in fluid mechanics. They do not encourage students to connect information across topics or courses, an important component in graduating entrepreneurially minded engineers[4,5,6].

Realizing this student perception of, and difficulty with, thermal fluids courses, plus the shortfall of existing activities, a project-based learning module was designed at the Rochester Institute of Technology for Thermal Fluid Sciences II (MCET 530), a senior level mechanical engineering technology course. It was hypothesized that by implementing a module focused on how to integrate and apply knowledge across several topics within thermal fluids, students would gain a better understanding of fundamental concepts and know how to apply them, becoming better engineers.

The module is a project-based, hands-on activity designed to address student difficulty with fundamental heat transfer principles, such as conduction and convection. The module also requires students to not only make connections between multiple heat transfer concepts, but also back to thermodynamics. In the activity students connect abstract ideas within thermal fluids by analyzing the cooling of various types of pizza slices from delivery to consumption. The project provides students not only with the understanding of basic concepts and principles, but also how this information can be integrated to solve a problem. This takes students above basic problem solving and makes them think about how to approach a real-world solution.

This preliminary work was motivated by the questions: did students perceive this activity to help them connect information regarding the different types of heat transfer to solve a real-world problem? Did this hands-on activity improve knowledge retention and comprehension, as demonstrated by exam performance? A preliminary study was conducted to determine if the activity did help students connect information across topics and gain a better understanding of fundamental principles.

Heat Transfer Course Module

Overview

The work proposed here consists of an educational module designed for Thermal Fluid Sciences II, a core Mechanical Engineering Technology course at the Rochester Institute of Technology focused on Thermodynamics and Heat Transfer. The module promotes entrepreneurially-minded problem-solving by encouraging students to connect and apply principles across topics within thermal fluids to solve a real-world problem.

Details

In mechanical engineering technology at the Rochester Institute of Technology, undergraduate students, typically in their fourth or fifth year, are required to take the course Thermal Fluid Sciences II. This course covers topics in both Thermodynamics II and Heat Transfer. For the Heat Transfer content, students learn how thermal energy moves by conduction, convection, and radiation in real-world systems. Each key concept consists of several related topics, such as Thermal Circuits, Heat Diffusion Equation, and Transient Conduction, which were presented via lectures in class. The goal of this module was to encourage students to not only connect information across these heat transfer topics, but also back to what was learned in Thermodynamics.

The project starts by each student selecting two slices of pizza. In this course since students are only taught one-dimensional heat transfer, they analyze the heat transfer leaving the sides of one slice and the top of the other. A comparison of the heat transfer analysis of each slice is done throughout the project.

To start, students create schematics of the initial temperature distribution in each slice of pizza. They use a combination of bulb and infrared thermometers to measure the initial temperature from the center of the slice of pizza to the outside. For each slice, several data points are taken from the center to the edge of the slice (side for once slice, top for the other).

The ambient temperature is recorded, along with the time of delivery and time of initial temperature measurement. Figure 1 shows a student and author example of the initial temperature distribution for each slice of pizza.

The overall length, width, and thickness of each slice is measured using calipers. The thickness of each layer, i.e. crust, sauce, cheese, and pepperoni, is also measured and recorded.

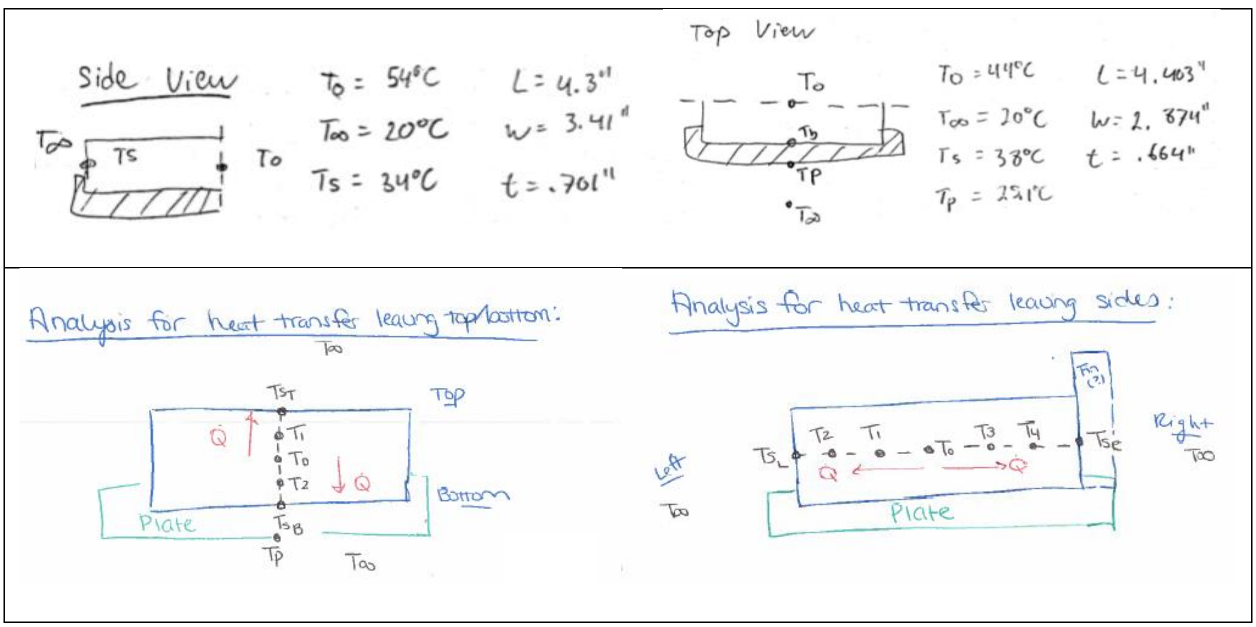

Figure 1: Examples of initial temperature distribution schematics by student (top) and author (bottom)

After establishing an initial temperature distribution, students then draw the resistance network for each slice of pizza. The resulting resistance network will depend on what type of pizza slice was chosen, and therefore vary among students. For example, did the student choose a slice with just cheese, or cheese and pepperoni? Is the thickness of the cheese consistent between slices?

Did the student choose a center piece or a crust piece? All of these factors will change their resistance networks. For example, the student with the crust piece will need to consider fin resistance in the analysis of the heat transfer in the direction of the crust. Based on their type of pizza slice, the students then calculate the total resistance for each of their slices. An example of a student and author resistance networks are shown in Figure 2.

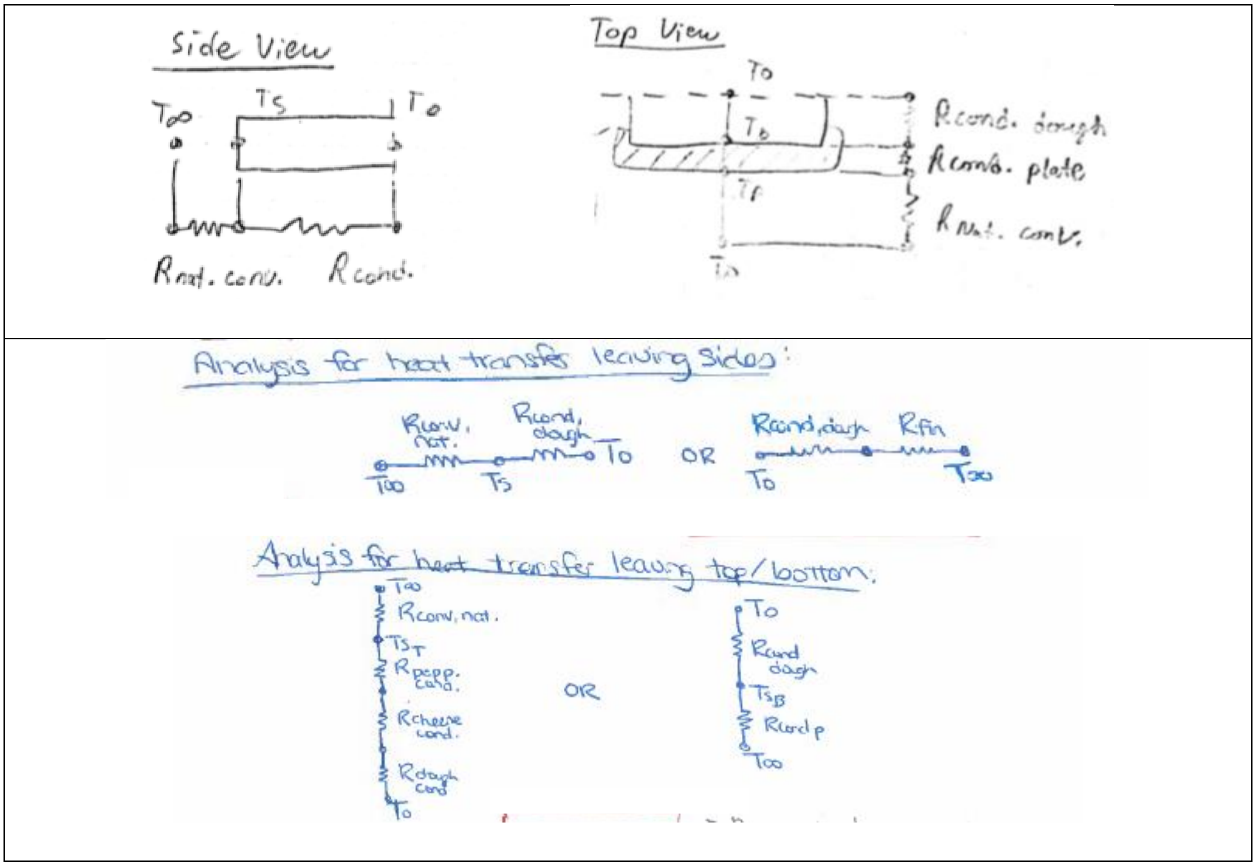

Figure 2: Examples of resistance networks by student (top) and author (bottom)

During this process students will need to apply the resistance equations for conduction, Equation 1, and convection, Equation 2. As mentioned, students may also need to apply the fin resistance equation, Equation 3.

$$R_{conduction} = \frac{L}{kA} \quad \text{Eq. (1)}$$

$$R_{convection} = \frac{1}{hA} \quad \text{Eq. (2)}$$

$$R_{fin} = \frac{1}{h(A_{base} + \eta_{fin} A_{fin})} \quad \text{Eq. (3)}$$

Where L is the length of the pizza [m], k is the thermal conductivity of the material [W/m-K], h is the convection heat transfer coefficient [W/m^2-K], A is the surface area of the pizza [m^2], A_{base} is the area with no fin [m^2], η_{fin} is the fin efficiency, and A_{fin} is the area of the fin [m^2].

To determine the total resistance students must be able to differentiate between a conduction and convection process. They need to be able to determine the thermal conductivity of the material, k, for all conduction processes (i.e. heat transfer through the dough, cheese, or pepperoni layers). This requires them to conduct independent research to determine average values. This research was done during class time and resources shared via a class discussion on the course page. The instructor also contributed a resource a few days prior to the project being due[7].

Students also need to determine the convection heat transfer coefficient, h. The author has observed that students typically take different approaches for this parameter. Some conduct independent research to determine an average cooling convection coefficient. Others calculate the variable using natural convection principles – determine a Rayleigh number to calculate the average Nusselt number, which can be used to calculate the convection coefficient, h. The relation between Nusselt number and the convection coefficient is provided in Equation 4, where L_c is the characteristic length.

$$Nusselt\ Number, Nu = \frac{hL_c}{k} \qquad \text{Eq. (4)}$$

Students quickly learn that they need to identify all of the processes occurring in their cooling scenario first to be able to determine the equations needed to reach a solution. They also learn it is beneficial to identify known and unknown variables at the start. This helps determine which assumptions might need to be made about the real problem to reach a logical solution.

The next step is for students to discuss how the total resistance for each slice would change if the cooling process was sped up with a standard tabletop fan. Students need to identify that this change in scenario only changes the convection coefficient, h, and therefore need to only recalculate this parameter and the convection resistance. Students start by determining the average speed of a household fan so that they can calculate Reynolds number, which is used to calculate the Nusselt number. The convection coefficient can be determined using Nusselt number and Equation 4.

Often times when students arrive to this step they will realize they need to go back to their total resistance calculation and account for natural convection. This step serves as another "check point" for students as they compare their natural and forced convection coefficient values. If their forced convection coefficient value is less than the natural convection value they should realize a mistake has been made. This is a great discussion point between the instructor and students. The instructor can use the two different pizza slices as a tangible object to discuss (1) the difference between natural and forced convection principles, and (2) why the different slices of pizza (heat transfer from the sides versus top) have vastly different convection coefficients for both the natural and forced processes.

Finally students determine the total rate of heat transfer for both slices of pizza using Equation 5, where ΔT is the temperature difference and R_{total} is the total resistance.

$$Q_{total} = \frac{\Delta T}{R_{total}} \qquad \text{Eq. (5)}$$

Students repeat this process first for natural convection and then forced convection. They must make a comparison not only between the side and top heat transfer analyses, but the different convection methods. Students can then repeat this calculation using their knowledge of thermodynamics and the 1st Law to make a comparison with their heat transfer analysis.

Finally students need to combine their knowledge of steady and transient conduction with the multi-modes of convection. They are asked to determine the optimal time and temperature to eat the pizza starting from delivery. They have to describe all assumptions they would make and the approach they would take analytically. Typical solutions use a transient plane wall conduction analysis, shown in Equation 6. Where T(x,t) is the temperature at a specific time and location [K], T_∞ is the ambient temperature [K], T_i is the initial temperature [K], A_1 and λ_1 are coefficients based on the Biot number when using a one-term approximation for a transient solution, τ is the Fourier number, x is the distance at the temperature of interest [m], and L is the overall length [m].

Students are then asked to back calculate what the estimated delivery time is. They can estimate how accurate their answer is by assuming a route and calculating a delivery time with Google Maps.

$$\frac{T(x,t)-T_\infty}{T_i-T_\infty} = A_1 e^{-\lambda_1^2 \tau} \cos\left(\frac{\lambda_1 x}{L}\right) \qquad \text{Eq. (6)}$$

Some students take this analysis a step further by continuing their temperature measurements for the duration of the class. They create a temperature distribution as a function of time, which can be compared with a calculated distribution using Equation 6.

Learning Outcomes

This module was designed around *four main learning outcomes*, outlined below. A preliminary qualitative assessment was done using an anonymous student survey and a preliminary quantitative assessment was done through a comparison of exam grades. Future work will look at assessing the learning outcomes in detail with a larger data set.

***Learning Outcome 1*: Students will be able to apply 1-D steady state conduction heat transfer.**

a. Students need to apply knowledge of resistance networks to determine the total resistance in different heat transfer situations, i.e. heat transfer from the side of a slice of pizza versus the top.

b. Students need to apply knowledge of fin conduction if analyzing a piece of pizza with crust.

c. Students need to apply knowledge of 1-D steady state conduction to calculate the total heat transfer through a slice of pizza.

Learning Outcome 2: **Students will be able to apply 1-D steady state natural and forced convection heat transfer.**

a. Students need to apply knowledge of a how to determine the convection heat transfer coefficient in a natural convection situation.

b. Students need to apply knowledge of a how to determine the convection heat transfer coefficient in a forced convection situation.

c. Students need to understand how the different methods of convection, natural and forced, change the total resistance and heat transfer values.

Learning Outcome 3: **Students will be able to evaluate systems under transient conduction heat transfer conditions to calculate temperature and energy transfer by position and time.**

a. Students need to apply knowledge of plane wall transient conduction to determine the temperature distribution throughout the pizza as a function of time.

Learning Outcome 4: **Students will be able to apply fundamental heat transfer and thermodynamic principles to a real-world application.**

a. Students must apply their knowledge of heat transfer and thermodynamics to make assumptions about, and successfully analyze, a real-world problem.

Assessment and Evaluation

The author delivered the course Thermal Fluid Sciences II (MCET 530) in Fall 2017 (35 students), Spring 2018 (72 students), and Spring 2019 (85 students) without the hands-on activity, and with the activity in Fall 2018 (38 students) and Fall 2019 (34 students). After execution of the activity in Fall 2019, the effectiveness of the developed activity in achieving the desired learning outcomes was investigated. Students were assessed at the end of the activity with an exam composed of two problems, one focused on conduction and one on convection. Performance on this problem was compared between students who participated in the activity and those who did not during semesters Fall 2017 to Fall 2019. Perception of the activity's impact on student learning was also assessed via anonymous surveys.

The preliminary study used a survey where questions were written in the form of statements or questions and students were asked their level of agreement on a 7 point Likert scale between 1 (strongly disagree) and 7 (strongly agree). It is noted that as this is a preliminary assessment the questions were not peer reviewed. However, they were based on other peer reviewed published papers[4]. Future work will include an expert review of survey questions. The survey was administered at the end of the fall 2019 semester, upon completion of the project. To date, the preliminary study consists of one administration of the survey to purely see if the project was (1) enjoyable to the students and (2) if students perceived it to increase their understanding.

Results

The goal of the survey was to determine if the students' learning experience benefited from the addition of a hands-on activity focused on fundamental heat transfer concepts and integrating these with fundamental thermodynamic concepts. The survey also sought to determine if students found this activity to be effective in enhancing their understanding of the material. Of the 34 students enrolled in the fall 2019 Thermal Fluid Sciences II course, 12 survey responses were obtained. The demographic of the students surveyed were those who opted to take the final, typically students with a class average below 85.

The first set of questions, shown in Figure 3, focused on the delivery of the activity in the course. Of the students surveyed, only less than 10% believed the activity was not as useful as a traditional homework or lecture in terms of being an effective means of understanding the material. In terms of having class time to work on the project, all students surveyed believed it was time well spent.

When asked if the activity helped students prepare for an exam on which similar concepts were tested, 60% of students strongly agreed it was helpful while less than 20% of students surveyed were indifferent.

When asked if the activity helped students understand and apply conduction and convection to a real problem, 90% of students were in agreement with over 80% responding with “agree” or “strongly agree.” Less than 10% of students were indifferent if the activity improved understanding.

When asked specifically about steady conduction and students’ understanding of conduction through different materials, 85% of students felt the activity improved their understanding. When asked specifically about convection and students’ understanding of natural versus forced convection, over 90% of students felt that the activity improved their understanding.

When asked if the activity helped students understand transient conduction, only 30% of students responded with “agree” or “strongly agree” with the majority of students only “partly agreeing.” This indicates that the transient conduction component of the module could be improved.

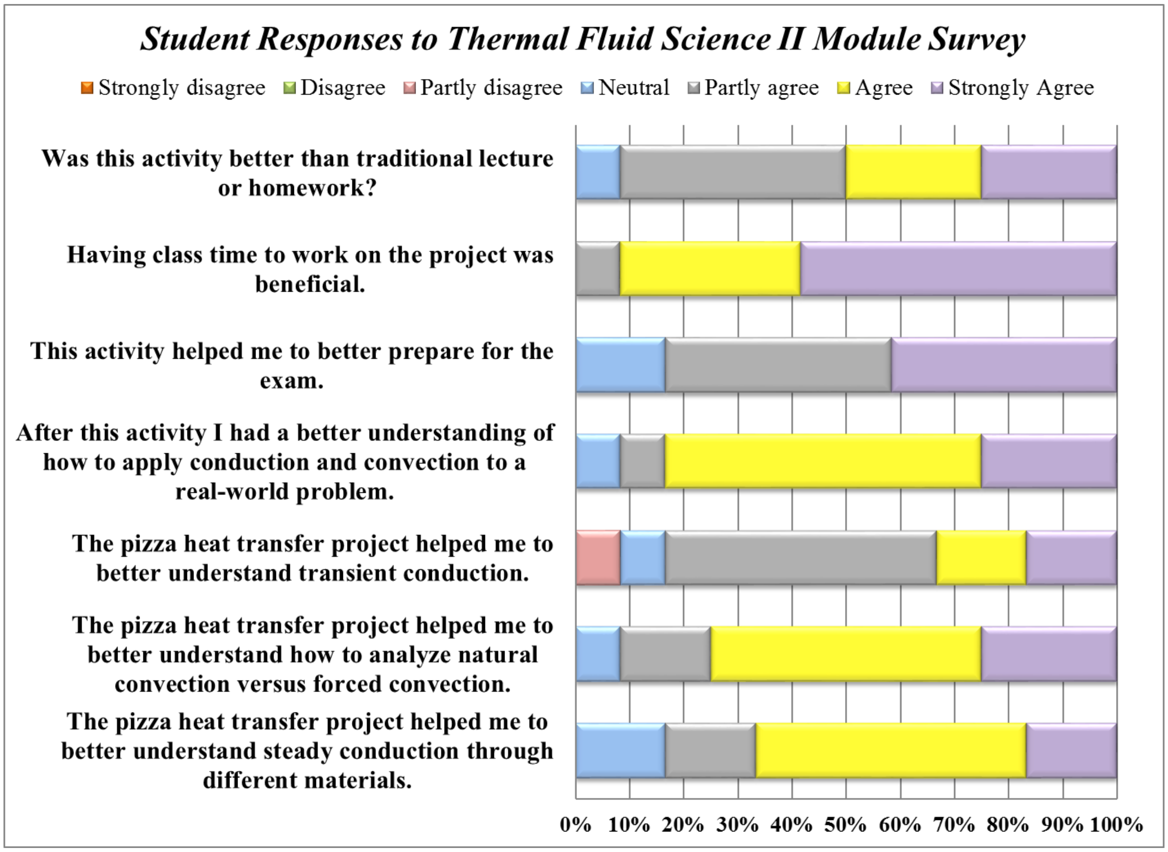

Figure 3: Student responses to anonymous survey given in Thermal Fluid Sciences II (MCET 530)

A few follow-up questions on future surveys could be on how well the students thought the activity helped them to connect information across topics within heat transfer, but also across heat transfer and thermodynamics.

A preliminary quantitative assessment was done by comparing two scores, the class average from a heat transfer-focused exam and final course average for the class, between the sections that completed the module and ones that did not. The Fall 2018 and Fall 2019 show an improvement in both the class averages and the heat transfer-focused exam average when compared with the Fall 2017 and Spring 2018 sections. However, an improvement was only seen when the Fall 2018 and Fall 2019 sections were compared with the Spring 2019 sections' class average. This may be because the Spring 2019 sections' exam average was well-above a typical average. Typically the author strives for an exam average of 85%.

Table 1: A comparison of scores between students who completed the module and those who did not

Semester	Section	Students Enrolled	Project in Course	Class Average	Exam Average
Fall 2017	01	35	No	87	83
Spring 2018	01	38	No	88	84
	02	34	No	86	84
Fall 2018	01	38	Yes	89	86
Spring 2019	01	43	No	88	93
	02	42	No	84	91
Fall 2019	01	34	Yes	88	89

Assessment of the module shows that focusing on a real-world situation related to heat transfer and thermodynamics is engaging to students. The majority of students perceived this activity to be a more effective approach in improving their understanding of heat transfer principles, which is supported by exam and course averages. Therefore, the topic of the module will remain unchanged. However, as indicated by student surveys, the transient component of the module can be improved upon. A better assessment can be conducted in future work as well. Expanding the survey questions to inquire about student perception of connections made across topics, and then designing an exam problem to quantitatively assess connections made.

Conclusions

This paper describes the author's early efforts to develop an entrepreneurially-minded course module requiring students to connect information across topics within heat transfer, and then to thermodynamics, to solve a real-world problem. This hands-on module uses a project-based approach where students conducted an experiment to investigate the cooling of pizza. Students had to apply the 1st Law of Thermodynamics and fundamental heat transfer principles, such as conduction and convection, to determine the optimal temperature to eat the pizza and an estimated delivery time.

To date the author has implemented the project into her course twice and plans to conduct a more in-depth study in the future. Preliminary results indicate the developed module increased student engagement in, and understanding of, heat transfer topics. Exam scores between the sections that completed the module and did not complete the module were also compared to provide quantitative data regarding increased learning effectiveness. Preliminary findings conclude that students perceive this module to be a great tool for not only improving learning effectiveness and engagement, but also helping them connect information. A comparison of exams scores and class averages between the two semesters the module was delivered and the three semesters the module was not, showed an improvement in scores in two of the three semesters.

Future work will consist of administering a pre- and post-survey, once at the beginning of the semester and then at the end, to gauge improvement in student learning of basic heat transfer concepts and connections made between topics. In addition to improved student surveys, future work will also evaluate the developed module using quantitative data from well-designed exam problems to validate preliminary findings. Statistics regarding reliability will be developed as the study is continued.

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Developing a New Course about Planning and Operation of Plug-In Electric Vehicles in Smart Grid

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1. Introduction

This paper briefly presents the subjects and descriptions of the recently developed undergraduate and graduate courses about planning and operation of plug-in electric vehicles (PEVs) at State University of New York (SUNY), College at Buffalo, Buffalo, NY, US. The courses will be presented in Fall 2020 under the titles of "ENT 473: PEVs in smart grid" and "ENT 573: Planning and operation of PEVs in smart grid" for undergraduate and graduate students, respectively.

The graduate course, that is, ENT 573, includes the latest advancements in the planning and operation of PEVs in smart grid from the viewpoint of independent system operator (ISO), electric distribution company (DISCO), electric generation company (GENCO), PEV aggregator, market retailer, and end-user customer. The planning and operation problems that are studied in this course include charging station placement and sizing in electric distribution system, charging management of PEVs, demand-side management (DSM), generation scheduling and unit commitment (UC), spinning reserve provision, power loss minimization of distribution system, power market participation, and energy scheduling considering the technical specifications of PEVs. The course comprises several chapters that are introduced and described in the following.

In the first chapter, there is an introduction to the current status of energy security, greenhouse gas emissions, and global warming. Moreover, this chapter includes the governments' policies for PEVs development like tax cuts and subsidies. The current status and future of PEVs in auto-market are the other subjects of the introduction chapter.

In the second chapter, PEV technology like PEV types and standards, energy storage systems of PEVs, and concept and standards of grid-to-vehicle (G2V) and vehicle-to-grid (V2G) services are discussed.

The third chapter discusses the threats and opportunities of PEVs for electric power system, presence of PEVs in power market and ancillary services, and concept of PEV aggregator.

The fourth chapter deals with the planning problems of PEVs in smart grid like charging station placement and sizing from a DISCO's viewpoint. The planning problems are studied with the goals of power loss reduction of electric distribution system, distribution system reconfiguration, distribution feeder's congestion management, distributed generation, distribution system expansion postponement, and distribution system reliability improvement.

The operation problems of PEVs in smart grid are studied in the fifth chapter. Herein, the problems are investigated from a GENCO's and a DISCO's point of views. This chapter covers the subjects of charging management of PEVs, DSM, generation scheduling and UC, spinning reserve provision, frequency regulation, and generation system reliability improvement that are studied from a GENCO's viewpoint. In addition, the subjects like distribution system reliability improvement, power loss minimization, system reconfiguration, feeder's congestion management, power market participation, and renewables' power smoothing are studied from a DISCO's point view.

The optimization techniques that are useful in the planning and operation problems of PEVs are studied in the last chapter. These optimization techniques include heuristic optimization algorithms, artificial intelligence optimization techniques, learning-based optimization methods, linear programming, and non-linear programming.

Moreover, in the undergraduate course (ENT 473), just the concepts of the above-mentioned subjects are discussed.

Each course is considered as a regular 3-credit-hour course. Additionally, the course of “Power System Analysis 1” needs to be considered as the prerequisite course for ENT 573. Moreover, the students’ learning assessment will be based on students’ class participation, assignments, written exams, researches, computer simulation projects (just for ENT 573), and presentations.

2. The Reasons for Addition of the Courses to Curriculum

A considerable portion of energy consumption, carbon emissions, and global warming are related to the transportation sector. Fig. 1 shows the air pollution in Donora, PA, US, on Sep. 19, 2017 [1]. Transportation electrification is seen as one of the solutions to the above-mentioned issues, since PEVs can be charged by the clean and free renewable energy sources. Fig. 2 illustrates a charging station in SUNY Buffalo State College, Buffalo, NY, US.

On the other hand, the governments across the world are implementing tax cuts and financial incentives to accelerate the transition from the internal combustion engine (ICE) vehicles to the electric ones to achieve their own energy security and climate change mitigation goals. Fig. 3 shows the map of fuel cost savings per year for a vehicle in each state of US, when driving on electricity instead of gas [2]. As can be seen, there is a considerable potential to minimize the fuel consumption expenses. The predicted world PEV and ICE vehicle sales are shown in Fig. 4 [3]. As can be seen, it is predicted that the PEV sales will surpass the ICE car sales by 2039.

Consequently, PEVs, as the new electricity consumers, will consume a considerable portion of electricity in the near future. Therefore, students and electrical engineers need to be familiar with the planning and operation techniques of PEVs.

In the following, in Sections 3-4, some of the planning and operation problems of PEVs are presented and described in brief.

Fig. 1. Air pollution in Donora, PA, US, on Sep. 19, 2017 [1].

Fig. 2. A charging station in State University of New York (SUNY), College at Buffalo, Buffalo, NY, US.

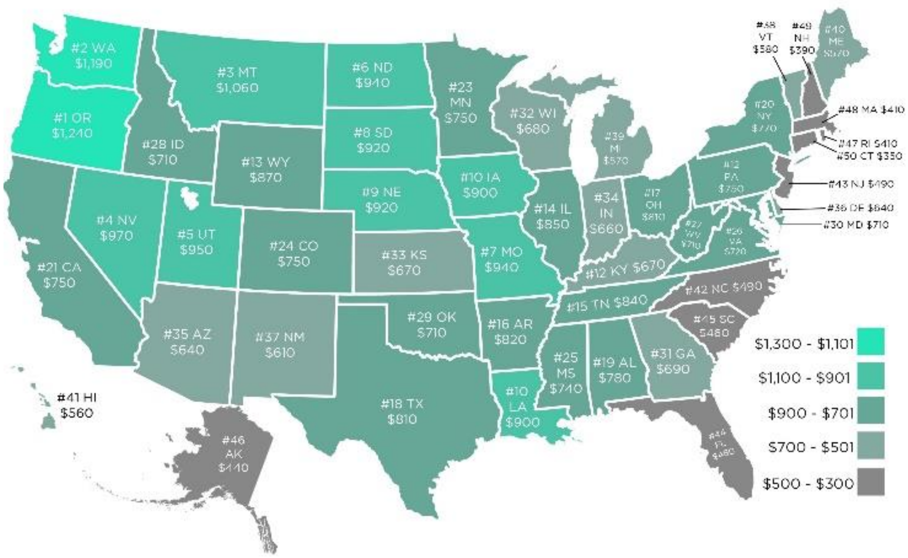

Fig. 3. Map of fuel cost savings per vehicle in the US ($/year) when driving on electricity instead of gas [2].

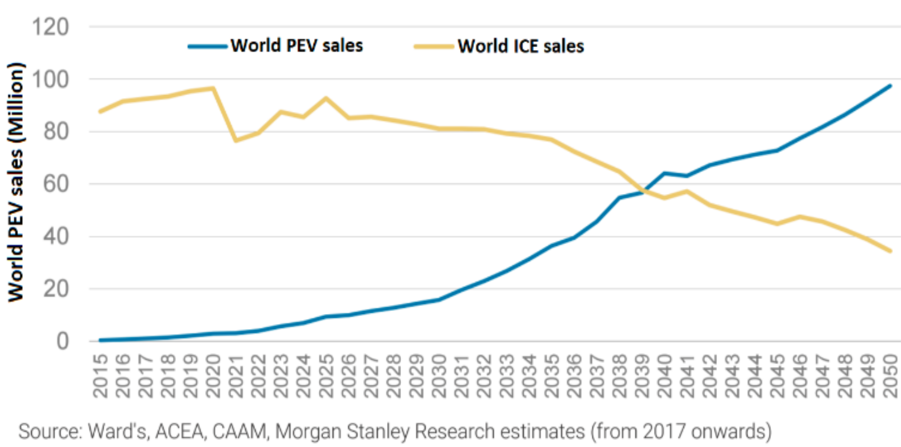

Fig. 4. A prediction about the world PEV and ICE vehicles sales [3].

3. Planning Problem of PEVs in Smart Grid

3.1. Charging Station Sizing and Placement: Cooperation with a Distribution Company

In this part of paper, the problem of charging station allocation is studied. Fig. 5 shows the electrical single-line diagram of electric distribution system under study and the hourly geographical routes of PEVs in San Francisco, CA, US [4]. The distribution system includes two medium-voltage electrical distribution feeders (F1 and F2) supplied by the 33/11 kV sub-transmission transformer. Each feeder includes a circuit breaker (C.B.) and a recloser (R.C.). Herein, just the first feeder (F1) is studied and the second one (F2) is utilized to transfer part of load of F1 to F2 during the fault occurrence using the normally open switch. The probability of transferability is considered about 60%. The system includes 28 electrical distribution buses and 27 branches. The buses supply different electricity consumers including the residential (Res), commercial (Com), and industrial (Ind) customers. Moreover, the system includes six normally close switches in the beginning of branches to isolate the faulty zone. The other specifications of system and problem have been presented in reference [4].

Minimizing the total cost of planning problem by optimal allocation of charging stations in the distribution system, while considering the economic factors such as inflation and interest rates, is the objective function of this study. Fig. 6 shows the results of problem simulation that include the optimal hourly size and location of charging stations in the typical day [4]. As can be seen, charging stations with different sizes are allocated in the specific buses of electric distribution system. Moreover, the size of charging stations needs to change during the day, and even some of charging stations do not accept any PEV in some intervals.

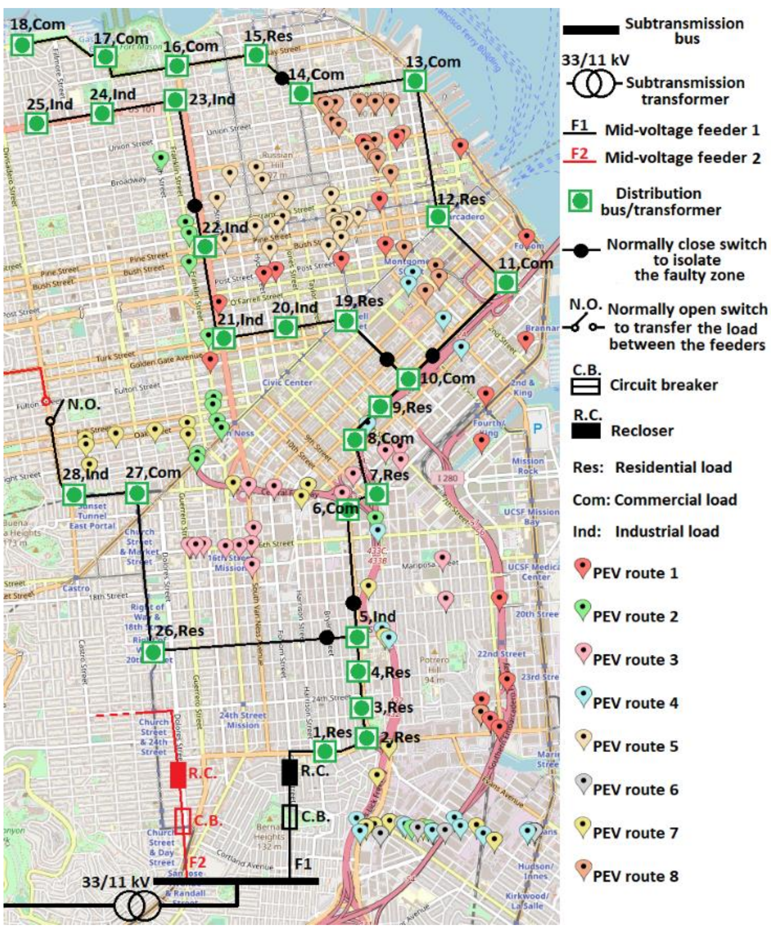

Fig. 5. The single-line diagram of electrical distribution system and the hourly geographical position of PEVs in San Francisco, CA, US [4].

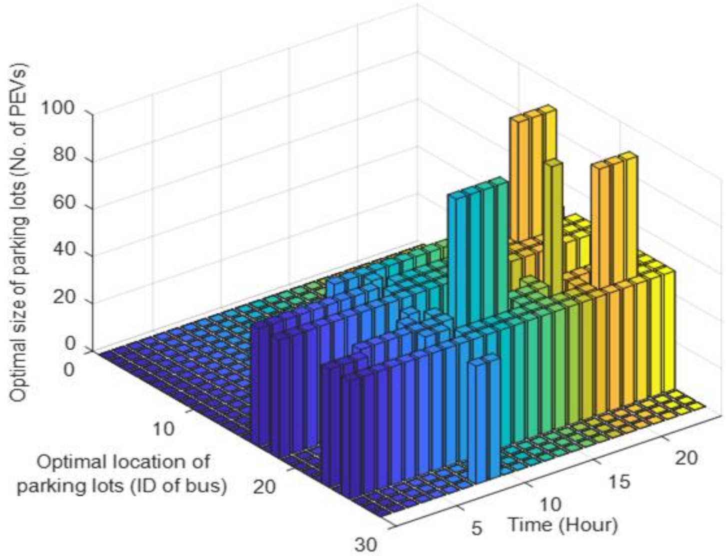

Fig. 6. The optimal hourly size and location of charging stations in the typical day [4].

4. Operation Problems of PEVs in Smart Grid

4.1. Demand-Side Management: Cooperation with an Independent System Operator

Fig. 7 graphically shows different programs of DSM and their performance. In this part of the paper, the effect of implementation of load shifting program on the demand profile of Electric Reliability Council of Texas (ERCOT) is studied. In this program, the PEV drivers are encouraged to transfer part of their charging demand from the peak period to the valley period. This type of DSM has many advantages for the ISO, like ERCOT, as well as generation, transmission, and distribution systems. Herein, the optimal value of incentive (discount on charging fee which is considered for the PEV drivers to participate in the load shifting program) and the maximum value of load factor are investigated for various PEV penetration levels (low, moderate, and high).

All the details of problem have been presented in [5]. Table 1 shows part of the problem simulation results. As can be seen, different values of incentive need to be assigned, where the more PEV penetration, the less incentive. As is noticed, the load factor of ERCOT is raised from about 92% to around 96% by optimal implementation of DSM for PEVs. Fig. 8 illustrates the hourly PEVs demand, loads demand, and total demand profile of ERCOT before and after optimal implementation of DSM for PEVs considering low, moderate, and high PEV penetration levels.

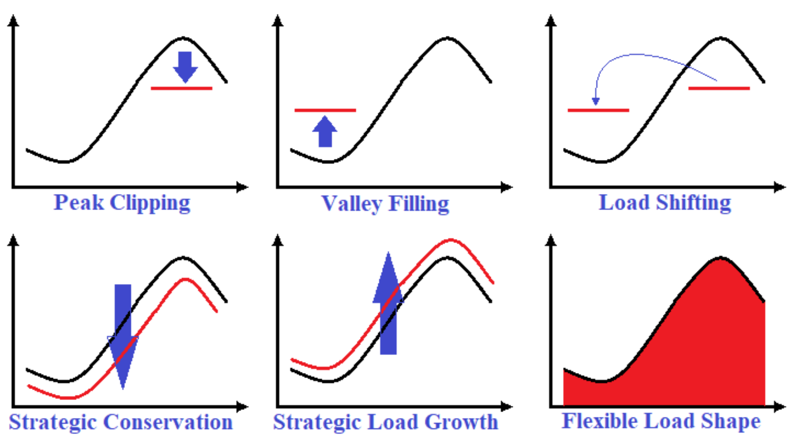

Fig. 7. DSM programs and their performance.

Table 1. Optimal value of incentive and maximum value of load factor before and after optimal implementation of DSM for different PEV penetration levels in ERCOT [5].

Outputs	DSM	Low penetration	Moderate penetration	High penetration
Optimal incentive (%)	Before	0		
	After	70	40	20
Optimal load factor (%)	Before	92.11		
	After	96.57	96.51	96.07

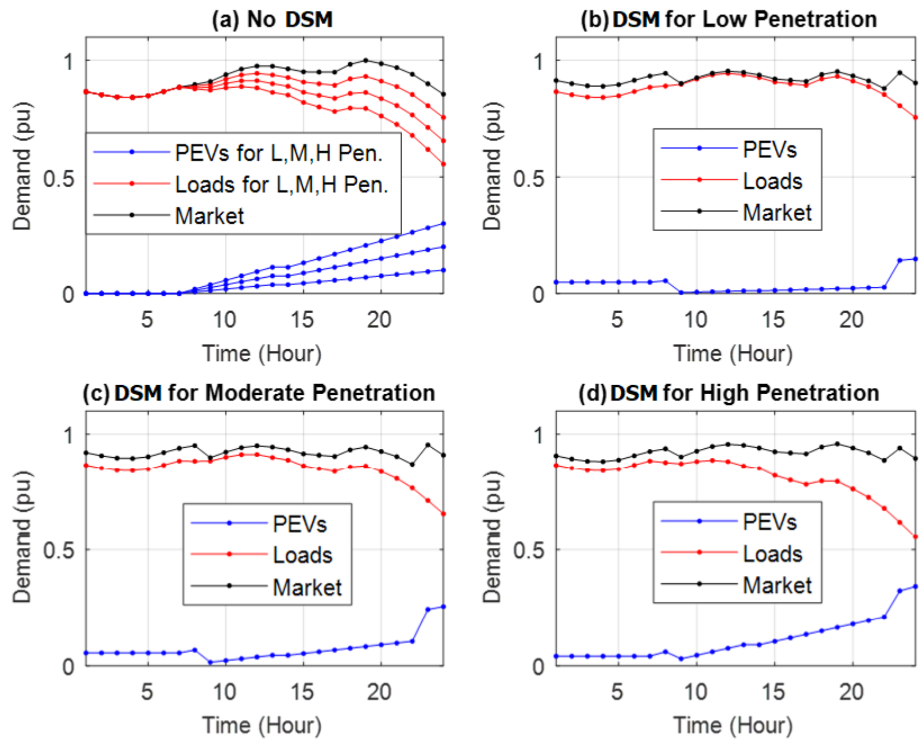

Fig. 8. Hourly demand profile of ERCOT market. (a) Demand profiles before DSM for low (L), moderate (M), and high (H) PEV penetration levels. Demand profiles after optimal DSM (b) for low PEV penetration (with 70% discount as the optimal incentive), (c) for moderate PEV penetration (with 40% discount as the optimal incentive), and (d) for high PEV penetration (with 20% discount as the optimal incentive) [5].

4.2. Minimizing Power Generation Cost: Cooperation with a Generation Company

In this part of study, the PEVs are involved in the generation scheduling and UC problems to minimize the total power generation cost of a GENCO. All the details of the problem and specifications of the generation system have been presented in reference [6]. Table 2 presents part of the problem simulation results. As can be seen, the primary value of minimum total cost of problem is about 0.55050 million $/day; however, after optimal fleet management (FM) of PEVs, it decreases for any PEV penetration level.

Table 3 presents the optimal generation scheduling and commitment of generation units after optimal FM of PEVs considering a high PEV penetration level. The quantities in red color and the highlighted squares indicate the differences in the generation scheduling and commitment of units compared to the problem results without FM of PEVs, respectively. As is noticed, the generation scheduling of units G5-G10 as well as the commitment of units G7-G10 have changed by optimal FM of PEVs. The reasons for these outcomes are that the most expensive and pollutant generation units (G8-G10) have been shut down or their generation level have reduced during the peak period, and the commitment and generation level of the least expensive and least pollutant units (G5-G7) have increased during the off-peak period.

Table 2. Optimal amount of incentive and minimum total cost of problem with/without optimal FM of PEVs considering different PEV penetrations [6].

Outputs	Before FM	After FM		
		Low penetration	Moderate penetration	High penetration
Optimal incentive (%)	0	20	30	10
Incentive cost ($)	0	444	2258	902
UC cost (Million $/day)	0.55050	0.54699	0.54147	0.54250
Minimum total cost (Million $/day)	0.55050	0.54743	0.54373	0.54341
Cost saving ($/day)	-	3062	6766	7089

Table 3. Optimal generation scheduling and commitment of generation units after optimal FM considering a high PEV penetration level [6].

Hour	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
1	200	200	120	100	**100**	**23**	**10**	0	0	0
2	200	200	120	100	**100**	**12**	**10**	0	0	0
3	200	200	120	100	**94**	10	**10**	0	0	0
4	200	200	120	100	**92**	10	**10**	0	0	0
5	200	200	120	100	**98**	10	**10**	0	0	0
6	200	200	120	100	**100**	**24**	**10**	0	0	0
7	200	200	120	100	**100**	**39**	10	0	0	0
8	200	200	120	100	100	**39**	10	**10**	0	0
9	200	200	120	100	100	**20**	10	0	0	0
10	200	200	120	100	100	**42**	10	**0**	0	0
11	200	200	120	100	100	**48**	10	10	**0**	0
12	200	200	120	100	100	**56**	10	10	**0**	0
13	200	200	120	100	100	**53**	10	10	**0**	0
14	200	200	120	100	100	**43**	10	10	**0**	0
15	200	200	120	100	100	**40**	10	**0**	0	0
16	200	200	120	100	100	**36**	10	**0**	0	0
17	200	200	120	100	100	**32**	10	**0**	0	0
18	200	200	120	100	100	**47**	10	10	**0**	**0**
19	200	200	120	100	100	**48**	10	10	10	**0**
20	200	200	120	100	100	**44**	10	10	**0**	**0**
21	200	200	120	100	100	**37**	10	0	**0**	0
22	200	200	120	100	100	**10**	10	0	0	0
23	200	200	120	100	100	**41**	10	10	0	0
24	200	200	120	100	**100**	**14**	**10**	0	0	0

4.3. Minimizing Spinning Reserve Provision Cost: Cooperation with a Generation Company

Herein, the PEVs participate in the spinning reserve provision problem, and compete with the generation units to provide spinning reserve capacity. The details of study can be found in reference [7]. Part of the problem simulation results are presented in Fig. 9 and Table 4.

Figs. 9.a and 9.b show the hourly spinning reserve capacity in the normal condition provided by the generation units and PEVs, before and after optimal FM of PEVs (30% incentive), respectively. Moreover, Fig. 9.c illustrates the hourly amount of difference in the total spinning reserve capacity of system before/after FM. In addition, daily spinning reserve capacity percentage provided by the generation units and PEVs in the normal condition is shown in Fig. 9.d [7]. As can be seen, a considerable daily amount of spinning reserve capacity is granted to the PEVs. Table 4 presents the other simulation results of problem [7]. As can be seen, by optimal FM of PEVs, remarkable cost saving is acquired for each PEV penetration level.

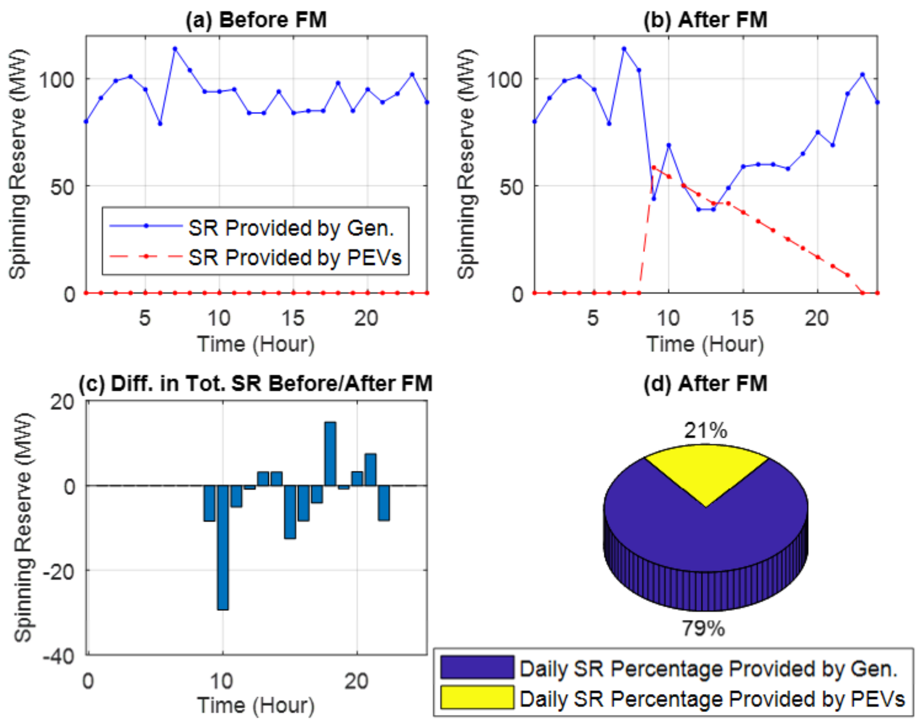

Fig. 9. Optimal hourly spinning reserve (SR) capacity (MW) in the normal condition provided by the generation units and PEVs (a) before and (b) after FM (30% incentive). (c) Value of difference (MW) in the hourly total spinning reserve capacity of system before/after FM. (d) Daily spinning reserve capacity percentage provided by the generation units and PEVs in the normal condition [7].

Table 4. Problem simulation results before and after optimal FM considering different PEV penetration levels [7].

Outputs	Before FM	After optimal FM		
		Low penetration	Moderate penetration	High penetration
Optimal incentive (%)	0	10	30	30
Incentive cost in normal condition ($)	0	169	2121	3535
Incentive cost in contingency ($)	0	2	23	39
Minimum total cost (Million $/day)	0.55050	0.54739	0.54360	0.54019
Cost saving ($/day)	-	3109	6895	10305

4.4. Minimizing Distribution System Operation Cost: Cooperation with a Distribution Company

In this part of paper, the charging/discharging pattern of PEVs is optimally managed to minimize the operation cost of electric distribution system that includes the cost terms of power loss cost, energy-not-supplied (ENS) cost, system reconfiguration cost, FM cost, and energy storage systems' (ESS) operation cost.

Fig. 10 shows the geographic and single-line diagram of electric distribution system that includes one sub-transmission substation, four distribution feeders (DFs 1-4), four initially close switches, three initially open switches, 47 distribution buses, four charging stations (installed on the 2nd bus of 1st feeder, 10th bus of 2nd feeder, 12th bus of 3rd feeder, and 13th bus of 4th feeder), four wind turbines (WT1-WT4), and four ESSs (installed on 12th bus of 3rd feeder, 13th and 15th bus of 4th feeder, and 11th bus of 2nd feeder). The other details of problem and system have been presented in reference [8].

Table 5 presents part of the problem simulation results. As can be seen, there are remarkable reductions in the value of total operation cost, energy loss, and ENS. Fig. 11.a illustrates the optimal amount of incentive proposed to the PEV drivers to let the DISCO charge (G2V) and discharge (V2G) their vehicles based on the optimal pattern. Moreover, Fig. 11.b shows the hourly amount of G2V and V2G powers in each charging station.

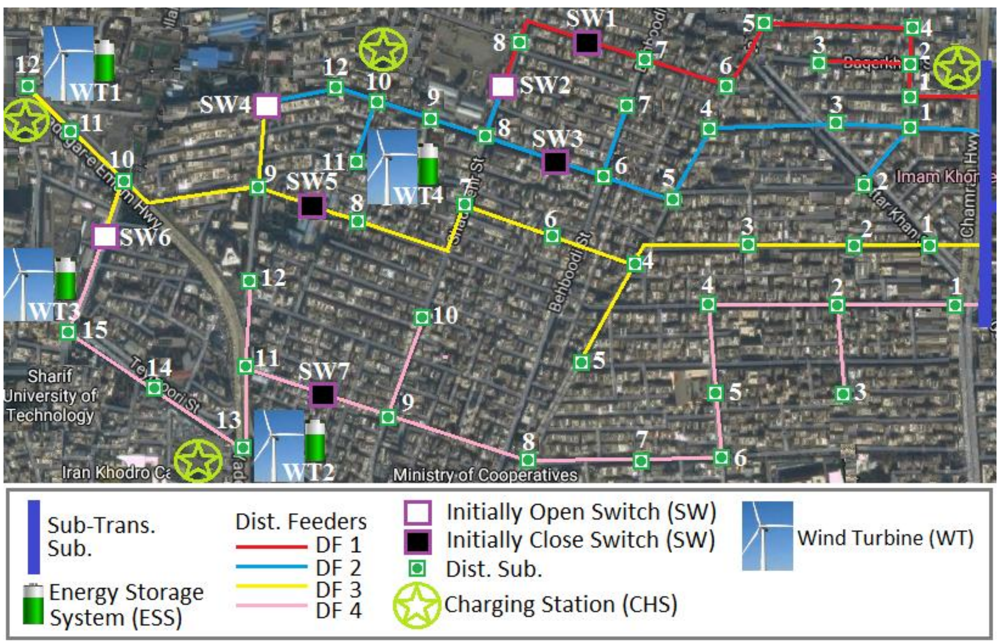

Fig. 10. Geographic and single-line diagram of the electric distribution system [8].

Table 5. Problem simulation results before and after optimal operation of system [8].

	Operation cost ($/day)	Energy loss (MWh/day)	ENS (MWh/day)
Before	18759	367.90	0.3499
After	11806	191.27	0.2932

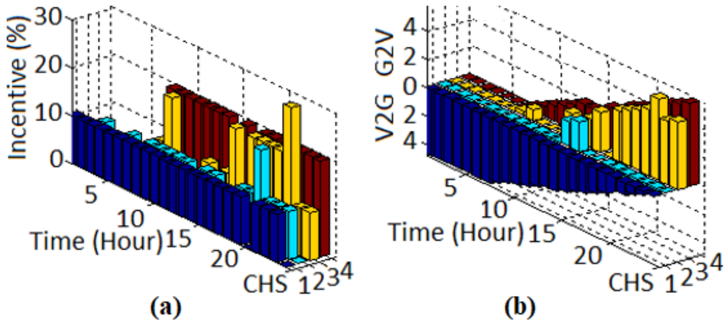

Fig. 11. (a) Optimal amount of incentive proposed to the PEV drivers. (b) Hourly amount of G2V and V2G powers in each charging station [8].

4.5. Participating in Energy Market: Cooperation with an Aggregator

In this section, PEV drivers participate in the energy market by means of an interface which is called aggregator. The aggregator has the role of interacting with both drivers and electricity market operator. All the details of problem can be found in reference [9]. Part of the problem simulation results is presented in Table 6 [9]. As can be seen, the profit of aggregator is raised from $558/day to $794/day, $951/day, and $1051/day for low, moderate, and high PEV penetrations, respectively.

Table 6. The problem simulation results considering different PEV penetration levels [9].

Outputs	Before operation	After optimal operation		
		Low penetration	Moderate penetration	High penetration
Optimal incentive (%)	0	70	40	40
Incentive cost ($)	0	139	136	228
Income ($/day)	558	934	1088	1279
Maximum profit ($/day)	558	794	951	1051
Enhancement ($/day)	-	236	393	492

5. Conclusion

In this paper, the subjects and descriptions of the newly developed 3-credit-hour undergraduate and graduate courses about planning and operation of PEVs (ENT 473 and ENT 573, respectively) at SUNY Buffalo State were presented. It was mentioned that the undergraduate course has been developed to teach the concept and basis of planning and operation problems of PEVs in smart grid. However, the graduate course aims at performing researches, studying, carrying out projects, simulating the problems, and analyzing the results of different planning and operation problems of PEVs in smart grid. Moreover, the problems need to be studied from the viewpoints of ISO, DISCO, GENCO, PEV aggregator, and end-user customer. In addition, “Power System Analysis 1” is a prerequisite course for ENT 573.

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Educational Neural Network Development and Simulation Platform.

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Abstract

An educational software platform has been developed to introduce students to the design and operation of neural networks. The platform consists of a graphical user interface (GUI) written in C# where network parameters can be applied in the construction of the network. Currently, the platform can manage a fully-connected three-layer neural network that recognizes the hand-written digits in the MNIST database and can function as an educational tool to introduce neural network computing concepts. The GUI allows the user to specify the number of neurons in the various network layers, select from 3 different activation functions as well as a number of other network parameters. The weights, biases and layer output values can be modified from double representation to power-of-two integer representation with a specified number of hot-bits. The application capability to read and modify previously trained weights and biases and run the network in inference mode enables quick evaluation of the modifications effect on network accuracy. The functionality to visualize a block diagram of the network as well as the construction of convolutional neural networks (CNNs) to recognize images in the CIFAR-10 database is underway. The platform has been used as development tool to provide weight and bias files to be used as memory initialization files to implement the neural network on reconfigurable hardware (e.g. FPGAs); thus, evaluation of the impact of various weight and bias representations on hardware can be assessed.

1. Introduction

The development of this software platform (program) started as an initial effort to understand the construction of neural networks and provide easy access to network parameters. The online text "Neural Networks and Deep Learning" by Michael Nielsen [1] and associated python code was initially used to run a three-layer fully-connected neural network that learned the weights and biases by using the gradient-descent backpropagation algorithm. Although this is a rather simple neural network architecture, it is an excellent architecture to introduce to students. The architecture is understandable to a freshman engineering student and fully-connected network architectures are often parts of more complex deep-learning networks such as convolutional neural networks.

The neural network python code to recognize the MNIST hand-written digits was run in Spyder through the Anaconda Environment. The python code provided results as expected per the text, however modifications to network parameters and access to the learned weights and biases values were cumbersome. To fully understand both the forward (inference) and backward (learning) propagation technique, as well as gain un-encumbered access to the network parameters, weights and biases, the python code was re-written in C# and with a graphical user interface (GUI). This continues to be work in progress; as different needs are identified the interface and associated code are being added/modified as necessary to support the teaching and research efforts of efficient hardware implementation of the neural network.

2. Educational Aspects

In order to work with the software, students must be introduced to the concept of a network database that contains training and testing data. If the network is a supervised network, this database must also contain associated labels to be used for the training and testing of the network. If students are using pre-existing databases (such as MNIST [2] or CIFAR-10 [3]) or create their own database, the file structure must be understood such that the data is acceptable to their program. The MNIST database of handwritten digits is a good example to introduce to students.

The network architecture is exposed through the network parameters. In this case the architecture consists of 3 layers: Input, Hidden and Output Layers. The training parameters for the network consist of the number of epochs to train on, the mini-batch size (backpropagation update interval) and the learning rate. Students are presented with the concept of a neuron which produces an output based on the matrix product of the neuron inputs with the neuron weights. The product is then offset with a bias value and passed through an activation function to produce the neuron output that is used as the neuron input for the next layer.

An introductory course in Digital Systems typically does not cover the hardware aspects of multiplication and division other than to mention that these operations take many clock cycles to complete. The opportunity to discuss the benefits of performing multiplication by simple left or right shifts and a few partial product summations is provided by representing the weights as powers of 2, with very few hot-bits, a concept proposed by Marchesi, et al. [4], as well as Tang and Kwan [5]. Table 1 shows the results of representing both the weights and biases for the MNIST hand-written digit recognition network with various hot-bits over a decimal range from -4 to 4, note there is little improvement in accuracy after 2 hot-bits. Figure 1 presents an example for students to see the benefit of such a multiplication scheme if compared to the full-fledged 16-bit multiplication process.

Table 1. Neural Network Accuracy vs. hot-bits.

Hot Bits:	1	2	3	4	5	6	7	8
Accuracy:	92.2	95.2	95.4	95.4	95.3	95.4	95.3	95.3
Note: Weights and Biases over range [2^4, -2^4, hb]								

Students are then presented with the implementation of the neural network in VHDL on an FPGA. Figure 2 shows an overview of the network and the details of each neuron.

Example: multiply image pixel value 10 by weight value 2.5
(2 shifts and a partial product addition)

Decimal: 2.5 x 10 = 25			
Hexadecimal A = decimal 10:	0A00:	0000 1010 .0000 0000	
Multiply by 2.0 left shift 1 bit:	1400:	0001 0100 .0000 0000	partial product 1
Multiply by .5 right shift 1 bit:	0500:	0000 0101 .0000 0000	partial product 2
	1900	0001 1001 .0000 0000	addition of partial products

1900: $1 \times 16^1 = 16$
$9 \times 16^0 = 9$
25

Figure 1. Example of multiplying a pixel value by a weight represented with 2 hot bits.

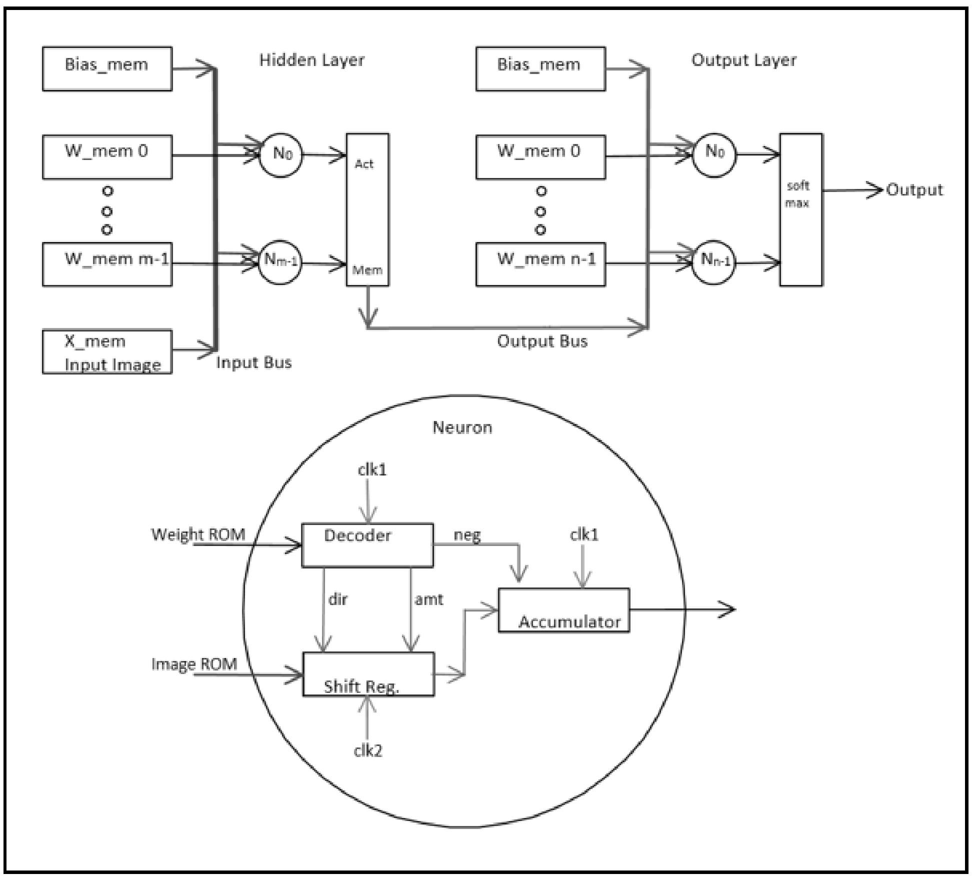

Figure 2. Hardware Implementation of Neural Network.

The neuron consists of only a decoder, a shifter and an accumulator. The shift register is modified based on the type of hot-bit representation that is applied.

The software platform has been demonstrated in a freshman digital systems course at Monroe Community College Rochester, New York to introduce students to the concept of a Neural

Network and a neuron's weights and biases. The platform is shown to produce the weight and bias memory initialization files (*.mif) necessary for VHDL simulation. VHDL coding is then provided which implements the neuron matrix product, accumulation and activation processes to implement the network on Field Programmable Gate Array (FPGA) hardware. Backpropagation is only briefly described to the students as the network training method which updates the weights and biases to improve network accuracy. Backpropagation is presented as a best-fit analogy utilizing an error function and adjusting the weights and biases in the direction that reduces the value of the error (gradient descent). This involves derivatives which freshman engineering students should be familiar with at least in one-dimension.

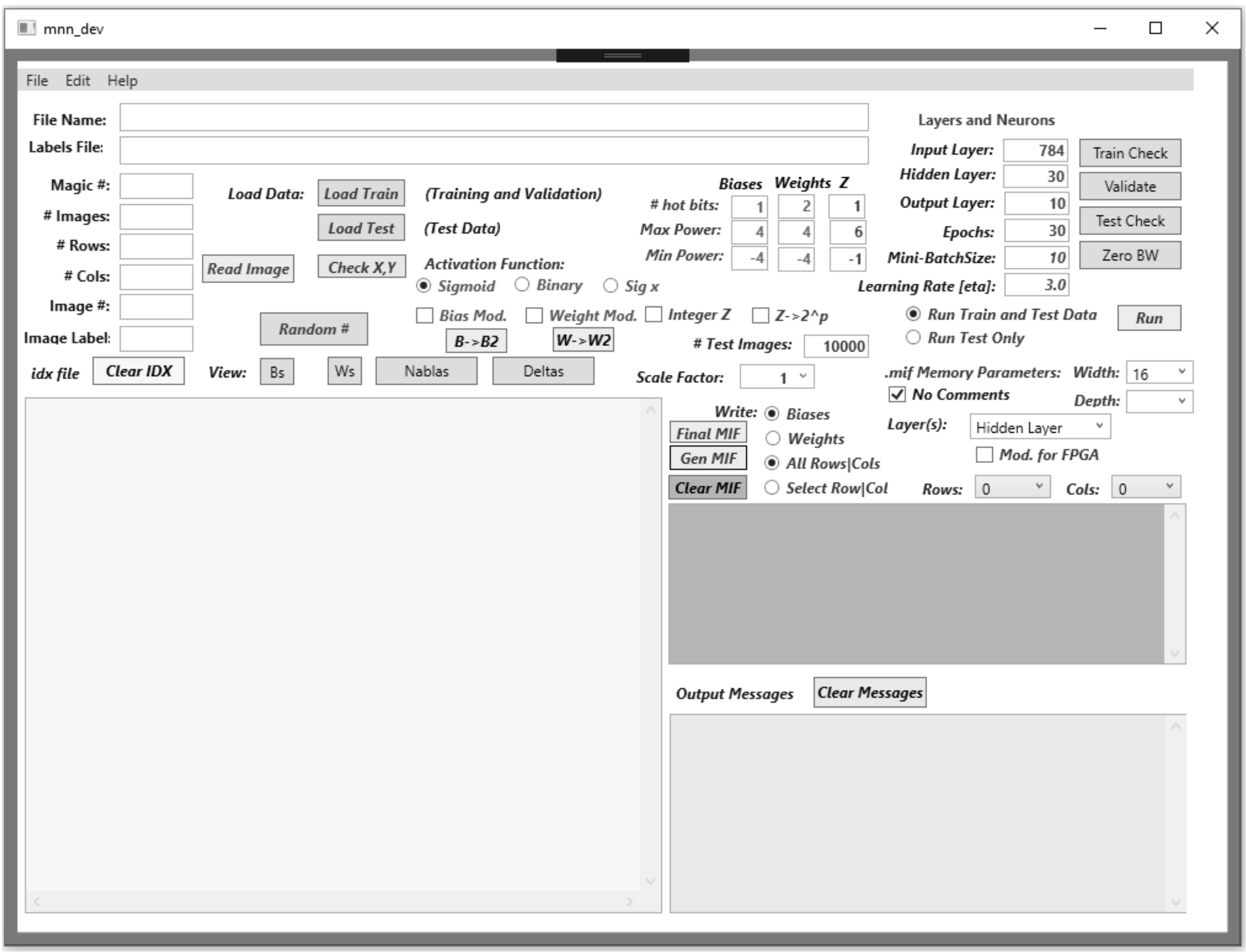

Figure 3. Graphical User Interface of multilayer neural network (mnn) program.

3. Neural Network Program Interface

Figure 3 shows the GUI as it first appears upon running the program. Default values for the MNIST hand-written digit recognition using a three-layer fully-connected neural network populate most of the input textboxes. The user must specify the training and testing data. The GUI contains a number of pushbuttons to perform various tasks such as loading and checking the testing and training data, reading an image, modifying weights and/or biases to powers of 2, and running the network. The three textboxes provide user feedback about the various operations triggered by the pushbuttons. The right-side, mid-section area contains the controls for producing the input *.mif files for FPGA implementation.

4. Network Parameters

The initial platform is based on the three-fully-connected layer neural network that identifies the MNIST hand-written digits. Therefore the input layer consists of a fixed number of input neurons (784) which is the flattened 28 x 28 gray-scale pixel image. The output layer is also fixed at 10 neurons representing the 10 identifiable digit possibilities. The hidden layer neurons can be modified to any sensible value between the input and output layer number of neurons. The original python coded network used 30 hidden layer neurons which is used as the default value in the C# GUI platform. The sensitivity of network accuracy to various network parameters such as the number of hidden layer neurons, learning rate, number of epochs and mini-batch size can thus be analyzed, as will be discussed in sections 7 and 8.

The platform has the capability of displaying any of the training or testing image pixel data and its associated label by simply specifying the image number and selecting the “Read Image” button. The MNIST database uses an *.idx file extension to store vector and arrays in binary format. The lower left textbox labeled *.idx file on the GUI is where the image pixel data is displayed. The “Clear IDX” button should be selected to clear the “idx file” text box prior to reading the image. Figure 4 shows the GUI with training image 452 pixel data displayed. The biases and weights can also be displayed by specifying the layer for the biases or layer as well as the rows (neurons) for the weights. These biases and weights can also be scaled and written into a memory initialization file (*.mif) format for use in hardware implementation. The right mid-section of the GUI contains the controls for this capability.

5. Case Study – Training

The network training and testing files which contain the training and testing data and labels must be opened and read (loaded) into the network. The network parameters can then be modified from the default values to the user desired values, (note that some network parameters cannot be changed due to the network architecture). The default sigmoid activation function can also be changed, as well as restricting the network layer outputs to integer or powers of 2 values. The network will then train for the specified number of epochs and at the specified learning rate and other specified network parameters. The network accuracy is then displayed for each epoch in the “Output Messages” textbox on the GUI. Figure 4 shows the GUI after a network training run with default values. The “Output Messages” textbox shows the network accuracy for each epoch and the time required to train the network. At this point the trained weights and biases could be saved to be used in subsequent inference mode program runs. The weights and biases could also be appropriately scaled and written to memory initialization files for FPGA simulation.

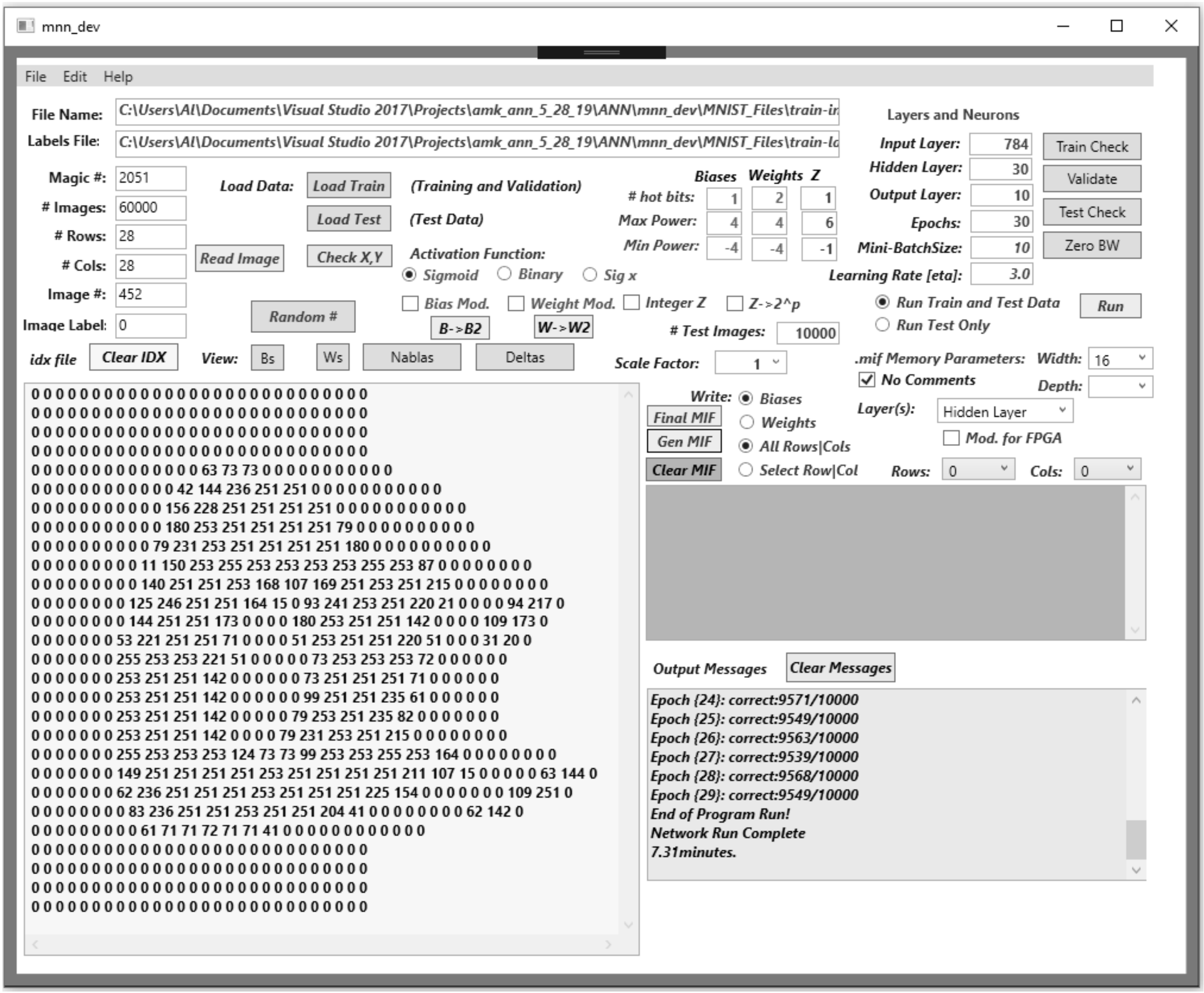

Figure 4. GUI displaying image pixel data as well network training results.

6. Case Study – Inference

If the network is to be used in inference mode only, the previously learned weights and biases from network training must be loaded into the network. The "Output Messages" textbox provides user feedback that the appropriate steps have been taken. The testing files must also be opened and loaded into the network. Some network parameters such as the number of hidden layer neurons cannot be changed as they are now dependent on the previously saved weights and biases. The weights and biases can now be modified to various ranges and combinations of hot-bits for analysis. The "Run Test Only" radio button should be selected for an inference only run mode. Figure 5 shows the network output after an inference only run.

7. Case Study – Learning Rate Sensitivity

Figure 6 is a plot of the network accuracy versus the learning rate. The learning rate was varied from 1 to 12. The three curves represent either the epoch 30 value, the maximum value over the 30 training epochs or the average value of the 30 epoch training values respectively. This plot is a good indicator of why the default learning rate value is set to 3.

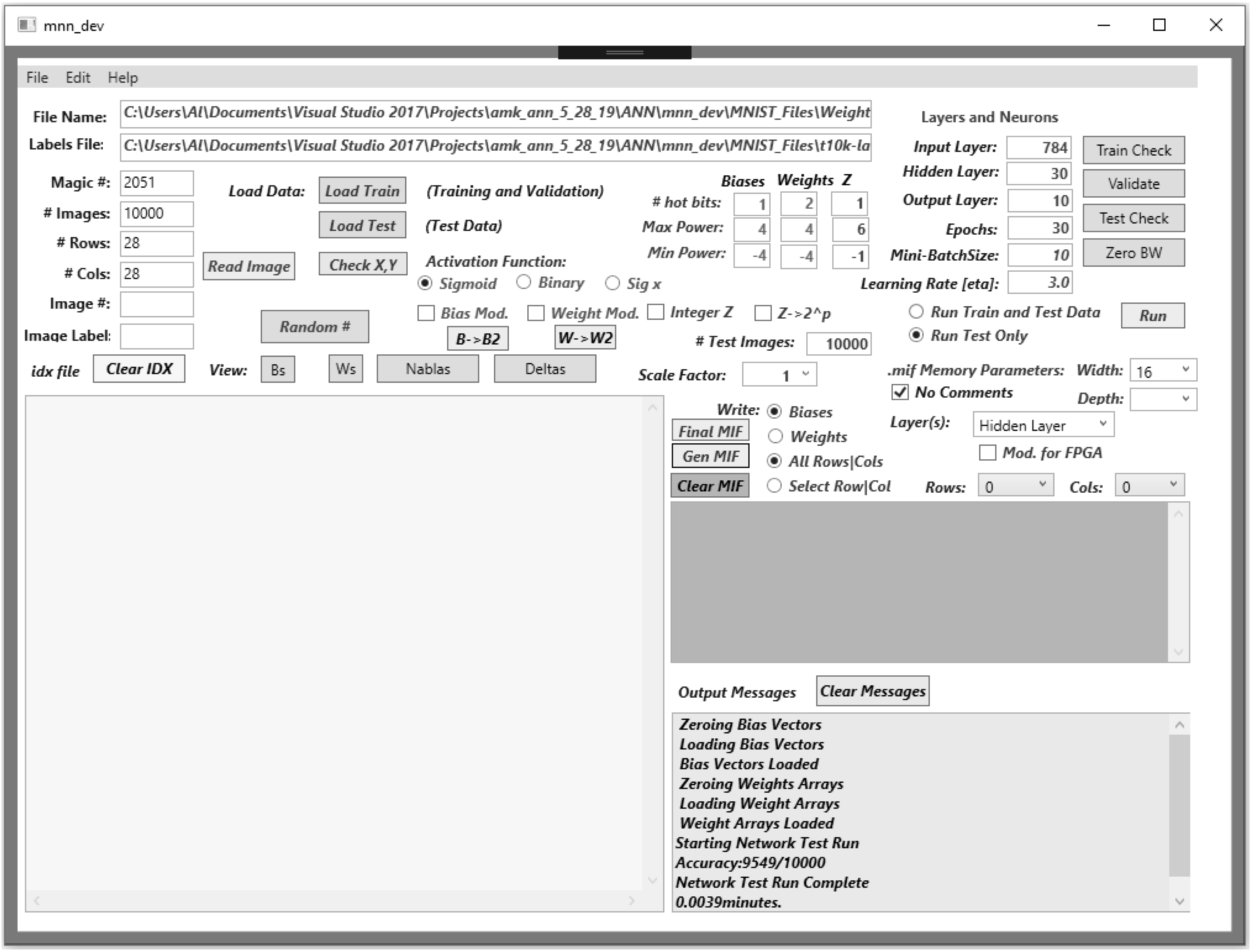

Figure 5. GUI after and inference only program run.

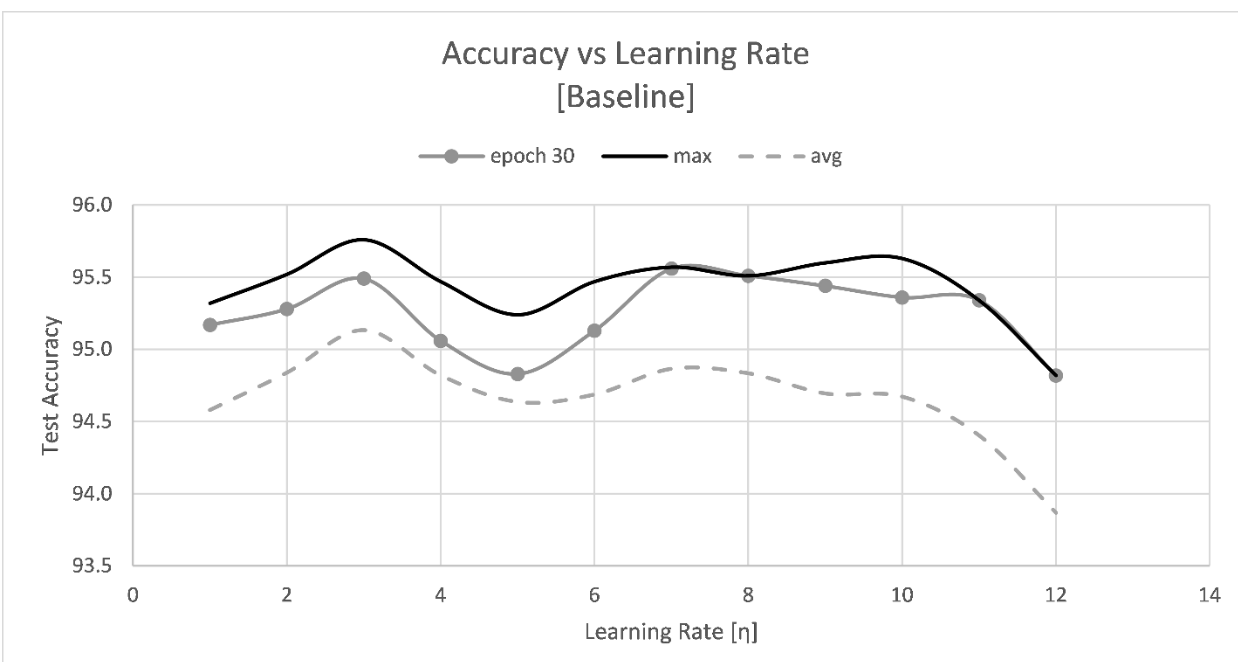

Figure 6. Network Accuracy vs. Learning Rate.

8. Case Study – Hidden Layer Neurons Sensitivity

Figure 7 is a plot of the network accuracy versus the number of hidden layer neurons. The number of neurons varied from 10 to 100. The 3 curves represent either the epoch 30 value, the maximum value over the 30 training epochs or the average value of the 30 epoch training values respectively. This plot shows the trade-off between network accuracy and the network size (hidden layer neurons), moving from 30 to 100 neurons changes accuracy by only 1.5%.

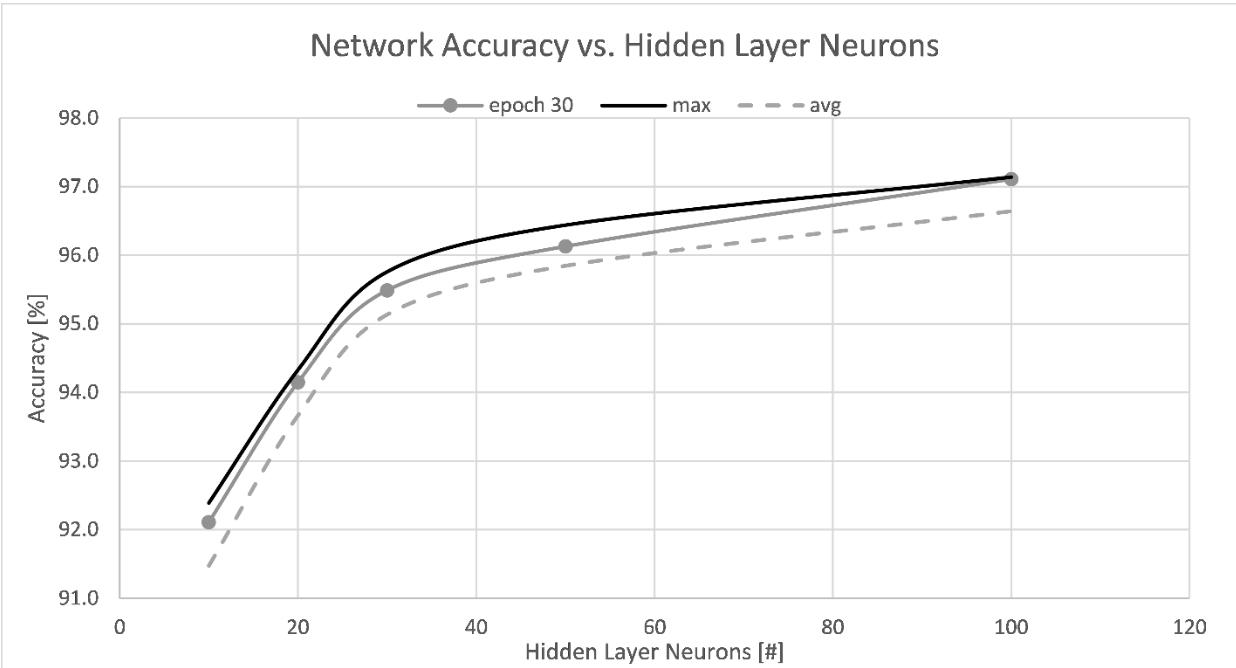

Figure 7. Network Accuracy vs. Number of Hidden Layer Neurons.

9. Future Work

To enhance the usability of the platform certain tasks will be automated. For instance, instead of running the network once for each different learning rate or each different number of hidden layer neurons, the program will accept a range of values and run the analysis followed by tabular and graphical output options.

Loading additional databases such as the MNIST character database or the CIFAR-10 database is also on the list of future improvements as well as capability to construct convolutional or other neural networks along with the visualization of the network block diagram.

The next version of the platform will implement the above additions and also start from a clean GUI. The current GUI although versatile, is somewhat cluttered due to the fact that various components were added as required by research needs. A new fresh approach using multiple forms/tabs such as one for the block diagram view, the main form and subsequent output forms will provide a richer student experience.

10. Conclusion

The Neural Network development platform discussed in this paper has proven to be a useful teaching and research tool. As a teaching tool, it can be used in a freshman digital systems course in a two-year engineering science program to introduce students to neural networks, which provides motivation to the students as FPGA hardware and HDL language concepts are explored. As a research tool, the program can be used to investigate the relationship between network parameters and network accuracy, and provide input files for use in FPGA hardware simulation and hardware implementation.

Acknowledgement

This work was supported in part by the tuition assistance programs at Monroe Community College and Rochester Institute of Technology.

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Carbon Footprint of Alternative Wood Product Retirement Strategies

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Abstract: Like many undergraduate and graduate engineering programs, the Master of Engineering (MEng) program in Sustainable Engineering at the Rochester Institute of Technology (RIT) concludes when students have completed a capstone project. As currently implemented capstone projects can be individual or group projects. Students engaged in capstone typically investigate specific problems for both on and off-campus clients. Projects are overseen by a faculty member and project deliverables typically include a formal project writeup as well as a summary presentation to the faculty supervisor and the clients. This article describes the findings of a two semester capstone project that was commissioned to investigate the environmental consequences that arise from several alternative wood product end of life retirement strategies. Results suggest that for wood products and other similar items (those fabricated from high carbon content, biodegradable materials) recycling and combustion strategies at end of life may ultimately generate more greenhouse gas emissions than a landfill strategy.

Introduction

The Sustainable Engineering graduate program at the Rochester Institute of Technology, is offered in two modes. Students enrolled in the Master of Science in Sustainable Engineering (MSSE) must complete a traditional, independent research thesis and defend it before their research committee in order to graduate. The expectation is that the research thesis makes a unique contribution to the Sustainable Engineering body of knowledge. The MSSE program is designed to appeal to students who desire a true research experience and wish to cultivate their research skills. Students enrolled in the Master of Engineering in Sustainable Engineering (MESE) must complete an applied "capstone project" in order to graduate. Students can engage capstone projects as part of a team, or they can work individually to fulfil the requirement. Usually, students working on a capstone project investigate and attempt to resolve a specific applied problem for a client. The MESE program is designed to serve students who are more applications oriented, or who aren't comfortable with the uncertainties of research.

The MESE capstone is meant to serve as a summary experience, and there is the expectation that students utilize concepts and tools that were acquired through the Sustainable Engineering curriculum. The projects are developed and overseen by a faculty capstone coordinator. The capstone coordinator cultivates and develops projects in concert with potential clients. Project clients can be internal, on campus individuals/organizations as well as external, off campus entities such as governmental organizations, charities, and private sector concerns.

This report describes the findings from an atypical capstone project. The work reported here emerges from a capstone project where the student partnered with a faculty client to explore an open ended research question, rather than engage in a more routine applied project with specified deliverables. This approach represents something of a halfway point between the research focused MSSE degree program and the traditional applications oriented MESE program.

This project was undertaken to study the environmental impact (specifically the greenhouse gas emissions) associated with the end of life disposition of wood products. The analysis offered here combines findings from the literature describing the carbon content of wood species and literature evaluating greenhouse gas emissions arising from aerobic and anaerobic decomposition of wood.

The paper is organized as follows:

The initial section will describe a general product life cycle model and overview the ways in which products are likely to move through their life cycle stages. The next section will describe the domain of wood products and why they are of particular interest here. An analysis section will follow describing the carbon footprint calculations for the emissions that arise from the ultimate wood disposition strategies considered here. A discussion/conclusions section will summarize the findings and a final notes section will offer impressions on this atypical capstone approach.

A general product life cycle model

Figure 1 depicts a general product life cycle model.

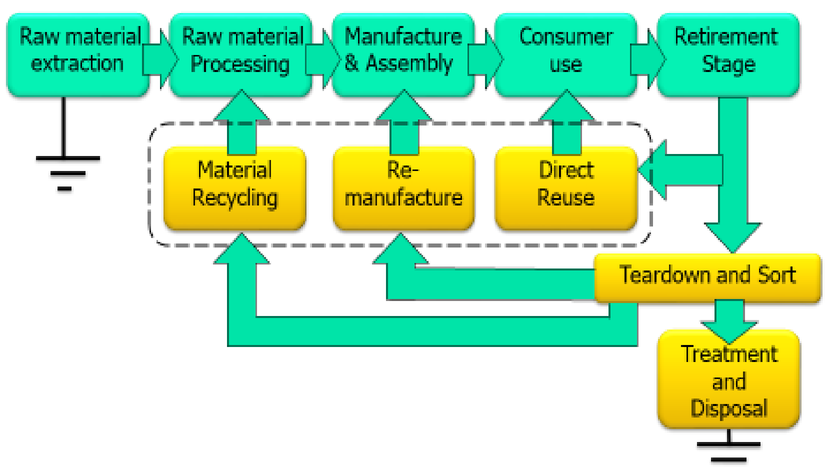

Figure 1. General Model of the Product Life Cycle

Raw Material Extraction: Most products are fabricated from a variety of materials, and those materials must be extracted from a fundamental source. Metals are refined from ores extracted from the earth. Plastics are created by refining petroleum and gas products extracted from underground. The raw materials for wood products are harvested from forests. These extraction operations can generate a variety of environmental impacts including local land transformation and degradation, water contamination, and greenhouse gas and other air emissions.

Raw Material Processing: Once the raw materials are available, they must be transported to processing centers where they can be transformed into the intermediate materials that are suitable for manufacturing purposes. Iron ore is transformed into steel products (sheets, beams, etc.), petroleum is refined into various plastics (polypropylene, vinyl, etc.), and logs are converted into a variety of intermediate wood materials (dimensional lumber, plywood, etc.). These raw material processing operations rely on energy and material inputs and generate their own environmental impacts.

Manufacture and Assembly: Intermediate materials must be transported to facilities where they will be combined with other materials to produce finished products. Again, manufacturing and assembly operations rely on a range of energy and material inputs, and they may generate environmental impacts of concern.

Consumer Use: Once a product has been generated, it moves through a supply chain and eventually ends up in the hands of a consumer. While in use by a consumer, a product may consume resources and/or generate environmental impacts of its own (i.e. a lawn mower consumes gasoline and generates greenhouse gas emissions). Eventually, the consumer will likely retire the product. The product might be retired for a range of reasons, including:

- the product is no longer needed
- the product is obsolete
- the product is no longer functional

Retirement: Depending on the design of the product, the context within which the product was designed, developed and sold, and the reason for the product's retirement, several options may be available for dealing with the product when the consumer chooses to dispose of it. These include:

- direct reuse: a product is transferred, essentially as is, to another consumer (as would happen with a used automobile that is "traded in" to purchase a new vehicle)
- remanufacture: a product is transferred to a facility where it may be taken apart, inspected, refurbished, and returned to service (as happens with many automotive components like alternators, and constant velocity joints)
- material recycling: the form of the product is destroyed and the materials are recovered (as occurs with waste cardboard boxes or aluminum beverage containers)
- treatment and ultimate disposal: if none of the previous disposition options are available, appropriate treatment and disposal procedures should be used for ultimate disposition. These methods can include remediation and release of gaseous or liquid wastes, biodegradation, and incineration and/or landfill of solid waste.

The Reuse, Remanufacture, and Recycling end of life strategies may prolong a product's useful life or extend the useful life of the materials from which a product is constructed. However, virtually all products will eventually be relegated to ultimate disposal. Likewise, material recycling methods tend to degrade materials at each iteration (a process known as "downcycling"). Eventually, recycled materials will no longer have required properties and will require ultimate disposition.

Characteristics of Wood Products

Wood products are ubiquitous. Wood is used to fabricate durable items (timber framing, dimensional lumber, furniture, flooring, etc.) as well as products with very short useful lives (paper goods, pencils, paint stirrers, one way pallets, etc.). Wood has many features that make it a useful raw material. Wood is widely available and relatively inexpensive. It exhibits good compressive and tensile characteristics. Wood is attractive and, in appropriate applications, it is highly durable. Wood also offers characteristics that are advantageous from a sustainability perspective. It is a natural product, and, when harvested appropriately, it is a renewable resource. It can be shaped and transformed using processes that are environmentally benign (cutting, turning, nailing, screwing, etc.), and in use it generates few if any harmful emissions.

Wood products follow essentially the same general product lifecycle described in Figure 1. Raw materials are harvested from the earth, the raw materials are processed into intermediate materials suitable for manufacture, those intermediate materials are transformed into products, those products are used by consumers, and eventually the products are retired. Environmental impacts including the generation of greenhouse gases may arise during all wood product life cycle stages. Importantly, even though the reuse, remanufacture, and recycle options may be available at the time of retirement, eventually wood products will require ultimate disposition.

Ultimate disposition of wood products may take several forms:

- the product may be left to biodegrade aerobically either in its original form or following transformation (landscaping mulch, animal bedding, etc.)
- the product may be incinerated, with or without energy recovery
- the product may be deposited into a landfill where it will degrade aerobically and anaerobically

This project focuses on the greenhouse gas emissions that arise during the ultimate disposition of wooden materials. The intent is to quantify the CO_2 equivalent emissions (CO_2 eq) that arise from the ultimate disposal of a fixed amount of wood. Specifically, we determine the CO_2 eq emissions associated with the ultimate disposal of 10 kilograms of wood via each of four ultimate disposition strategies:

- complete aerobic biodegradation
- incineration without energy recovery
- mixed aerobic and anaerobic biodegradation as would occur in a modern landfill
- incineration with energy recovery

Analysis

Carbon content of wood: Greenhouse gas emissions arising during the ultimate disposal of wood material obviously depend on the carbon content of the wood itself. The carbon content of wood varies from biome to biome, across species, and within species. Kim and Song [1] utilize the assumption that most woods contain about 50% carbon. Thomas and Martin [2] surveyed 31 published studies that reported 253 species-specific carbon content entries. Findings from these studies include:

- the maximum observed carbon content was 60.7%
- the minimum observed carbon content was 41.9%
- across biomes the mean carbon content for conifers (softwoods) was 50.8%
- across biomes the mean carbon content for angiosperms (hardwoods) was 47.7%

Here, in order to describe emissions from softwoods and hardwoods we consider the ultimate retirement CO_2 eq emissions from wood assuming carbon contents of 45%, 50%, and 55%.

CO_2 eq emissions under complete aerobic decomposition and incineration without energy recovery: Complete aerobic decomposition of wood and complete incineration of wood (without energy recovery) will result in the same greenhouse gas emissions. Under these two retirement strategies each of the carbon atoms in the retired wood will be pair with two oxygen atoms and be transformed into CO_2. Carbon has an atomic weight of 12, while a molecule of CO_2 has an atomic weight of 44. Therefore, each unit of carbon present in the wood will be converted to 44/12 = 3.67 units of CO_2 . CO_2 emissions corresponding to the disposal of 10 kg of wood for the 3 carbon concentration cases are shown in Table 1.

Table 1. CO_2 emissions from 10 kg of wood under aerobic decomposition or incineration without energy recovery

	Carbon Content of Wood		
	45%	50%	55%
CO_2 eq (kg)	16.50	18.33	20.17

To illustrate the calculations, consider the 55% carbon content case. Under this condition, 10 kg of wood will contain 5.5 kg of carbon. If all of the carbon in the wood is returned to the atmosphere by aerobic decomposition or incineration, 5.5 x 3.67 = 20.17 kg of CO_2 emissions will be generated.

CO_2 eq emissions under aerobic and anaerobic decomposition (landfill scenario): and incineration without energy recovery: When organic material such as wood is deposited in a modern landfill, it may undergo both aerobic and anaerobic decomposition. Both modes of decomposition generate greenhouse gases. As noted earlier, aerobic decay produces CO_2 . However, anaerobic decomposition results in the production of methane (CH_4), a greenhouse gas 21 times more potent than carbon dioxide [3].

There has been limited work on the degradation of wood in landfills [4][5][6]. For the work conducted here, two characteristics of wood degradation in landfills are of major interest: the fraction of the carbon in wood that decomposes under landfill conditions, and the relative amounts of CO_2 and CH_4 that are generated as wood decays anaerobically.

Micales and Skog [7] report that 0% – 3% of the carbon from wood is released into the atmosphere as CO_2 and CH_4 once the material has been landfilled. Wang et al [4] observed the decomposition of 4 wood species in laboratory scale landfills, and reported carbon conversion rates of 0.0%, .1%, 1.8%, and 7.8% for eucalyptus, radiata pine, spruce, and red oak, respectively. For this study we will examine cases with carbon conversion rates of 1%, 3%, 5%, and 7%. Micales and Skog [7] suggest that landfill gas is emitted as 60% CH_4 and 40% CO_2. However, Wang et al [4] assume that landfill decomposition generates one mole of CO_2 for every mole of CH_4. The calculations here invoke this same assumption.

Based on the assumptions outlined above, the greenhouse gas emissions for landfilled wood can be calculated for several decomposition cases. Table 2 summarizes the greenhouse gas emissions from landfilled wood with varying carbon content at several decomposition fractions.

Table 2. CO_2 eq emissions from 10 kg of wood, landfill decomposition

	Carbon decomposition			
	1%	3%	5%	7%
45% carbon content (kg CO_2 eq)	0.712	2.137	3.562	4.987
50% carbon content (kg CO_2 eq)	0.792	2.375	3.958	5.542
55% carbon content (kg CO_2 eq)	0.871	2.612	4.354	6.096

To illustrate the calculations, consider the case of wood with 55% carbon content in a landfill where 5% of the carbon content of the wood will degrade. 10 kg of such wood will contain 5.5 kg of carbon. Of that carbon, only 5%, or .275 kg, will degrade under landfill conditions. Half of the .275 kg of carbon (.1375 kg) will transform into .5042 kg of CO_2. The remaining carbon will become .1833 kg of CH_4. The greenhouse gas potential of .5042 kg of CO_2 is .504 kg CO_2 eq. The greenhouse gas potential of .1833 kg of CH_4 is .183 x 21, or 3.850 kg CO_2 eq. Total greenhouse gas emissions for this scenario are 4.354 kg CO_2 eq.

Note that the greenhouse gas emissions from landfilled wood are much lower than those from aerobic decomposition or incineration, even when a very high (7%) landfill decomposition fraction is assumed. For instance, for wood with 55% carbon content, the emissions arising under the worst greenhouse gas scenario considered in Table 2 (7% decomposition fraction) are 30% of those arising from aerobic decomposition or incineration as shown in Table 1 (6.096 kg CO_2 eq vs 20.17 kg CO_2 eq). Even though the aerobic decomposition that occurs in landfills generates CH_4, a much more potent greenhouse gas than CO_2, the fraction of carbon that is converted into CH_4 and CO_2 in the landfill is so small that the overall greenhouse gas potential from landfill emissions is reduced dramatically from that observed under aerobic decomposition or incineration.

<u>CO_2 eq emissions under incineration with energy recovery:</u> Incineration of wood products at the time of ultimate disposal emits greenhouse gases but also generates useful heat energy. If the wood is landfilled, very little, if any heat energy will be recovered (for our purposes, we are ignoring the small amount of heat energy that might be harvested from a landfill that is designed to capture, clean and combust anaerobically produced methane). Clearly, the strategy to landfill wood at ultimate retirement generates fewer greenhouse gas emissions than incineration. However, to fairly compare the emissions from a landfill disposal scenario to those from an incineration strategy, we must expand the landfill scenario to include heat generation capability equivalent to that of the wood incineration system.

When combusted, 10 kg of wood with 50% carbon content will produce 18.33 kg of CO_2 eq emissions (Table 1) and recoverable heat energy. Table 3 provides low and high heating values for the combustion of hardwoods and softwoods [8]. Our calculations will use the average of the two values.

Table 3. Heating values for hardwoods and softwoods

	Low heat value (MJ/kg)	High heat value (MJ/kg)	Average heat value (MJ/kg)	Heat from 10 kg wood (MJ)
Hardwood heat content	19.80	21.30	20.55	205.5
Softwood heat content	20.70	22.10	21.40	214.0

The last column in Table 3 describes the heat energy that is generated when 10 kg of hardwood or softwood is incinerated.

The heat recovered from incineration of wood is likely used to replace or offset heat that would be provided by fossil fuels in furnaces, boilers, kilns, etc. A fair comparison of the incineration and heat recovery retirement practice to landfilling requires that we expand the landfilling strategy to include generation of heat from fossil fuels.

Table 4 lists emissions associated with combustion of commonly used fossil fuels [9]. In addition, the table provides the greenhouse gas emissions that would result from combustion of amount of each listed fuel that would provide the energy equivalent to the incineration of 10 kg of softwood (214.0 MJ) and 10 kg of hardwood (205.5 MJ). These emissions should be added to those associated with landfilling in order to fairly compare the overall emissions from incineration (with heat recovery) and landfilling (with heat generation).

Table 5 summarizes the emissions generated when softwood is landfilled (50% carbon content is assumed) and heat energy is created by combustion of various fossil fuels. Table 6 provides the same information for landfilled hardwood.

Table 4. CO2 Emissions values from fossil fuel combustion

	CO_2 emissions ($kg\ CO_2/MJ$)	Emissions equivalent to 10 kg softwood combustion ($kg\ CO_2$ eq)	Emissions equivalent to 10 kg hardwood combustion ($kg\ CO_2$ eq)
anthracite	0.0983	21.036	20.201
diesel	0.0693	14.830	14.241
gasoline (non-ethanol	0.0676	14.466	13.892
propane	0.0589	12.605	12.104
natural gas	0.0503	10.764	10.337

Table 5. CO_2 eq emissions from landfill of 10 kg softwood plus equivalent heat generation from fossil fuels (bold entries represent CO_2 eq emissions below those observed with the incineration disposition strategy.

	Carbon decomposition fraction			
	1%	3%	5%	7%
	Values are $kg\ CO_2$ eq			
anthracite	21.828	23.411	24.994	26.578
diesel	**15.622**	**17.205**	18.788	20.372
gasoline (non ethanol)	**15.258**	**16.841**	18.424	20.008
propane	**13.397**	**14.980**	**16.563**	**18.147**
natural gas	**11.556**	**13.139**	**14.722**	**16.306**

Table 6. CO_2 eq emissions from landfill of 10 kg hardwood plus equivalent heat generation from fossil fuels (bold entries represent CO_2 eq emissions below those observed with the incineration disposition strategy)

	Carbon decomposition fraction			
	1%	3%	5%	7%
	Values are $kg\ CO_2$ eq			
anthracite	20.993	22.576	24.159	25.743
diesel	**15.033**	**16.616**	**18.199**	19.783
gasoline (non ethanol)	**14.684**	**16.267**	**17.850**	19.434
propane	**12.896**	**14.479**	**16.062**	**17.646**
natural gas	**11.129**	**12.712**	**14.295**	**15.879**

Conclusions/Discussion

Recall (Table 1) that direct incineration of 10 kg of wood with 50% carbon content will generate 18.33 kg CO_2 eq emissions. Also, recall that combustion of 10 kg of wood will generate recoverable heat energy, about 205.5 MJ for hardwood combustion and 214 MJ for softwoods. Tables 5 and 6 describe the emissions that would be observed if the ultimate disposition strategy were to landfill the 10 kg of wood and replace the heat generated from wood combustion with heat generated from fossil fuel combustion. The bold entries in Tables 5 and 6 occur where the landfill/fossil fuel disposition approach generates fewer greenhouse gas emissions than the direct incineration/heat recovery option.

That the overwhelming number of cases considered (26 out of 40) favor landfilling and fossil fuel heat generation over the direct incineration approach is striking. Cases where the incineration option is favored are those where the fraction of landfill carbon degraded is high, the replacement fossil fuel generates a large amount of greenhouse gas, or a combination of these two scenarios. Where landfill carbon degradation occurs at low levels and "clean" fossil fuels are available, the landfill/fossil fuel approach exhibits lower total emissions. 18 of the 40 landfill/ fossil fuel cases examined offer emissions more than 10% below emissions from the incineration case. 8 of the 40 cases report landfill/fossil fuel emissions more than 20% below the emissions reported for the incineration approach.

These results suggest that combustion of wood waste for energy recovery may not be an environmentally responsible disposal strategy when properly designed landfills or low carbon fossil fuels are available. It may be more appropriate, from a greenhouse gas perspective, to retire wood materials to landfill rather than to combust them. Available research suggests that very little (less than 10%) of the carbon in wood is transformed into greenhouse gases under landfill conditions. Perhaps the disposition of wood material in landfills represents a potentially useful carbon sequestration approach. After all, during their growth phase trees extract carbon directly from the atmosphere. Depositing wood material underground at end of life where it may be sequestered indefinitely could be helpful in reducing the level of atmospheric greenhouse gases.

We must emphasize that this preliminary analysis is manifestly incomplete. Simplifying assumptions have been invoked and important concerns have been omitted. For instance, modern landfill designs include technologies to accelerate decomposition and harvest the methane generated from anaerobic decay. The ability to capture methane generated from landfill might help tip the scales of this analysis even further in favor of the landfill/fossil fuel retirement approach. On the other hand, this analysis has omitted the carbon overhead required to make fossil fuels available for combustion. It takes energy to extract, refine, and transport fossil fuels. The analysis here has considered only the heating value of the end product fossil fuels. It has not considered the greenhouse gas implications of making those fuels available. Future work will take up some of these assumptions and omissions.

Final pedagogical notes

Much of the work for this project was carried out as an atypical, open ended capstone project in fulfillment of the requirements for the Master of Engineering in Sustainable Engineering. At the conclusion of the research, the capstone student drafted a summary paper [10] and evaluated the project from a pedagogical point of view. The results are of course anecdotal, but of interest nonetheless. The student who conducted much of the research cited 3 aspects of this project that resonated most deeply with him.

The nature of the research problem: The capstone project was offered to the student as an independent applied research problem: "What happens to solid wood at the end of its useful life, and what are the greenhouse gas implications?" Research on open ended problems can be uncertain, time consuming, even frustrating. However, the student accepted these challenges and believed that real advantages accrued from working on this type of project.

- "These types of open ended projects allow the student to form their own ideas and approach towards a solution rather than following a previously outlined sequence of steps"
- "These benefits include students being able to identify their inspiration or passion by having more freedom compared to alternative projects."
- "This open ended project inspired the student to take a detailed look at many different products and left the student with an enlightened outlook on how the products human use every day can impact the environment. Even though the project was "finished" in terms of the semester, the student gained a holistic understanding of a new educational topic."

The opportunity for the student to become the teacher: In the course of performing the research work for this project the student faced numerous occasions where he had to explain topics, methods and results to the capstone advisor. This seems to have promoted a deeper understanding of the material than might have occurred in a more traditional project.

- The approach to this project allowed "the student to become the expert and educate others".
- "In the case of this project, the student had no prior knowledge on wood varieties or the retirement scenarios associated and allowed the student to adapt and investigate the different topics that interested the student."
- "… this freedom allows for independent growth of their own knowledge on a subject at their own pace and then consult their professor."
- "This approach has proven to allow for an open free-thinking mindset that could ultimately generate conclusions that differ from the middle of the road common thinking."
- "There is value in allowing the student to think and learn for themselves."

The freedom to not worry about grading: This capstone project was set up as a contract. Once final deliverables had been completed satisfactorily, an agreed upon grade would be issued. This student seemed to respond very favorably and very much appreciate this minor alteration to traditional grading practices:

- "… when certain sources of stress are removed from the classroom the student is allowed to fearlessly excel and think differently from what the professor intended."
- "Rather than the student's mind being consumed with due dates or fear of not getting that "A+" the student can spend that brain power on a new innovative approach to a problem."

The student closed his observations with a final note on the value of open ended inquiry:

- "Rather than telling a student what or how to think, it is the educator's duty to provide the students with the tools to do the thinking and learning on their own. This is where the true value in engineering education ultimately lies."

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Application of Risk Management Principles to Assess Unmanned Aerial Vehicle (UAV) Routing Options and Other Hazards for Commercial Delivery in Urban Areas

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Abstract

The FAA currently restricts the operation of small Unmanned Aerial Vehicles (sUAVs) by requiring the UAV (drone) pilot to maintain visual contact with the UAV, that is, restricting operations to line-of-sight control. This limits the operation of UAVs to a very short distance, which is not conducive to commercial deliveries, especially in an urban setting with numerous tall buildings. However, some commercial operators have already demonstrated completely autonomous UAV operations, although in rural settings. This paper proposes the application of risk management techniques to assess the feasibility and safety of progressing to an interim phase of semi-autonomous UAV operations in an urban setting, which could serve as a blueprint for progressing towards commercial package deliveries. The author identified two major problems preventing the approval of UAV operations beyond line-of-sight: the hazard to personnel on the ground if a UAV goes down, and the related concern of controlling UAV traffic to avoid inflight collisions as the numbers of UAVs increase. The purpose of this study is to explore the feasibility of replacing line-of-sight control with semi-autonomous UAV procedures based on a two-camera system for see-and-avoid, along with a continuous communications system for the monitoring, control, and recording of UAV operations.

The method proposed by this paper is to first identify the ten most significant hazards associated with semi-autonomous UAV operations in an urban setting. This will be followed by assessing the risk posed by each of these hazards, using a federal government risk assessment matrix. Finally, risk management strategies will be proposed to control and mitigate these risks. The ten hazards, along with their risk assessment and proposed risk mitigation strategies, will then serve as ten propositions or questions in a qualitative survey. Purposive sampling will be used to identify ten participants, drawn from a population of pilots trained in UAV operations. The survey will be administered to these participants, asking them to evaluate the proposed risk mitigation strategies. Some of the main topics included in the study are route planning, altitude control, and separation of UAVs in flight. The study will assess the use of established urban roadways as the main routing structure, where UAVs are visualized as flying cars above an already organized flow of traffic, the exposure of risk to pedestrians is minimized, obstacles such as buildings are avoided, and vehicle enclosures serve to protect the occupants of motor vehicles. The study will also address the use of altitude control both to separate UAV traffic in opposite directions (and at intersection turns), and to overfly overpasses and wires. Control and self-separation of UAVs may initially be accomplished with an open registry on a server, accessible by all users and government officials, where operators input proposed flight plan routes. A route is activated for each airborne UAV. UAV use of computerized speed control and GPS for lateral control is so precise, that users may generate an accurate moving target display of all UAVs on a monitor based solely on the flight plan. Two educational benefits of this study are a demonstration of risk management techniques in the solution of a real-world problem, and the

importance of addressing operational considerations in the design and manufacture of devices such as UAVs.

The results of this study indicate that overall, the estimates of likelihood, severity, and level of risk assessed by the participants closely matched predictions, and that these proposed safety procedures should reduce the overall risk of commercial drone operations in urban areas.

Keywords-Unmanned Aerial Vehicle (UAV); Notice to Airman (NOTAM); Risk Management; Human-Computer Interaction (HCI); Federal Aviation Administration (FAA): Time-Based Management (TBM); Vertical Takeoff and Landing (VTOL)

Introduction

In recent years there has been much interest in using small Unmanned Aerial Vehicles (sUAVs) for commercial delivery of packages. However, current FAA rules limit the radius of operations by requiring the UAV operator to keep the UAV in sight. Although some commercial operators have already demonstrated completely autonomous UAV operations, in rural settings, this may represent too much of a jump in the operational use of technology in urban areas without first proving their safety and reliability. This paper proposes a gradual, controlled evolution of UAV operations beyond line-of-sight by applying risk management principles, to assess proposed risk mitigation procedures that are designed to provide an equivalent level of safety. One of the benefits of assessing the feasibility and safety of UAV operations in interim, semi-autonomous phases is that a plan can be developed to serve as a blueprint for progressively integrating UAV commercial deliveries in urban areas. This paper addresses the commercial delivery of packages in urban areas with high-rise buildings, congested streets, and an increasing density of UAVs in the airspace, which presents a more demanding area of operations.

The author identified two major problems preventing the approval of UAV operations beyond line-of-sight: the hazard to personnel on the ground if a UAV goes down, and the related concern of surveilling and controlling UAV traffic to avoid inflight collisions as the numbers of UAVs increase. The purpose of this study is first, to explore the feasibility of replacing line-of-sight control with a two-camera system for see-and-avoid using a continuous communications system and second, the use of a central registry allowing the display of all active UAV flights for surveillance.

The ten hazards addressed in this paper are related to two overriding concerns: reducing the risk to personnel on the ground if a UAV goes down, and reducing the risk of inflight UAV collisions as the numbers of UAVs increase. Some of the risk mitigation strategies proposed include a routing system that overflies existing roadways like a flying car; a two-camera system for visual navigation and collision avoidance; a cell phone communications system for the continuous monitoring, control, and recording of UAV operations; a two-level altitude separation system for UAVs flying in opposite direction; and a low-cost surveillance system based on UAVs complying precisely with their GPS-based flight plans. This study sought to determine whether the use of commercial UAVs in urban areas can expand safely in controlled, progressive stages. It is predicted that this progressive approach using semi-autonomous UAV operations with continuous monitoring and control will indicate that the commercial use of UAVs in urban areas is viable with an acceptable level of safety. Some of the main topics included in the study are route planning, altitude control, separation of UAVs in flight, and safely controlling the descent rate if a UAV goes down.

The method proposed by this paper is to first identify ten of the most significant hazards that are associated with semi-autonomous small UAV commercial operations in an urban setting. This will be followed by propositions for risk mitigation strategies to control and reduce the risk posed by each hazard. It is assumed that without measures to reduce the risk posed by the hazards, the overall risk will exceed a desirable level of safety. Therefore, propositions for risk mitigation strategies will be presented as the second step in the risk management process. Assessment of the risks posed by the hazards will then be withheld until after the risk mitigation strategies are proposed and assumed to be in effect. Assessing the risk posed by each of these hazards will be accomplished with a simple federal government risk assessment matrix (Fig. 1). A complex federal government risk assessment matrix is also included for comparison (Fig. 2). An initial assessment of the risks was completed in a pilot study. Finally, the ten hazards, the proposed risk mitigation strategies, and the initial risk assessments will then serve as ten propositions or questions in a qualitative survey. Purposive sampling will be used to identify ten participants, drawn from a population of UAV Part 107-trained pilots. The survey will be administered to these participants, asking them to evaluate the hazards, the proposed risk mitigation strategies, and the initial risk assessments, followed by their own risk assessments and recommendations for revisions to the strategies.

Background

1. Definitions

Small Unmanned Aerial Vehicle (sUAV): an unmanned aerial vehicle weighing less than 55 pounds and governed by FAR Part 107 [1].

Notices to Airman (NOTAMs): notifications issued to pilots before a flight, advising them of conditions that may affect the conduct of the flight [10].

Risk Management (RM): a formalized method for dealing with hazards that affect a certain environment, providing for the identification of hazards, assessing the risk posed by the presence of the hazards, and strategies to eliminate or mitigate the risk posed by the hazards [8].

Human-Computer Interaction (HCI): A multidisciplinary field of study focusing on the design of computer interaction devices and the process of interaction between humans and computers [11].

Federal Aviation Administration (FAA): The governmental agency of the United States that regulates all aspects of civil aviation and the surrounding international waters.

Time-Based Management (TBM): An FAA Nextgen time-based scheduling tool that controls aircraft to arrive at specific fixes at specific times, allowing air traffic controllers to manage aircraft in congested airspace with a more efficient and consistent flow of traffic [12].

Vertical Takeoff and Landing (VTOL): a preferred flight capability for congested areas that allows hovering, vertical descent, and vertical ascent at a landing site.

2. Current State of Authorized Small UAV Operations

The focus of this study is on the rules governing the use of small Unmanned Aerial Vehicles (UAVs), which are addressed in FAA Part 107 [1]. Small unmanned aerial vehicle means a UAV weighing less than 55 pounds on takeoff, including any cargo or other expendable items attached to the aircraft [1]. However, this study intends to apply risk management principles to assess whether commercial use of small UAVs can be allowed in urban areas with an acceptable level of safety, in which case certification would proceed in accordance with FAA Part 135 [2]. Currently, one of the biggest restrictions to UAVs is the requirement for the operator or observer to remain within unaided visual line of sight (VLOS) of the UAV [1], which would negate the viability of commercial operations. Part 107 also requires small UAVs to remain at or below 87 knots (100 mph) and at or below 400 feet above the ground [1], which will not impact this study.

For addressing surveillance of UAVs, the FAA established the Unmanned Aircraft System (UAS) Traffic Management (UTM) Pilot Program (UPP) in April, 2017, under the FAA Extension, Safety and Security Act of 2016 [3]. The intent of this UTM program is to identify the initial set of industry and FAA capabilities for surveillance of UAVs. This is a huge program, with established test sites, that will take some time to realize operational capabilities. One of the proposals of this paper is to establish an inexpensive, near-term surveillance system, based on the inherent precision in the NextGen system design.

For addressing flight over personnel, the FAA has released a Notice of Proposed Rulemaking (NPRM) [4] that would allow the operation of small UAVs over people under certain conditions, based on three categories of operation. This NPRM would result in changes to FAA Part 107. The FAA has also released an Advance Notice of Proposed Rulemaking (ANPRM), announcing its intention to finalize guidance concerning the remote identification of small UAVs prior to finalizing the rule on the operation of small UAVs over people [5]. One of the proposals of this paper is to establish a method for controlling the rate of descent if a UAV goes down, which fits within the guidelines of these proposed rules. The FAA has also published AC 107-2 [6], which provides guidance for complying with FAR Part 107, including the certification of small UAV remote pilots and small UAV operational restrictions.

There are currently a limited number of commercial delivery drone services operating under the FAA's UAS Integration Pilot Program [7]. These include medical package delivery by UPS in Wakefield County, North Carolina, and residential package delivery by Wing (associated with Google) in Christiansburg, Virginia.

3. Principles of Risk Assessment and Management

Risk management is based on the premise of comparing risks and benefits, that is, are the benefits worth the risk. The risk management process involves three steps: identification of significant hazards, assessment of the risk posed by these hazards, and management of the risk to control or mitigate the outcome if an event associated with the hazard occurs [8]. The application of these three steps should be accomplished by personnel familiar with the equipment and operating environment under study. This study begins with the identification of ten significant hazards faced by UAVs involved with commercial delivery of packages in urban areas. The FAA defines a hazard as a condition that could lead to, or contribute to, an unplanned or undesired event [8]. The process continues with the assessment of the risk posed by these hazards, if an undesirable event associated with the hazard occurs. Risk assessment involves the quantification of risk by combining two attributes for each hazard: estimates of the likelihood of an event occurring and the severity of the outcome if the event occurs, as in Fig. 1.

The FAA publishes four guidelines for assessing likelihood. Probable means that an event will occur several times. Occasional means that an event will probably occur sometime. Remote means an event is unlikely to occur, but is possible. Improbable means an event is highly unlikely to occur. The FAA also publishes four guidelines for assessing severity. Catastrophic means that an event results in fatalities and/or total loss of property. Critical means that an event results in severe injury and/or major damage. Marginal results in minor injury and/or minor damage. Negligible results in less than minor injury and/or less than minor damage. With an assessment of the risk posed by each hazard complete, risk management involves the introduction of strategies or procedures to control or mitigate the risk posed by these hazards. Risk management then becomes a cyclical process in which the effectiveness of risk mitigation procedures is re-assessed by applying the matrix again. The application of the three risk management steps for this study are amplified in the following paragraphs, with one exception. It is assumed that the current risk of UAV operations in urban areas is unacceptable without mitigation strategies. Therefore, after identifying the hazards associated with these operations, the second step will present risk mitigation procedures, followed by the assessment of risk after the safety procedures are assumed to be in effect. This is the same procedure used in the survey, where participants trained in UAV operations are asked to assess the risk after assuming that the risk mitigation procedures are in effect.

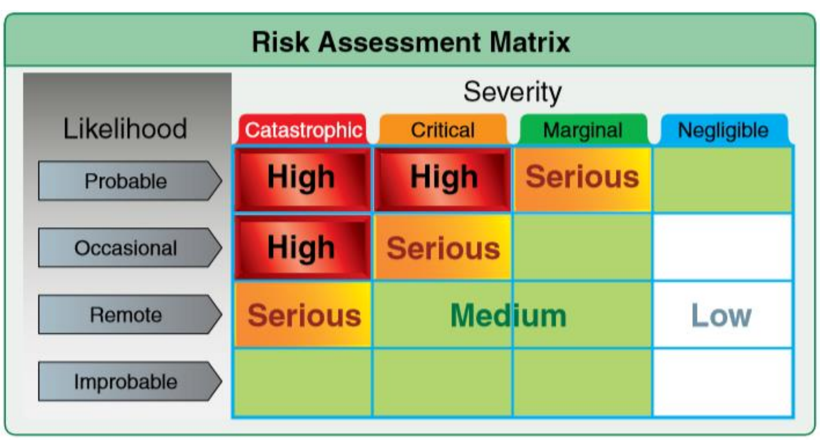

Figure 1. Simple FAA sample risk assessment matrix (FAA-H-8083-2)

Risk Likelihood		Risk Severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely Improbable	1	1A	1B	1C	1D	1E

Figure 2. Complex FAA sample risk assessment matrix (AC 107-2)

Methods

1. Hazard Identification

Adopting a principle of gradual evolution, several operating conditions have been identified as being more demanding and should be deferred for future evolutionary stages. Some of these deferred operating conditions include night flying, flight in low visibility, and heavy-weight package delivery. Considered high-risk conditions, the current risk mitigation strategy for these conditions may be considered to be elimination of the risk by the avoidance of these conditions. After reviewing potential operating conditions in urban areas, ten hazards of UAV operations have been identified as the most significant, and are listed below.

- Route planning must consider the danger that UAVs pose to personnel and property on the ground, in the event that a UAV goes down.
- The possibility of inflight collisions is an additional hazard with UAV operations, which is addressed with altitude separation for opposite direction UAVs.
- As the number of UAVs increase, the surveillance and separation of UAVs must be addressed with procedures for lateral and longitudinal separation, and a capability for monitoring UAVs in motion.
- Extending operations beyond line of site represents an increased hazard unless continuous control is maintained, supplemented with a two-camera system for see-and-avoid capability.
- The possibility of UAV engine or systems failures is a hazard that requires advance planning and procedures, including a capability for controlling the descent if a UAV goes down.
- Demanding environmental and operating conditions (night, low visibility, ice, winds, birds, mountainous terrain, heavy weight) represent increased hazards to UAV operations.
- The delivery area requires a safe and secure landing and takeoff site.
- The potential for accidents requires an ability to review flight parameters and camera video leading up to the time of the event.

- Controlling the hazard to personnel and property on the ground requires the tracking of UAV systems reliability.
- Unforeseen hazards, usually temporary restrictions to operations, may pop-up at any time and must be monitored and avoided.

2. Risk Management and Mitigation

Propositions to mitigate risks for the ten hazards are now discussed.

- Route planning. Although direct flights over sparsely populated areas (fields, railroad lines, transmission lines, waterways) are optimal for UAV operators, this is usually not an option in urban areas with high-rise buildings and overpasses. This study proposes the use of established urban roadways as the main routing structure, where UAVs are visualized as flying cars above an already organized flow of traffic, the exposure of risk to pedestrians is minimized, obstacles such as buildings are avoided, and vehicle enclosures serve to protect the occupants. This system also allows the use of automotive GPS navigation apps to reach all street addresses.

- Collision avoidance between UAVs. It is proposed that UAVs overflying roadways follow the flow of traffic, which means bearing to the right of a roadway. It is further proposed that UAVs utilize a two-level altitude separation structure, where UAVs proceeding in opposite directions are separated by 100 feet, and maintain this fixed altitude until completing any turn at an intersection. Fixed altitudes will also provide for the safe overflight of any overpasses and wires. Opposite-direction altitudes could be governed by several schemes. One scheme could be based on the labeling of our interstate highways, which continuously change direction, but have an overall east-west or north-south direction. If the overall direction is east-west they have even-number labels, while overall north-south directions have odd labels. Labeling all roadways in a similar manner, the FAA hemispheric rule could be used to determine assigned altitudes: overall north and east directions use odd altitudes (300 feet), while overall south and west directions use even altitudes (200 feet). A second scheme could be based on a single municipal reference point, placed northeast of and outside of the city limits, with north-south and east-west imaginary lines emanating from the point. Using the hemispheric rule, if a flight direction is (overall) towards the reference lines (north and east) use an odd altitude (300 feet), while a direction (overall) away from the reference lines (south and west) uses an even altitude (200 feet). A third scheme for separating opposite direction traffic could involve labeling all roads as one-way paths (similar to New York's one-way street system). A fourth scheme could be assigning opposite-direction altitudes to all roads individually, even with changing altitudes along the road (like changing speed limits), easily accomplished with automotive GPS-based navigation databases.

- Surveillance and longitudinal separation of congested UAV traffic. Control and self-separation of UAVs may initially be accomplished with an open registry on a server, accessible by all users and government officials, where operators input proposed flight plan routes. A route is activated for each airborne UAV. UAV use of computerized speed control for time-based management (TBM) [12], and GPS for lateral control, is so precise that users may generate an accurate moving target display of all UAVs based solely on the flight plan. these moving target display devices may be designed by using the principles of Human-

Computer Interaction (HCI) [11]. It is proposed that each operator utilize a team of dispatchers to activate, monitor, and deactivate all UAV flights.

- Extending operations beyond line of site represents an increased hazard unless a see-and-avoid capability from onboard the UAV is maintained. Adopting a principle of gradual and controlled evolution, it is proposed that UAVs utilize a two-camera visual navigation system (one downward looking and one forward looking). This also requires a continuous communications and control system for accessing the cameras and flight parameters. This may be accomplished with a cell phone system which is designed for seamless contact with vehicles in motion.

- The possibility of UAV engine or systems failures is a hazard that requires advance planning. Failures causing UAVs to come down should have provisions to control descent rate in order to minimize impact damage with personnel or property below. Engine failure could include a backup engine or, for quadcopters, the drag of wind-milling rotors that slow the vertical descent rate. If the UAV cannot continue flight, its descent rate must be slowed, such as with a small, light-weight parachute that deploys when exceeding a specified descent rate. An alarm that activates in these situations would alert personnel on the ground below. Loss of UAV cameras and/or communications may be handled with autonomous guidance systems that have already been proven by some UAV manufacturers. These systems could guide the UAV to a landing, a return to the takeoff point, or continuation to destination where the flight will be terminated. Provisions should include ground retrieval capability with company or contract vehicle pickup.

- Demanding environmental and operating conditions (night, low visibility, ice, winds, birds, mountainous terrain, heavy weight) represent increased hazards to UAV operations. Using the principle of gradual and controlled evolution, it is proposed that the first stage of UAV operation be limited to daylight conditions with 3 or more miles of inflight visibility, wind speed 10 mph or less, and no inflight icing conditions. Operating weight and speed should also be restricted during initial phases of evolution.

- The delivery area requires a safe and secure landing and takeoff site, with required dimensions established by the manufacturer. It is proposed that each building (residence, apartment, business) have a secure area allowing for vertical landing and takeoff, with a receiver on hand for each delivery. It is assumed that a customer order constitutes authorization by the building owner for use of the airspace above the landing area.

- The potential for accidents requires an ability to review flight parameters and camera video leading up to the time of the event. Rather than weigh down the UAV with a heavy recording system, it is proposed that streaming video and flight parameters over the communications link be used to record the flight data at a remote recording site.

- Controlling the hazard to personnel and property on the ground requires the tracking of UAV operational reliability. It is proposed that a history of vehicle system failure rates be maintained with appropriate information categories such as UAV model, number of flights, system failures, operating conditions, time in service, etc.

- Unforeseen hazards, usually temporary restrictions to operations, may pop-up at any time. It is proposed that an operator's team of dispatchers also monitor any temporary conditions that may affect flights, such as parades, and post them in a central repository for viewing by all operators. This is similar to the NOTAM system [10] used for aircraft operations.

The above propositions to mitigate risk will now be assessed using the simple FAA risk assessment matrix (Fig. 1).

3. Risk Assessment

Risks are assessed after application of proposed mitigation procedures, using the FAA's simple matrix (Fig. 1), with estimates for likelihood and severity. Risk mitigation strategies for all hazards are assumed to be combined, when considering the overall risk for a specific hazard.

- Route planning in congested areas to minimize risk to personnel and property on the ground.

  Strategy: overflying existing roadways like a flying car allows the use of automotive GPS navigation apps to reach all street addresses, while avoiding buildings and minimizing risk to pedestrians and vehicle-enclosed occupants below.

  Estimated Likelihood: occasional (when combined with failure backup strategies)

  Estimated Severity: marginal (when combined with strategies to control descent rates)

  Predicted Risk: medium

- Collision avoidance by vertical separation of congested UAV traffic.

  Strategy: follow the organized flow of roadway traffic (bearing to the right) while utilizing a two-level altitude structure to separate UAVs traveling in opposite directions by 100 feet (and where turns at intersections are completed before changing altitudes).

  Estimated Likelihood: remote (when combined with both UAV surveillance and camera-communications strategies)

  Estimated Severity: critical (less when combined with strategies to control descent rates)

  Predicted Risk: medium

- Collision avoidance by horizontal separation and surveillance of congested UAV traffic.

  Strategy: the precision of GPS (lateral navigation) and computerized speed control (longitudinal TBM separation) allows for a moving display (surveillance) of all active UAV aircraft, based on activated flight plans published in an open registry.

  Estimated Likelihood: remote (when combined with both UAV collision avoidance altitudes and extended sight via camera-communications strategies)

  Estimated Severity: critical (less when combined with strategies to control descent rates)

  Predicted Risk: medium

- Maintaining control of UAVs while extending visual operations beyond line of sight.

Strategy: use of an extended-sight 2-camera system with continuous cell phone communications (for monitoring, control, and recording) to maintain see-and-avoid and visual navigation capability beyond line-of-sight.

Estimated Likelihood: occasional (when combined with failure backup strategies for autonomous operations, tracking of UAV reliability, and strategies to control descent rates).

Estimated Severity: marginal (when combined with failure backup strategies for autonomous operations and strategies to control descent rates).

Predicted Risk: medium

- The possibility of UAV engine or system failures is a hazard that requires advance planning.

  Strategy: use of UAVs with redundant capabilities for propulsion and other systems; provisions to control descent rate if a UAV goes down (to minimize impact with personnel or property below); reversion modes for autonomous navigation and flight control; a dispatcher team to monitor UAV performance and implement alternate procedures; and company or contract vehicles for UAV retrieval.

  Estimated Likelihood: occasional (when combined with the tracking of UAV reliability for preventive maintenance).

  Estimated Severity: marginal.

  Predicted Risk: medium

- Demanding environmental and operating conditions (night, low visibility, ice, winds, birds, mountainous terrain, heavy weight) represent increased hazards to UAV operations.

  Strategy: defer operations in these conditions for future phases until experience is gained, while adopting now: UAV lights, heated surfaces, and limitations for weight and wind.

  Estimated Likelihood: remote (when adopting recommended limitations).

  Estimated Severity: marginal (when combined with strategies to control descent rates).

  Predicted Risk: medium

- The delivery area requires a safe and secure landing and takeoff site.

  Strategy: use of UAVs with VTOL capability at an enclosed or protected delivery area (dimensions established by UAV manufacturer), with building owner authorization and a human receiver on-site.

  Estimated Likelihood: remote (when combined with failure backup strategies).

  Estimated Severity: marginal (when combined with strategies to control descent rates).

  Predicted Risk: medium

- The potential for accidents requires an ability to review historical flight parameters and camera video leading up to the time of the event.

Strategy: use of the cell phone communications system to record UAV flight parameters and streaming video from the 2-camera system, in lieu of a heavier on-board recorder.

Estimated Likelihood (of not having a record): remote (when combined with failure backup strategies and the tracking of UAV reliability).

Estimated Severity (if not having a record): marginal (when combined with strategies to control descent rates).

Predicted Risk: medium

- Controlling the hazard to personnel and property on the ground requires the tracking of UAV operational reliability.

  Strategy: maintain a record or history of individual and fleet UAV performance with appropriate information categories that include UAV model, number of flights, time in service, system failures and failure rates, operating conditions, etc., to follow standards for the preemptive removal from service or replacement of parts when planned service life is reached, in order to minimize inflight failures.

  Estimated Likelihood (of inflight failure): remote (when combined with failure backup strategies).

  Estimated Severity (if inflight failure): critical (when combined with strategies to control descent rates).

  Predicted Risk: medium

- Unforeseen hazards may pop-up at any time and temporarily affect or restrict operations.

  Strategy: The dispatch team monitors the news, weather, GPS notams, municipal information systems, etc. for parades, fires, and other events that may limit UAV operations.

  Estimated Likelihood (of encountering unanticipated events): remote.

  Estimated Severity (if encounter unanticipated events): marginal (when combined with collision avoidance by vertical separation).

  Predicted Risk: medium

Results and Discussion

Qualitative surveys were constructed in accordance with standard qualitative guidelines [9], and distributed to participants trained in the current rules of operation pertaining to Unmanned Aerial Vehicles (UAVs). There were 10 usable responses collected from these aviation professionals. All of the data was self-reported by the participants and provided voluntarily.

1. Predicted Estimates of Likelihood, Severity, and Risk

A pilot study was used to have aviation professionals provide initial estimates of likelihood, severity, and risk, for the paired hazard and mitigation propositions. The individual values for these risk assessment estimates are detailed in Table 1

Table 1. Predicted estimates of likelihood, severity, and risk after adopting mitigation strategies.

Hazard & Proposition numeric label	Likelihood	Severity	Risk
1 (path)	occasional	marginal	medium
2 (altitude)	remote	critical	medium
3 (surveillance)	remote	critical	medium
4 (cameras)	occasional	marginal	medium
5 (descent rate)	occasional	marginal	medium
6 (environment)	remote	marginal	medium
7 (landing site)	remote	marginal	medium
8 (records)	remote	marginal	medium
9 (UAV reliability)	remote	critical	medium
10 (pop-up hazards)	remote	marginal	medium

The overall estimates of the respondents to the pilot survey indicate that the overall risk can be reduced to an acceptable level (medium). These estimates assumed that the entire set of safety propositions (risk mitigation strategies) are combined, providing a coherent operational environment for UAVs that allows the safe commercial delivery of packages in urban areas.

2. Participant Estimates of Likelihood, Severity, and Risk

The survey was administered to participants who had completed training in small UAV operational requirements. The individual values for the participant responses regarding their estimates of the likelihood of a problem developing, for each paired hazard and safety proposition, are detailed in Table 2. In this study, the estimates of likelihood were found to have no major difference among the participants. When compared to the predicted values of likelihood estimates, the results closely matched expectations.

Table 2. 10 Participant estimates of likelihood after adopting mitigation strategies.

Hazard & Proposition numeric labels	Participant Numeric labels									
	1	2	3	4	5	6	7	8	9	10
1	Rem	Rem	Rem	Rem	Rem	Rem	Rem	Rem	Rem	Rem
2	Occ	Rem	Rem	Rem	Rem	Rem	Im	Im	Rem	Occ
3	Occ	Occ	Rem	Occ	Occ	Rem	Occ	Rem	Rem	Occ
4	Occ	Rem	Rem	Occ	Occ	Occ	Occ	Rem	Rem	Occ
5	Rem	Rem	Rem	Rem	Rem	Rem	Occ	Rem	Rem	Rem
6	Rem	Occ	Rem	Occ	Rem	Occ	Rem	Im	Im	Rem
7	Rem	Rem	Occ	Rem	Rem	Rem	Rem	Rem	Im	Occ
8	Occ	Occ	Occ	Occ	Occ	Rem	Rem	Rem	Rem	Rem
9	Rem	Rem	Rem	Occ	Rem	Occ	Rem	Im	Im	Rem
10	Rem	Rem	Occ	Rem	Rem	Rem	Rem	Rem	Rem	Rem

The individual values for the participant responses regarding their estimates of the severity of a problem if it developed, for each paired hazard and safety proposition, are detailed in Table 3.

The estimates of severity were found to have a little more variation among participants than participant estimates of likelihood. However, there was still no major difference among the participants. When compared to the predicted values of severity estimates, the results matched expectations, but not as closely as the estimates for likelihood.

Table 3. 10 Participant estimates of severity after adopting mitigation strategies.

Hazard & Proposition numeric labels	Participant Numeric labels									
	1	2	3	4	5	6	7	8	9	10
1	Mar	Crit	Mar	Mar	Mar	Mar	Mar	Mar	Mar	Mar
2	Mar	Mar	Mar	Mar	Mar	Mar	Neg	Neg	Mar	Mar
3	Mar	Mar	Mar	Mar	Mar	Mar	Mar	Neg	Neg	Mar
4	Mar	Mar	Mar	Mar	Mar	Mar	Mar	Neg	Neg	Mar
5	Crit	Crit	Crit	Mar	Mar	Neg	Neg	Mar	Mar	Mar
6	Crit	Crit	Mar	Mar	Mar	Mar	Crit	Neg	Neg	Crit
7	Crit	Mar	Mar	Mar	Mar	Mar	Mar	Mar	Neg	Neg
8	Mar	Mar	Mar	Mar	Mar	Neg	Mar	Neg	Neg	Mar
9	Crit	Crit	Crit	Mar	Crit	Mar	Mar	Neg	Neg	Neg
10	Crit	Crit	Mar	Crit	Crit	Neg	Mar	Mar	Mar	Mar

The individual values for participant responses regarding the final, overall risk are not estimates, but are determined by entering the risk assessment matrix with the estimates of likelihood and severity for each paired hazard and safety proposition. These results are detailed in Table 4. These determinations of risk were found to have a small variation among participants, however, there was still no major difference among the participants. When compared to the predicted values of risk, the results matched expectations. Assuming that a risk value of medium represents an acceptable level of risk, the participant assessments closely match the predictions of medium risk if the ten risk mitigation strategies are combined and adopted.

Table 4. 10 Participant estimates of risk after adopting mitigation strategies.

Hazard & Proposition numeric labels	Participant Numeric labels									
	1	2	3	4	5	6	7	8	9	10
1	Med	Med	Med	Med	Med	Med	Med	Med	Med	Med
2	Med	Med	Med	Med	Med	Med	Low	Low	Med	Med
3	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med
4	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med
5	Med	Med	Med	Med	Med	Low	Low	Med	Med	Med
6	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med
7	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low
8	Med	Med	Med	Med	Med	Low	Med	Low	Low	Med
9	Med	Med	Med	Med	Med	Med	Med	Low	Low	Low
10	Med	Med	Med	Med	Med	Low	Med	Med	Med	Med

The overall consensus of the individual respondents to the survey, all of whom are trained in current UAV operations, is that the overall risk can be reduced to an acceptable level (medium). This occurs when the entire collection of safety propositions (risk mitigation strategies) are combined into a coherent system of procedures, so that UAV operations for the commercial delivery of packages in urban areas may be conducted safely.

Conclusions

The study presented in this paper examined ten hazards associated with the use of UAVs for the commercial delivery of packages in urban areas. Several strategies and procedures, designed to reduce the risk associated with these hazards, were then presented. A risk assessment, using an FAA matrix designed to assist with risk management, was then used to estimate the effectiveness of the risk mitigation procedures. This involved a pilot study to estimate the likelihood of a problem occurring, the severity of a problem if it occurred, and the net risk involved if the problem occurred. It was predicted that the risk involved with these hazards would be reduced to an acceptable level (medium), after the safety procedures were incorporated. Qualitative surveys were then distributed to ten stakeholders, personnel who are knowledgeable in UAV operations, soliciting their evaluation of the effectiveness of the risk mitigation strategies. This was accomplished by having the participants estimate the likelihood, severity, and overall risk with commercial drone operations, if the safety procedures were adopted. The survey also solicited open-ended comments and recommendations from participants that would further improve the safety of commercial drone operations in urban areas. The results of this study indicate that overall, the estimates of likelihood, severity, and level of risk assessed by the participants closely matched predictions, and that these proposed safety procedures should reduce the overall risk of commercial drone operations in urban areas. One educational benefit of this study is a demonstration of the application of risk management procedures in the design and development of a new vehicle. Another educational benefit of this study is that the importance of testing in an actual operational environment should be apparent. That is, although completely autonomous UAV capability has been demonstrated, regulating authorities will likely require additional functionality to allow for a more gradual integration of new vehicles into an existing environment.

Recommendations for Further Research

One recommendation for further study is to have commercial drone operators demonstrate limited proving runs in an urban setting, that include an evaluation of route following accuracy, and the demonstration of emergency landing procedures. This is similar to airline proving runs required for the addition of a new aircraft to their fleet. Another recommendation for further study is the setup and testing of an open server that accepts and stores UAV flight plans, allowing the associated display of UAV traffic in motion, to evaluate its effectiveness as a surveillance system based on NextGen precision.

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Singularity Functions Revisited: Clarifications and Extensions for the Deflection of Beams of Non-Uniform Flexural Rigidity under Arbitrary Loading

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Abstract

The engineering design process involves understanding of the applicability of structural elements associated with a particular application. Beam structural elements are the prototypical example, and it is not surprising that beam stresses and deflections are essential course topics in all undergraduate mechanical and civil engineering degree programs. Singularity functions are a well-known economical and practical solution method for beams subjected to multiple loads and supports. However, the method as presented in most contemporary textbooks is often unclear to the student and instructor alike in the handling of function discontinuities and integration constants. The method also appears to be limited to a small set of concentrated actions and polynomial functional forms, where more complicated loading conditions must be achieved through superposition.

These perceived limitations of the singularity function method were addressed in a recently published paper, where in particular, singularity functions representing general functional forms were re-introduced to construct shear-moment diagrams. The work herein is to extend this paper and show how these general functional forms can be used to determine the deflection of beams of non-uniform flexural rigidity subjected to arbitrary loads.

The solution methods presented here are at a level of mathematical rigor expected in a second-year undergraduate introductory strength of materials course or a subsequent undergraduate machine design course.

1. Introduction

The creative process in engineering design is inevitably constrained by external forces which induce stresses and deflections in the structure. Exoskeleton skyscrapers are a contemporary example, where the objective is to maximize usable space by the elimination of load bearing interior columns. Traditional exoskeleton buildings, such as the John Hancock Center [1] and the Alcoa Building [2] are comprised of an interior core region which takes the majority of the tower's load while a rectilinear exterior beam structure acts as a stabilizing feature. The One Thousand Museum [3] dispenses of the interior core altogether, whereupon the entire load is carried by an exoskeleton structure comprised of undulating, curved beam columns. These columns also contribute as key aesthetic design elements of the interior space. Examples in the arts include kinetic sculptures [4], which are comprised of a variety of structural support elements.

In these examples, beam structural elements are often a critical design component, and it is not surprising that beam stresses and deflections are fundamental course topics in all undergraduate mechanical and civil engineering degree programs. In the Mechanical Engineering Department at RIT, students are introduced to beam bending and deflection in a second-year strength of materials course (MECE 203). The approach is a traditional one, starting with pure beam bending, followed with transverse loading leading to the construction of shear-moment diagrams. Torsion of beams of circular cross-section is also covered. The discussion concludes with the derivation of beam deflection using Euler-Bernoulli beam theory assuming uniform flexural rigidity. Laboratory experiments support the theoretical foundation as well.

When a beam is subjected to a large number of external loads and moments, either in concentrated or distributed form, the process of constructing shear force and bending moment diagrams from repeated sectioning of the beam (as taught in MECE 203) can be a very tedious and time consuming process. Subsequent determination of beam deflection adds another layer of complexity to incorporate additional slope and displacements boundary conditions at singular points on the beam where the functional form of the bending moment is not directly integrable. Complicating the situation are beams which are comprised of different materials or beams which have non-uniform cross-sectional geometry.

Singularity functions for shear-moment diagrams and beam deflections greatly expedite the computational process by eliminating the need to invoke continuity boundary conditions at the singular points. At RIT, singularity functions are introduced in a follow-up upper-division undergraduate elective course (MECE 350), where the method is used to determine stress and deflection of straight and curved beams of non-uniform flexural rigidity. The method is also coupled with Castigliano's theorem and failure theories associated with static and dynamic loading. Singularity functions are reinforced at the graduate level in a mechanics of solids course (MECE 785) for the solution of statically indeterminate beams and determination of structural influence coefficients, and as introductory material for instruction in finite elements (MECE 605).

A sampling of contemporary textbooks [5-9] introduce and discuss the subject of singularity functions in a manner that can be confusing to both instructor and student. In addition to inconsistent sign conventions and inconsistent treatment of singular points among different textbooks, the essential perceived limitation is that the method can only be used for external loading represented by a limited predefined set of polynomial-based functional forms. In a recent paper by Boedo [10], clarification on the use of polynomial-based singularity functions and extension of the method to represent arbitrarily-defined external loads was presented.

The work herein is to extend this paper and show how these general functional forms can be used to determine the deflection of arbitrarily loaded beams of non-uniform flexural rigidity. The level of mathematical rigor employed in this paper is intentionally aimed at a level typically taught in an introductory-level calculus course and typically encountered by a first- or second-year mechanical engineering student.

2. Shear-moment distributions and beam deflections

Much of what follows in this section is taken from Boedo [10] and is presented here for completeness. Figure 1 shows a beam subjected to an external load distribution q(x). The origin of the x,y coordinate frame is attached to the left-most end of the beam, and the y-axis points upward. The load distribution q(x) includes external actions at the supports (concentrated reaction forces and moments) and is constructed using a combination of singularity functions shown graphically in Figure 2. In functional form, this set of singularity functions representing q(x) are given by

$$f_{-2}(x) = \langle x - a \rangle^{-2} \qquad (1)$$

$$f_{-1}(x) = \langle x - a \rangle^{-1} \qquad (2)$$

$$f_0(x) = \langle x - a \rangle^0 = \begin{cases} 0 & x < a \\ 1 & x > a \end{cases} \qquad (3)$$

$$f_n(x) = \langle x - a \rangle^n = \begin{cases} 0 & x \le a \\ (x-a)^n & x \ge a \end{cases} \qquad n = 1, 2, \ldots \qquad (4)$$

$$f_s(x) = \langle x - a \rangle^0 \, f(x) = \begin{cases} 0 & x < a \\ f(x) & x > a \end{cases} \qquad (5)$$

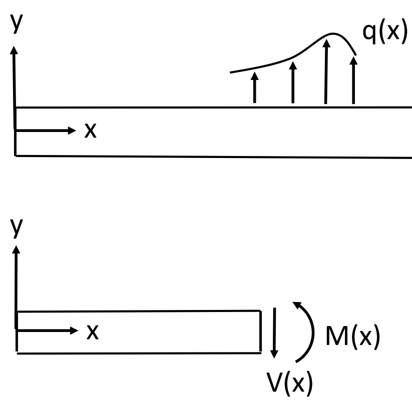

Figure 1. Sign conventions for beam bending

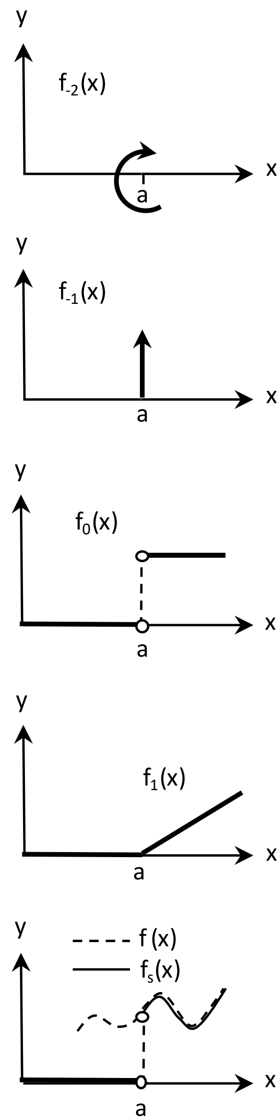

Figure 2. Singularity functions

where f(x) is a smooth function (i.e. continuous, finite, and possessing all derivatives) for $x > a$. In the foregoing, $n \geq 1$ is an integer, and a is an arbitrary real number. Open circles denote the singular points of the function.

Impulse singularity functions $f_{-2}(x)$ and $f_{-1}(x)$ are defined mathematically as a limit process applied to double- and single-pulse distributed loading, respectively [10]. The singularity function $f_0(x)$, also referred to as the step or Heaviside function, is strictly discontinuous at $x = a$ and defined only in the sense of one-sided limits as $x \to a$. Polynomial-based singularity functions $f_n(x)$ are all continuous for $n \geq 1$, but their nth-order derivatives are discontinuous at the singular point $x = a$.

Contemporary textbook publications do not address the general-form singularity function $f_s(x)$ shown in equation (5), and this function was reintroduced from previous publications by Boedo [10] as a powerful extension to the singularity function method. Neither the continuity of the function $f_s(x)$ nor its derivatives are required at the (singular) point $x = a$.

The integral properties of the singularity functions are given by [10]

$$\int \langle x - a \rangle^{-2}\, dx = \langle x - a \rangle^{-1} + K \tag{6}$$

$$\int \langle x - a \rangle^{-1}\, dx = \langle x - a \rangle^{0} + K \tag{7}$$

$$\int f_n(x)\, dx = \langle x - a \rangle^{n+1} / (n+1) + K \qquad n = 0, 1, 2, \ldots \tag{8}$$

$$\int f_s(x)\, dx = \langle x - a \rangle^{0} \, [g(x) - g(a)] + K \tag{9}$$

where g(x) is the anti-derivative of f(x) defined by $dg/dx = f(x)$.

Concentrated external load of magnitude P_0 and concentrated external moment of magnitude M_0 applied at an arbitrary point $x = a$ on the beam are represented by first- and second-order impulse singularity functions $q(x) = P_0 \langle x - a \rangle^{-1}$ and $q(x) = M_0 \langle x - a \rangle^{-2}$, respectively. The sign convention for q(x) represented by point and distributed loads is positive in the direction of the +y-axis. The positive sense of q(x) represented by the concentrated external moment M_0 is a rotation about the –z axis.

Figure 1 shows the sign conventions adopted for the shear force V(x) and bending moment M(x) defined on an arbitrary section cut. Applying force and moment equilibrium to an infinitesimal beam element of width dx, the functions q(x), V(x), and M(x) are related by

$$V(x) = \int q(x)\, dx + K_1 \tag{10}$$

$$M(x) = \int V(x)\, dx + K_2 \tag{11}$$

If $q(x)$ is constructed from singularity functions such that $q(x) \equiv 0$ for $x < 0$, it can be shown [10] that integration constants K_1 and K_2 are always zero.

Assuming Euler-Bernoulli beam theory, the deflection of the beam is given by the second-order differential equation

$$d^2y / dx^2 = M(x) / D(x) \qquad (12)$$

where flexural rigidity $D(x) = E(x)\, I(x)$, defined by Young's modulus $E(x)$ and area moment of inertia $I(x)$, is allowed to vary along the beam.

3. Sample problems

Three examples are illustrated to clarify the use of singularity functions in the determination of beam deflections where distributed loading and distributed flexural modulus are present. In each case, the external load distribution $q(x) \equiv 0$ for $x < 0$, so that the integration constants K_1 and K_2 in obtaining $M(x)$ are each zero.

3.1 Example I: Point-loaded beam with discontinuous flexural rigidity

Figure 3 shows a simply-supported beam of length L subjected to a concentrated load P at the beam midspan. The half-beam sections to the left and right of P have constant flexural moduli D_0 and $\alpha\, D_0$, respectively, where scale factor $\alpha > 0$. The distributed load $q(x)$ is given by

$$q(x) \;=\; -(P/2) < x >^{-1} + P < x - (L/2) >^{-1} \qquad (13)$$

Note that in this and succeeding examples, additional singularity functions for $x \geq L$ are not required to "turn off" the external load, as these additional functions do not contribute to the solution. Integrating twice gives $M(x)$, whereupon substitution of $M(x)$ into equation (12) results in

$$d^2y /dx^2 \;=\; -\, P <x>^1 /[\, 2D(x)\,] \;+ P <x - (L/2)>^1 /[\, 2D(x)\,] \qquad (14)$$

with boundary conditions $y(x = 0) = y(x = L) = 0$. The flexural modulus $D(x)$ itself is represented by step singularity functions as

$$D(x) = D_0 [\, <x>^0 \;+ (\alpha - 1) <x - (L/2)>^0 \,] \qquad (15)$$

Equation (14) with $D(x)$ defined in equation (15) can be rewritten as

$$\begin{aligned} d^2y /dx^2 \;=\; & -\,[P /(2D_0)] <x>^0 x \\ & -\,[P\, (1-\alpha)/(2D_0\, \alpha)] <x - (L/2) >^0 x \\ & +\,[P / (D_0\, \alpha)] <x - (L/2) >^1 \end{aligned} \qquad (16)$$

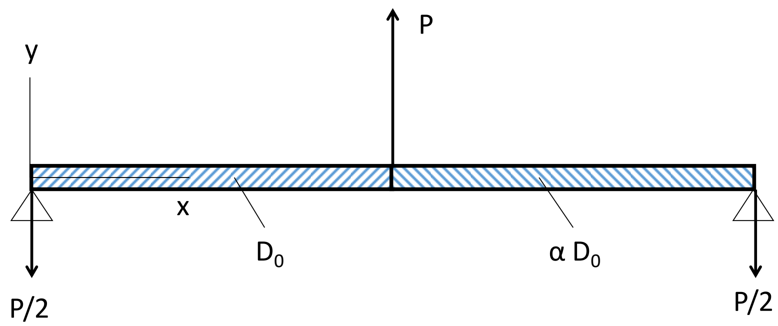

Figure 3. Point loaded beam with discontinuous flexural rigidity (Example I)

Integration yields

$$
\begin{aligned}
dy/dx = & - [P/(2D_0)] \langle x\rangle^0 (x^2/2 - 0) \\
& - [P(1-\alpha)/(2D_0\alpha)] \langle x-(L/2)\rangle^0 (x^2/2 - L^2/8) \\
& + [P/(D_0\alpha)] \langle x-(L/2)\rangle^2/2 + C_1
\end{aligned}
\quad (17)
$$

where equation (9) is applied to the integral of general-form singularity functions $\langle x\rangle^0\, x$ and $\langle x-(L/2)\rangle^0\, x$. Integrating again yields the beam deflection

$$
\begin{aligned}
y(x) = & - [P/(12D_0)] \langle x\rangle^0 x^3 \\
& - [P(1-\alpha)/(48D_0\alpha)] \langle x-(L/2)\rangle^0 (4x^3 - 3L^2x + L^3) \\
& + [P/(6D_0\alpha)] \langle x-(L/2)\rangle^3 + C_1x + C_2
\end{aligned}
\quad (18)
$$

Boundary conditions $y(x = 0) = y(x = L) = 0$ yield

$$C_1 = PL^2(1 + 2\alpha) / (48D_0\alpha) \quad (19)$$
$$C_2 = 0 \quad (20)$$

For $\alpha = 1$, the beam has uniform flexural rigidity D_0 throughout its span, and the deflection solution simplifies to

$$y(x) = -(P/D_0)[\langle x\rangle^0 x^3/12 - \langle x-(L/2)\rangle^3/6 - L^2x/16] \quad (21)$$

Figure 4 shows beam deflections for a family of scale factors $\alpha \geq 1$. Of particular interest is that the deflection approaches an asymptotic solution as α becomes large. As $\alpha \to \infty$, the right-most beam section becomes a rigid body, while the left-most beam section bends in a manner to maintain moment continuity at the midspan. To find the deflection for α in the range $0 < \alpha \leq 1$, the deflection shape for $1/\alpha$ from Figure 4 is reflected about the midspan, and its corresponding deflection magnitude is scaled by a factor of $1/\alpha$.

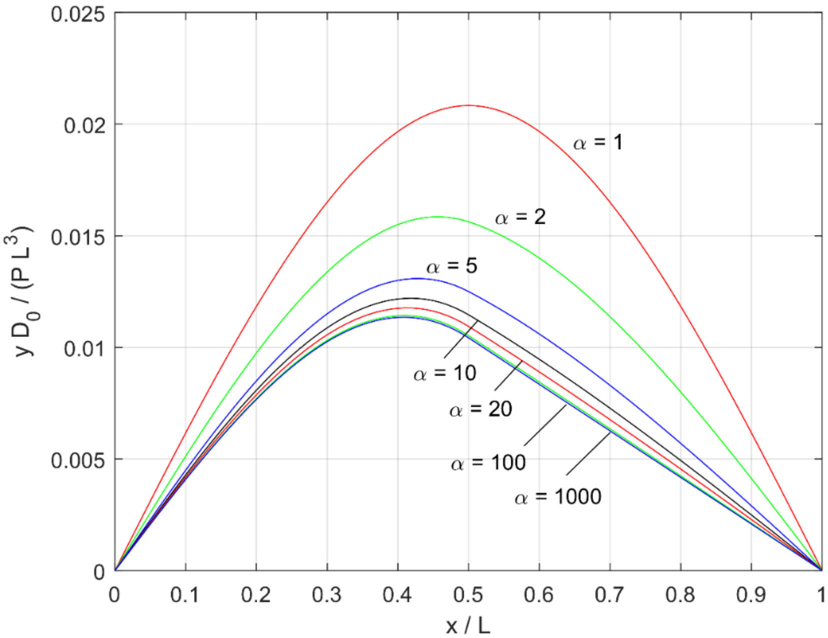

Figure 4. Beam deflections for point loaded beam with discontinuous flexural rigidity (Example I)

3.2 Example II: Cantilever beam with general distributed loading

Figure 5 shows a cantilever beam of length L and uniform flexural rigidity D_0 subjected to a distributed load of exponential form. The external load distribution q(x) for this example is given by

$$q(x) = R_0 \langle x\rangle^{-1} + M_0\langle x\rangle^{-2} + q_0 \langle x - a\rangle^0 e^{(a-x)/L} \tag{22}$$

where reaction force and moment at the support are given by

$$R_0 = q_0 L(e^{a/L-1} - 1) \tag{23}$$
$$M_0 = q_0 L(a + L) - 2q_0 L^2 e^{a/L-1} \tag{24}$$

The utility of the general-form singularity function is evident here to represent and integrate the exponential term $\langle x - a\rangle^0 e^{(a-x)/L}$. Since $q(x) \equiv 0$ for $x < 0$, the constants of integration can be dropped in finding V(x) and M(x).

Solving in the same manner as Example I with boundary conditions $y(x = 0) = dy/dx(x = 0) = 0$ results in the beam deflection

$$\begin{aligned} D_0 y(x) = {} & R_0 \langle x\rangle^3/6 + M_0\langle x\rangle^2/2 + q_0L\langle x-a\rangle^3/6 \\ & - q_0 L^2 \langle x-a\rangle^2/2 \\ & + q_0 L^3 \langle x-a\rangle^1 \\ & - q_0 L^4 \langle x-a\rangle^0 [1 - e^{(a-x)/L}] \end{aligned} \tag{25}$$

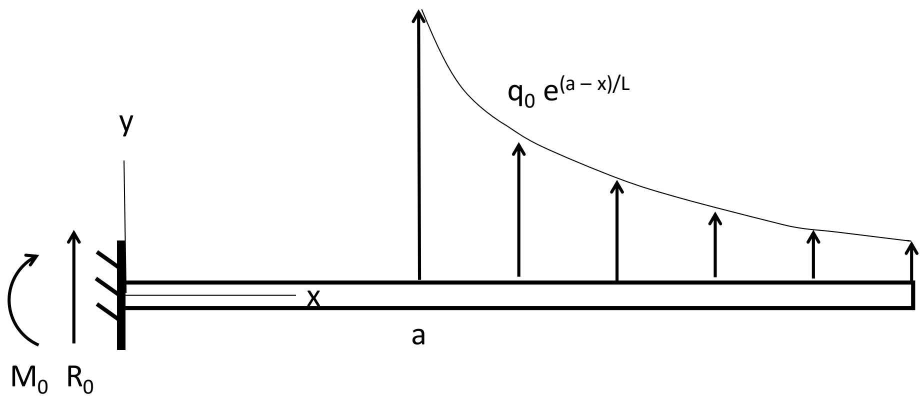

Figure 5. Cantilever beam with distributed load of exponential form (Example II)

The beam deflection δ at the free end (x = L) is evaluated from equation (25) and is given by

$$\delta \;=\; [\, q_0\, L^4 /(6D_0)]\; [\, e^{a/L\,-1} \;-\; (a/L)^3\,] \tag{26}$$

Figure 6 shows beam deflections for a family of parameters a/L. Apart from the special case a/L = 0, employing conventional section-cuts to determine either the moment distribution or the deflection curve itself is a very impractical method of solution.

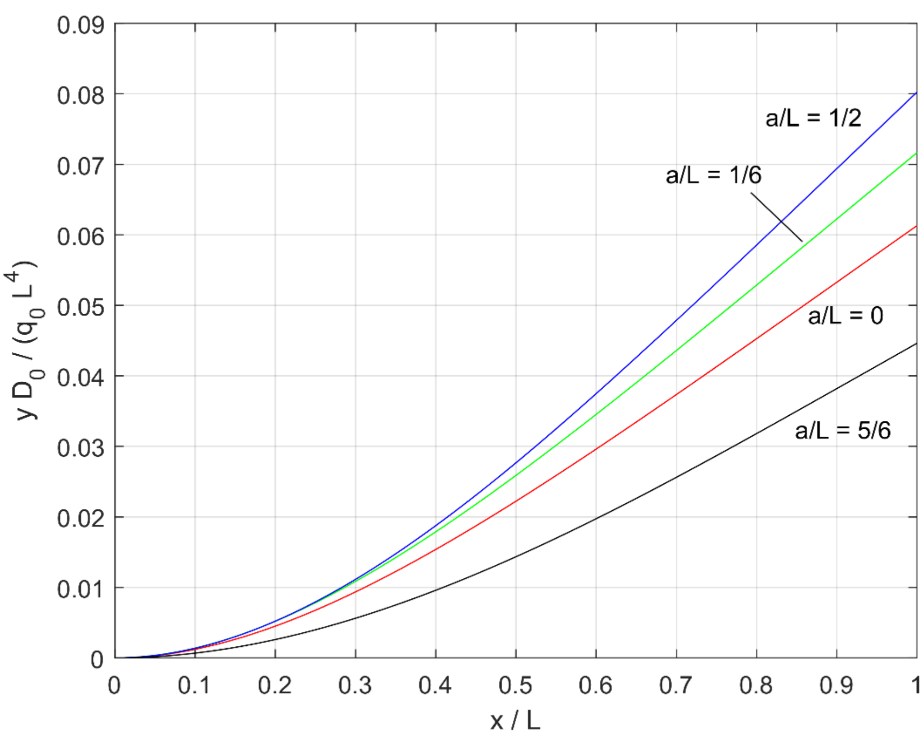

Figure 6. Beam deflections for cantilever beam with distributed load of exponential form (Example II)

3.3 Example III: Point Loaded Beam of Non-Uniform Diameter

Figure 7 shows a simply supported beam of solid circular cross-section and constant Young's modulus E_0 subjected to a concentrated load P at the beam midspan. The beam has a non-uniform diameter given by

$$d(x) = d_0 (1 + A \sin \pi x/L) \tag{27}$$

The beam deflection in this example is given by solution of the differential equation

$$d^2y / dx^2 = - 32P<x>^1 / [E_0\pi d_0^4 (1 + A\sin \pi x/L)^4] + 64P<x - (L/2)>^1 / [E_0\pi d_0^4 (1 + A\sin \pi x/L)^4] \tag{28}$$

with boundary conditions $y(x = 0) = 0$, $dy/dx\ (x = L/2) = 0$.

Further integration in closed-form is not possible here, so use of numerical integration will be employed. Defining $\xi = x / L$, $Y = E_0 d_0^4 y / (PL^3)$, equation (28) in non-dimensional form reads

$$d^2Y / d\xi^2 = - 32<\xi>^1 / [\pi (1 + A\sin \pi\xi)^4] + 64<\xi - 1/2)>^1 / [\pi (1 + A\sin \pi\xi)^4] \tag{29}$$

which can be rewritten as

$$d^2 Y / d\xi^2 = - (32/ \pi) < \xi >^0 f_1(\xi) + (64/ \pi) < \xi - 1/2 >^0 f_2(\xi) \tag{30}$$

where

$$f_1(\xi) = \xi / (1 + A \sin \pi\xi)^4 \tag{31}$$

$$f_2(\xi) = (\xi - 1/2) / (1 + A \sin \pi\xi)^4 \tag{32}$$

Formal integration of equation (30) gives

$$dY / d\xi = - (32/\pi) < \xi >^0 [g_1(\xi) - g_1(0)] + (64/\pi) < \xi - 1/2 >^0 [g_2(\xi) - g_2(1/2)] + C_1 \tag{33}$$

where

$$g_1(\xi) = \int_0^\xi [s / (1 + A \sin \pi s)^4] ds \tag{34}$$

$$g_2(\xi) = \int_0^\xi [(s - 1/2) / (1 + A \sin \pi s)^4] ds \tag{35}$$

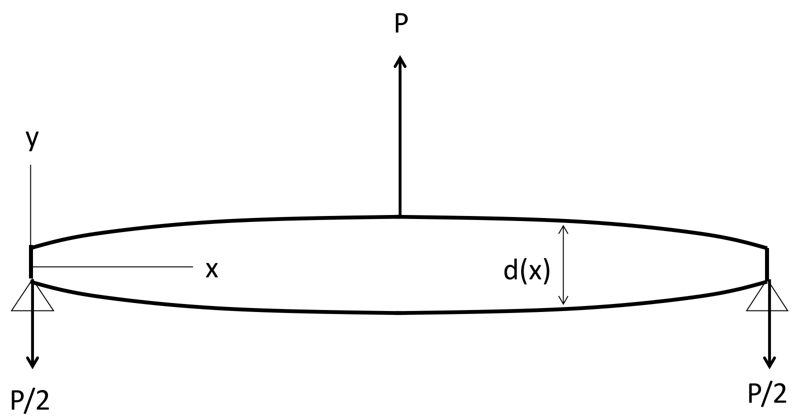

Figure 7. Point loaded beam of non-uniform diameter (Example III)

Employing the boundary condition $dY/d\xi\ (\xi = 1/2) = 0$ along with the observation that $g_1(0) = 0$ yields $C_1 = (32/\pi)\, g_1(1/2)$, so that equation (33) becomes

$$dY/d\xi = -(32/\pi) < \xi >^0 g_1(\xi) + (64/\pi) < \xi - 1/2 >^0 [\, g_2(\xi) - g_2(1/2)\,] + (32/\pi)\, g_1(1/2) \quad (36)$$

Formal integration of equation (36) gives

$$Y(\xi) = -(32/\pi) < \xi >^0 h_1(\xi) - (64/\pi)\, g_2(1/2) < \xi - 1/2 >^1 + (64/\pi) < \xi - 1/2 >^0 [\, h_2(\xi) - h_2(1/2)\,] + (32/\pi)\, g_1(1/2)\, \xi \quad (37)$$

where

$$h_1(\xi) = \int_0^{\xi} g_1(s)\, ds \quad (38)$$

$$h_2(\xi) = \int_0^{\xi} g_2(s)\, ds \quad (39)$$

by taking into consideration that $h_1(0) = 0$ and by setting integration constant $C_2 = 0$ from boundary condition $Y(\xi = 0) = 0$.

Numerical evaluation of the functions g_1, g_2, h_1, and h_2 can be facilitated using the fundamental theorem of calculus. Given $f(\xi)$ representing one of these functions, if the antiderivative function $F(\xi)$ is defined as

$$F(\xi) = \int_a^{\xi} f(s)\, ds \quad (40)$$

then $F(\xi)$ can be found from solution of the first-order initial value problem

$$dF / d\xi = f(\xi) \quad (41)$$

with

$$F(\xi = a) = 0 \tag{42}$$

which can be solved numerically using well-known extrapolation formulae (Euler, Runge-Kutta, etc.)

Figure 8 shows beam deflections for a family of shape factors A. Positive and negative values of A represent beam barreling and beam tapering, respectively. The g and h functions were evaluated by solving equations (41-42) using Euler's method with 10000 uniformly spaced steps from $\xi = 0$ to $\xi = 1$. Essentially identical answers were obtained with 5000 uniformly spaced steps. Alternative variable step integral methods, such as those found in Matlab, could also be applied here. Apart from the special case A = 0, the general-form singularity functions allow for relative ease of solution which relieves the student of contemplating more sophisticated and unnecessary analysis approaches, such as finite elements.

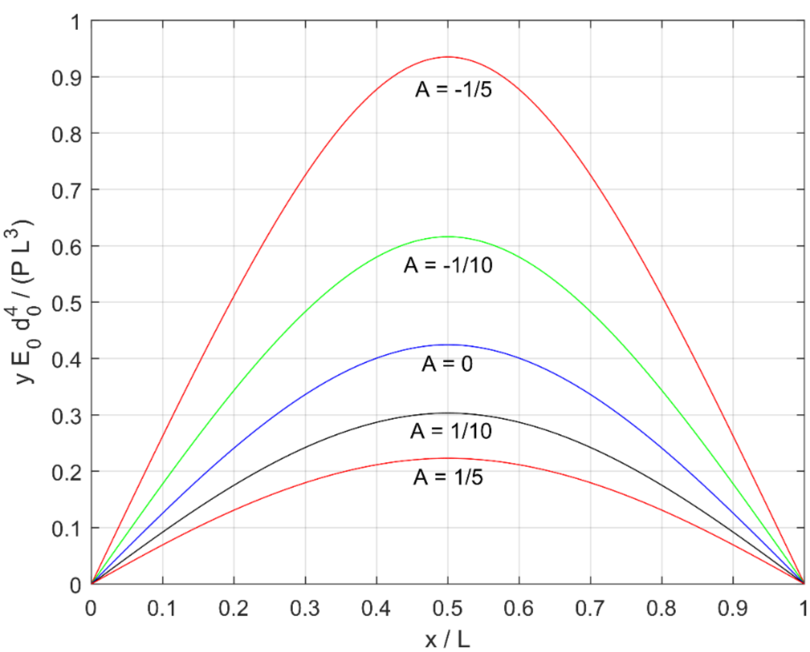

Figure 8. Beam deflections for point loaded beam of non-uniform diameter (Example III)

4. Discussion and Conclusions

This paper has extended previously published work to provide clarification and to offer extension on the use of singularity functions in the determination of beam deflections. Examples have been constructed to provide the student a systematic approach to the solution. The key feature of this paper not emphasized in current textbooks is the ability to apply the method to essentially any specified distributed load function and generally non-uniform flexural rigidity.

Alternatively, bending-induced beam deflection δ at an arbitrary location (x = a) on the beam can be determined from Castigliano's theorem by applying a dummy load Q at the beam location of interest and computing the definite integral

$$\delta \equiv y(x = a) \;=\; \int_0^L \left[M(x)\,(\partial M/\partial Q) \,/\, D(x) \right]\Big|_{Q=0} dx \qquad (43)$$

where displacement δ is positive in the direction of the dummy load. The midspan deflection for Examples I and III and the end beam deflection for Example II as given by equation (26) were checked in this manner. Castigliano's method has been the traditional solution recourse to solve for beams of non-uniform flexural rigidity. However, it appears that one can readily determine the entire shape y(x) using the integral property of the general-form singularity function with little additional computational effort.

Future work at RIT will incorporate the general-form singularity method into the mechanical engineering course curriculum. As the three examples have attempted to show, the efficacy of general-form singularity functions in a pedagogical sense is self-evident. It is impractical to expect students to solve such problems in a traditional sense using section cuts and additional continuity boundary conditions.

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Fostering an Entrepreneurial Mindset in Systems Simulation

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Abstract
Simulation is tool frequently used by companies when designing systems to evaluate alternative system designs. In particular, simulation is employed when the dynamic behavior of a system is not well understood and the decisions that are being made have significant economic or social impacts. However, courses in systems simulation typically focus on the technical and statistical aspects of model building and the comparison of design alternatives focused on operational performance of the system (that is, performance metrics that can be collected within the simulation itself.) This paper investigates how an entrepreneurial mindset can be fostered through activities/methods that encourage students to look beyond the operational aspects of system design to the overall value and impact of design alternatives. The development, implementation, and outcomes of two KEEN modules are presented to demonstrate the integration of an entrepreneurial mindset in a systems simulation course.

1. Introduction

The entrepreneurial mindset concept has gained momentum in science, technology, engineering, and math (STEM) disciplines in recent years. Bosman and Fernhaber [1] define the entrepreneurial mindset as "the inclination to discover, evaluate, and exploit opportunities." Having this mindset is necessary to become a highly successful engineer. Although technical knowledge is fundamental to engineering design and analysis, an engineer also needs to be able to determine which problems to solve, generate alternative solutions, evaluate the value of the solutions, and find opportunities to innovate. Through engineering education, the entrepreneurial mindset can be encouraged by integrating this concept with technical content to produce highly effective engineers.

Educators and researchers have looked at a variety of pedagogical methods for developing this entrepreneurial mindset in students. Bosman et al. [2] present on-line discussions as a means to develop the entrepreneurial mindset. Serious games are used by Bellotti et al. [3]. In addition, Korach and Gargac [4] discuss the use of active learning exercises to introduce the entrepreneurial mindset to first year engineering students. Vignola et al. [5] apply project-based learning in an engineering statistics course. And, Burden et al. [6] demonstrate how the entrepreneurial mindset can be developed through a software engineering course. These are just a few of the growing list of examples of how students can engage entrepreneurial mindset within their engineering courses.

This paper investigates how an entrepreneurial mindset can be fostered in a systems simulation course. In particular, we develop activities/methods that encourage students to look beyond the operational aspects of system design to the overall value and impact of design alternatives. In particular, the methods and activities in this work, were developed under the entrepreneurial mindset engineering educational framework put forth by the Kern Entrepreneurial Engineering Network (KEEN) [7]. In summary, the KEEN entrepreneurial mindset framework includes components of *curiosity*, *connections*, and *creating value*. These ideas coupled with the *engineering skillset* including *opportunity*, *design*, and *impact* can lead to *educational outcomes* for successful engineers. In the next sections, we discuss the development, implementation, and outcomes of two KEEN modules that demonstrate the integration of an entrepreneurial mindset in a systems simulation course.

2. Integrating Entrepreneurial Mindset Activities in Systems Simulation

When designing a system, companies frequently utilize simulation to evaluate alternative system designs. In particular, simulation is employed when the dynamic behavior of a system is not well understood and the decisions that are being made have significant economic or social impacts. (Examples include, design of sustainable production systems; design of hospital emergency departments, etc.) However, courses in systems simulation typically focus on the technical and statistical aspects of model building and the comparison of design alternatives focused on operational performance of the system (that is, performance metrics that can be collected within the simulation itself.) As a result, the boarder impacts and the value created under various alternatives may be overlooked.

To address this issue, as set of KEEN modules are being designed and implemented to foster an entrepreneurial mindset. In particular, the goal was to help students see how simulation can be used in system design to create value and facilitate innovation. In the next sections, two of these activities are presented. The first is an active learning assignment conducted in the first two weeks of the semester. The second is a project based learning activity that served as a midterm project for the course. The intent of these activities is to raise student awareness and apply their entrepreneurial mindset when conducting their term project during the second half of the course.

2.1 Activity 1: Simulation Everywhere!

The first KEEN module that we developed is titled, *Simulation Everywhere!* The objective of this activity is for students to discover the wide array of applications of simulation and to identify the significance of these applications. In particular, the assignment is designed to make students aware of the value of the role that simulation plays in solving problems throughout industrial and service organization.

The assignment is given within the first two weeks of the course as students are learning what simulation is, but do not yet have much experience with simulation modeling using simulation software tools or conducting simulation analyses. The assignment involved an individual and a group activity, as follows:

Individual Activity:

- Search the paper archive of the Winter Simulation Conference [8] (a leading conference on simulation) to obtain an application paper where simulation is used to solve a problem that is of interest to the student. (The paper archive of the Winter Simulation Conference is maintained by the INFORMS Simulation Society and is available on-line [9].)
- Read the paper and write your own one-paragraph summary that explains how simulation is used; the results/actions/improvements/conclusions/etc.; and broader impact (social, economic, societal, business, etc.)
- Be prepared to discuss your application with your assigned group during class in one week.

Group Assignment:

- In class (one week from the initial assignment), in groups of three students, discuss and select one application from your group.
- Create one visual-aid slide for the group's selected application.
- In class (in one week), one person selected by the group will give a 90 second summary presentation of the application to the class.

One of the objectives of this exercise is to get students exposed to a number of different application areas and to see the value that simulation can add in the context of the particular application. The individual assignment ensures that everyone actively participates provides a diverse set of applications to discuss. Since the students have very little exposure to simulation modeling at this point it is easy for them to focus on the application and the value of the solution rather than focusing on alternative modeling approaches. The group assignment enables the students to verbalize and explain their solution to their classmates while hearing about two other applications. Finally, the class presentations provide the students with exposure to more applications. In the fall semester, this activity was conducted with a class size of 39 students, so each student was exposed to at least fourteen applications. Figure 1 is an example of a visual-aid slide produced by one of the groups.

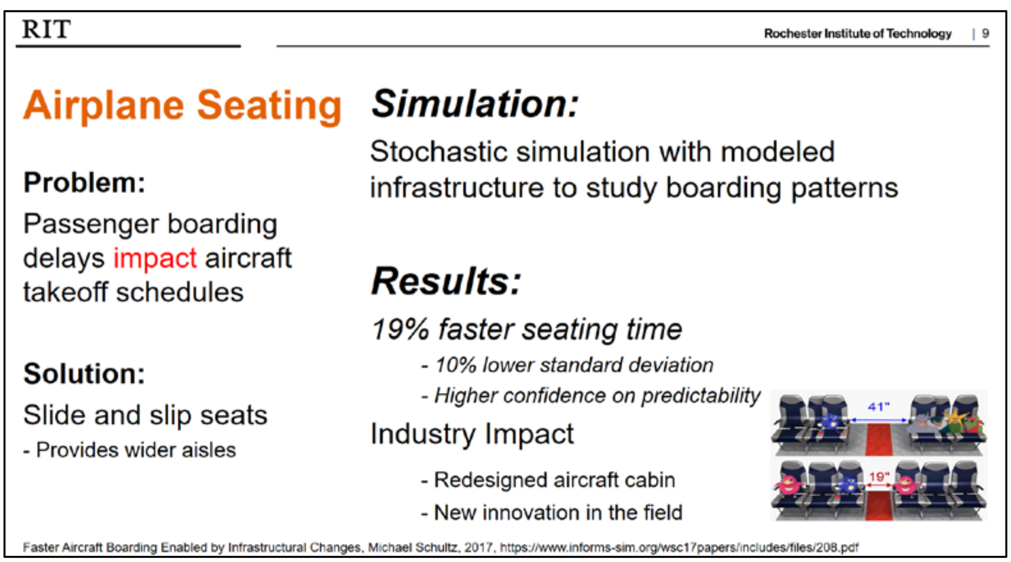

Figure 1: Example of a visual-aid slide of an application presented by a student group.

The airplane seating application shown in Figure 1 illustrates the entrepreneurial mindset being applied. Namely, the impact of the problem is clearly stated in terms of how passenger boarding impacts aircraft schedules. Further, the potential solution of the sliding seat is presented along with how simulation is applied to compare alterative systems. Finally, the operational performance measures and broader impacts are discussed in term of the potential benefits and impacts to the industry.

Overall, students were able to identify problems that existed in the application, how simulation was used, and how the simulation results were taken into account with the boarder aspects of the problem to aid in decision making and implementation.

2.2 Activity 2: Theme Park People Mover

The second activity used to encourage the use of an entrepreneurial mindset was a group midterm project. In this case, the students are given an open-ended problem. The objective is to consider value creation and broader impacts throughout design, analysis, and in forming recommendations. The particular exercise is designed around moving people among areas of a large theme park. The following information was provided to the students:

- Design a system to transport theme park guests between the lands within the Tiger's Den Amusement Park (TDAP). A conceptual diagram of the theme park is shown in Figure 2.

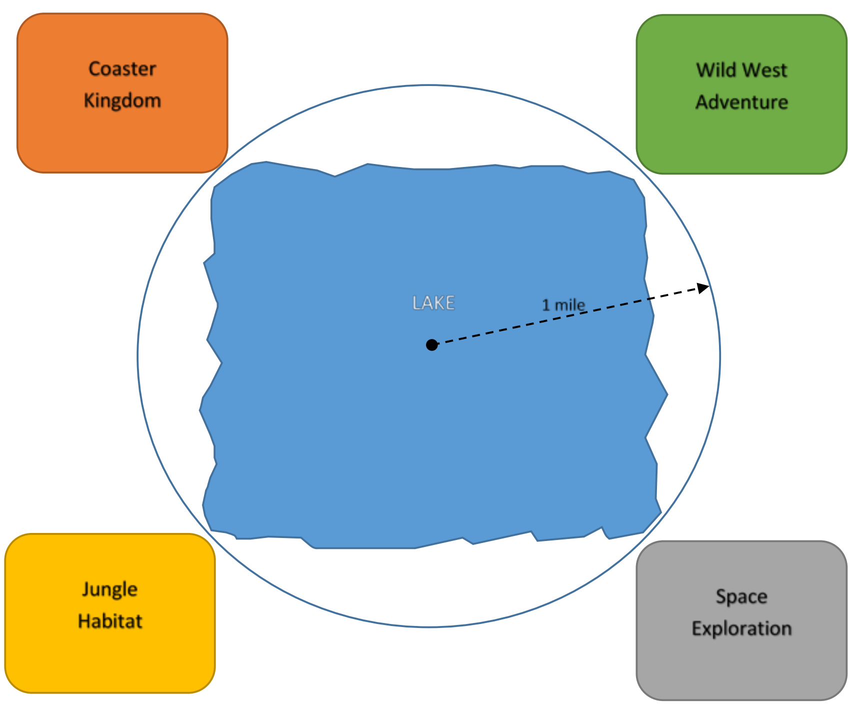

Figure 2: Diagram of the TDAP theme park.

- There are 4 lands surrounding a lake that has a radius of approximately 1 mile.
- The park is open from 9 a.m. to 9 p.m. each day.
- On average 400 guests per hour want to leave each land and travel to another land. The destination is equally likely to be any of the other lands.
- Guest travel in groups of 1-6 guests with the following probabilities (1(10%), 2(30%), 3(20%), 4(25%), 5(10%), and 6(5%)).
- The target date for operation is one year.
- The instructor will serve as the Chief Operating Officer (client and decision maker) for TDAP.
- Design and evaluate transportation system alternatives for the Tiger's Den Amusement Park (TDAP).
- Evaluation must assess the total value of the alternatives (including but not limited to initial cost, operational costs, operational performance, guest experience, and other factors.)
- You may estimate costs, times, etc. but cite sources. You may use the Internet, publications, etc., but you may not contact any person or business to get information.
- Thoughtful, specific questions to the COO about the park, transportation needs/wants, etc. are encouraged.
- Deliverables include a written report and class presentation.

This open-ended question allows for students to be creative about the potential solutions and to really consider the value that the solution will bring to the organization. Although busses may be an efficient way to transport people between locations, the guest experience will not be any different than riding a bus to school or to the market. In generating many creative solutions including boats, submarines, gondolas, trains, monorails, underwater tunnels/aquarium, among others, student were able to simulate how efficient the modes of transportation would be but also assessed many other factors including the guest experience or entertainment value, the impact of weather, accessibility for guests, safety, etc. By thinking through the value and innovation of the various alternatives, the groups generated some great alternatives. This assignment required that the students utilize aspects of the entrepreneurial mindset to achieve a successful outcome.

3. Outcomes and Assessment

The activities presented in the last section are two example of how an entrepreneurial mindset can be developed. In terms of the systems simulation course, the desired outcomes were achieved. In particular, as the students conducted their term project during the second half of the semester, the entrepreneurial mindset could be observed through the student reports and presentations. For the term project, students worked in teams (different teams than the midterm project) to use simulation to develop and evaluate alterative for an application (each groups is given a different application/problem). The deliverables for the term project are a report and a class presentation.

In previous semesters, students conducting these term project would focus almost exclusively on the system performance measures produced by the simulation models that they constructed. However, in this semester, student did a much better job of discussing the evaluation of alternatives and their recommendations in terms of the overall problem, the value of the alternatives, and the broader impacts.

In terms of assessment, a rubric is currently used for the term project that includes aspects of the problem solving process. As the activities associated with fostering the entrepreneurial mindset are developed and implemented for the systems simulation course, rubrics are under development that contain specific expectations for evidence of how the entrepreneurial mindset was applied.

4. Conclusion

In conclusion, methods and activities for fostering an entrepreneurial mindset within a systems simulation course were presented. In particular, an active learning exercise and a project based learning exercise were discussed in terms of how they encourage students to develop this mindset. In addition, the desired outcomes were achieved as evidenced by the student's increased awareness of the value of their solutions and broader impacts in the term projects. Future work in this area will be to continue to integrate aspects that will develop an entrepreneurial mindset in other systems simulation class activities and assignments, and to develop rubrics that will explicitly measure the extent to which each student has applied this mindset in their work.

Acknowledgements

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Skillset Shifts in First-year, First-semester Chemical Engineering Students

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Students' self-assessment of the academic success skills often suffers from a disconnect from the reality of their situation. At the beginning of their first year, students may consider themselves to be excellent at studying based on their success in high school, or they may expect to be behind because of a perceived deficit in their preparation compared to others. However, by the end of that first semester on campus, students usually have a better sense of where they stand in terms of their study habits, time management skills, and general help-seeking behaviors. To better understand how this process of self-discovery occurs for students entering the University of Rochester with an interest in chemical engineering, we administered the Academic Success Skills Survey [1] to four cohorts (F2016, F2017, F2018, and F2019) of first-year, first-semester students in an introductory chemical engineering course called "Sustainable Energy" (CHE 150). In the survey, we asked students for a self-assessment of their academic success skills at both the beginning and end of the semester. We also asked how much of their shift in skillset during the semester students attributed to the CHE 150 weekly workshops and assignments. In this manuscript, we share our results in the form of students' normalized gains in academic success skills as well as a narrative analysis of shifts in their skillsets as a function of both their evolving understanding of college life and the experiences and assignments they interacted with during the semester in CHE 150. Overall, our results suggest that the first semester is a crucial time to cultivate not only skills students will need to succeed as they progress through the chemical engineering curriculum, but also their locus of control around their own studying and success.

Background and Motivation

In 2005, representatives from the National Academies of Science, Engineering, and Medicine gathered at a symposium to discuss the economic, political, social and societal impact of growing global competition for producing the best skilled workforce in the science, technology, engineering, and mathematics (STEM) fields [2]. The goal was to identify and make recommendations for how the US could maintain its perceived lead in technological innovations. Despite the importance of increasing capable STEM graduates, results from the Trends in International Mathematics and Science Study (TIMSS) conducted every 4 years since 1995 show in 2015, the last year of available data, that the US has been measurably behind other countries in assessed skills in science and mathematics at the 4th and 8th grade levels for the last 20 years

[3]. The top performers include Singapore, Korea, Hong Kong SAR, Chinese Taipei, and Japan for mathematics, and the Russian Federation, Singapore, Korea, and Japan for science at the 4th grade; Singapore, Japan, Chinese Taipei, Korea, and Slovenia at the 8th grade. The TIMSS does show a decrease in the gender gap between boys and girls in the United States between 1995 and 2015, and a growing number of countries worldwide show higher achievement among girls than boys, especially in science by 2015 [3]. The concerns of the representatives of the National Academies in 2005 sparked initiatives to encourage more interest in STEM. Efforts initiated at the state level to increase the numbers of students pursuing higher education in the STEM fields have improved interest in STEM majors in college. Support for activities such as the Lego Mindstorm robotics competitions, first launched back in 1998, spurred increased interest in programming with interactive sensors, motors, and features that would allow a properly programmed robot at act autonomously [4], and this is only one of the many STEM-supportive programs that have been developed since the late 1990s and early 2000s.

At the University of Rochester, the number of women and students from historically marginalized populations has increased from 2010 through 2019 in the incoming first-year undergraduate population. However, studies in higher education have shown that despite equivalent preparation and test scores (GPA, AP, IB, SAT, and ACT) from pre-college study between first-year undergraduate men and women, twice as many men are likely to receive A's in their STEM subjects as women [5-7]. Men are twice as likely as women to repeat classes they have failed [5], while women show a loss in the self-confidence possesed as they enter college that results in lower class participation, lower performance, and lower grades—as early as their first year at college [6-7]. Longitudinal studies have shown the resulting impact can cause women to either transfer out of the major, or, even if they persist and complete, to lack the confidence to pursue advancement and positions of leadership once they enter the workforce [6-7].

Despite the increased efforts to attract women and students from historically marginalized populations to STEM fields in college, curricular development of the skillsets that will help these students succeed and the environment to encourage them through academic struggles are still lacking. The Society of Women Engineers (SWE) reported in 2018 that 32% of women leave STEM degree programs prior to graduation, only 13% of the workforce in engineering are women, and 30% of these women leave the engineering profession within 20 years while citing challenges in their workforce environment as their reason (e.g., having to prove their capabilities repeatedly to their colleagues, etc.) [8-11]. While workforce culture may require an aging-out of senior managers predisposed to accept credentials of incoming young men engineers over equally capable women, the culture of academia has the potential to be more responsive to positive changes.

Standard "chalk-talk" lecture methods which are ubiquitous in higher education do not appeal to all; Berhold et al. have found that women and students from historically marginalized populations, as well as white men, respond positively to diverse educators and methods [12]. Increased engagement with and diversity of role models is important in retaining STEM majors, as well as creating a sense of community and belonging among students. Providing a network that scaffolds not only academic achievement, but also comradery results in classmates and mentors who become lifelong connections and support systems.

Setting up this kind of learning community in a classroom moves away from a lecture-based focus and towards discussions in small groups around exercises and activities. This is the model author Raymond Landis used to teach his Chautauqua Short Course "Enhancing Student Success through a Model Introduction to Engineering Course," which was supplemented by his textbook, *Studying Engineering a Road Map to a Rewarding Career* [1]. Over three decades of teaching, Landis found that appropriate use of various academic success skills was a stronger indicator than intelligence of students' persistence and ultimate success in not only graduating with a degree in engineering, but also in persisting in an engineering career. His book addresses the importance of good study habits, the role of the active student in the classroom, and the need to reflect upon actions and attitudes towards a variety of academic challenges. In the text, he includes the "Academic Success Skills Survey," which is designed to gauge students' perceptions of their own academic success skillsets.

Steffen Peuker, a strong advocate of Landis' ideas, conducted a longitudinal study of students' successful graduation rates following their attendance in a first-year engineering course which exposed them to Landis' model [13]. After attending a short course on the model in 2014 and informed by Peuker's example, one of the authors (Monfredo) developed academic success workshops in a course called "Sustainable Energy" (CHE 150) for first-year chemical engineering students at the University of Rochester (UR). The workshops include activities and reflective essay assignments drawn from Landis' text. Assignments and in-class discussions revolve around a menu of topics that implicate students' emerging identities as engineers and professionals, including:

- personal definitions of success,
- identifying why one aspires to be an engineer,
- exploring how one might solve the National Academy of Engineering (NAE) Grand Challenges,
- understanding the depth of societal contributions made by engineers over the centuries,
- optimizing the knowledge gained and connections made through engineering coursework,
- interacting with upper-level students to gain insights into their success,
- and getting practice with time management and work-life balance for their future careers.

Students are encouraged to visit professors as a part of assignments in the course, and some portion of class time is reserved each semester for UR professionals to share their experiences in STEM fields and raise awareness about available resources for engineering students specifically (e.g., the engineering library, career services, academic tutors, etc.). Classroom activities range from simple and quick team-building exercises (e.g., building towers or bridges from notecards or newsprint, etc.) that provide a low-stakes window into engineering principles and informal opportunities for students to interact all the way to more formal laboratory exercises with assigned teams and peer evaluations. The course culminates in a final open-ended team design project to investigate the iterative nature of engineering design through a solar heating challenge in which students present the struggles they faced and their resulting solutions orally. Together, these assignments and activities aim to enhance the skillsets highlighted by Landis and Peuker as important for students' ultimate success as engineers.

CHE 150 has evolved over the semesters. The course was first offered in the F2015 semester for a total enrollment of 59 students; it included bi-weekly course meetings and most of the reflective assignments, team projects, guest speakers, and final oral presentations discussed above. Unfortunately, many of the students taking CHE 150 in the F2015 semester were also enrolled in organic chemistry together, and this course conflicted with the academic success workshop, so only 28 students attended the in-person component. The 31 students concurrently enrolled in organic chemistry wrote reflective essays instead to replace those in-person experiences. In the F2016 semester, the academic success workshops moved to being offered weekly, and students received additional machine shop training during the increased contact time. The F2017 semester was unchanged and remained essentially the same as the F2016 semester. The biggest shift occurred between the F2017 semester and the F2018 semester. A new instructor took over, reflective assignments were reduced, more team-building activities were added in the beginning weeks of the semester, a new laboratory exercise was added, projects were modified to include more evidence-based practices and peer evaluation components, and the final oral presentations were expanded to extend over four weeks to accommodate more in-depth discussions and feedback. These changes remained in place in F2019 except for the reduction of reflective assignments, more were added back into the curriculum as a result of encouraging feedback from upperclass students.

Based on the evolution of the course and the ability to begin comparing students' skillsets as seniors to their CHE 150 outcomes (staring with the F2015 cohort who graduated in the S2019 semester), the authors ask the following research questions in this study:

- How does a weekly workshop targeting critical academic success skills for engineers affect students' perceptions of those skills?
- What trends are there in students' perceptions of their post-course skillsets across semesters?
- What academic success skills are not being well-targeted by the weekly workshops?

Methods

To explore changes in students' perceptions of their own academic success skills, CHE 150 students were surveyed using the Academic Success Skills Survey [1] during five consecutive fall semesters (F2015, F2016, F2017, F2018, and F2019). The survey consists of 16 questions about academic success skills which students can respond to on a 5-choice "strongly agree" to "strongly disagree" scale (see Appendix A). In the F2015 semester, the survey was only administered at the end of the course, and the results of the F2015 post-survey are not included here for that reason; however, in all subsequent semesters, the survey was administered once in the first weeks of the course (pre-survey) and once at the end of the course (post-survey) so that changes in students' perceptions could be calculated. To quanyify survey results, responses to specific questions were assigned point values. Responses of "strongly agree" yielded 2 points, "agree" 1 point, "neutral" 0 points, "disagree" -1 points, and "strongly disagree" -2 points, resulting in a possible range of scores from -32 (all "strongly disagree") to 32 (all "strongly agree). Normalized gains between students' pre- and post-survey self-assessments were calculated using the average score for each cohort on each survey by the following formula:

$$NG = (\text{post} - \text{pre})/(\text{total possible} - \text{pre})$$

A normalized gain of 1.0 would mean that students' perceptions changed such that they strongly agreed to all questions to which they had previously responded with less agreement. Students' scores were only included in the cohort averages if they completed both the pre- and post-surveys in a given semester.

Because students are enrolled in multiple courses other than CHE 150 and students' perceptions may change for any number of reasons in their first semester, the course instructor designed a rating system to gauge students' perceptions of how significant the impact of specifically CHE 150 was on their skillset shifts. These rated questions were included on the post-survey only, and their format varied by semester, as seen in Table 1. Because of this variance, direct comparisons between semesters of quantitative results for each academic success skill will not be reported in this manuscript. Instead, general trends in students' post-course perceptions of their skillsets are investigated, which includes skills that might not be adequately targeted by the weekly workshops.

Table 1. Possible responses to "Impact of CHE 150 on this:" by semester

Semester	Response Format
F2016	Significant, A bit, None
F2017	Significant (5), 4, Some (3), 2, None (1)
F2018	N/A (no CHE 150 impact question included)
F2019	A lot, A little, None

The study activities for which the results are reported in this manuscript have been approved by the University of Rochester Internal Review Board (IRB) (F2016-F2018: ID#STUDY00003500, F2019: ID#STUDY00003848).

Results and Discussion

Overall, the pre-post normalized gains indicate that the weekly workshops improved students' perceptions of their academic success skills over the semester, as seen in Table 2. Of particular note are the low pre-survey average score in F2017, the high post-survey average score in F2018, and the relative lack of pre-post change in F2019, which are discussed in more detail below.

Table 2. Pre-post semester academic success skillset normalized gains: F2016-F2019

Semester	Course Enrollment	Response Rate (N)	Pre-survey Average Score	Post-survey Average Score	Pre-Post Semester NG
F2016	54	81.5% (44)	11.5	15	0.17

F2017	54	88.9% (48)	6.6	11.6	0.20
F2018	60	75.0% (45)	10.3	17.1	0.31
F2019	38	60.5% (23)	13.0	13.7	0.04

In the F2017 semester, pre-survey results suggest that, on average, students only agreed with six or seven of the questions about their academic success skills, although they realized a similar normalized gain when compared to other semesters in the data set. To explore this comparatively low result on the pre-survey, comparison across cohorts (e.g., demographics such as pre-college engineering exposure/coursework, gender, race/ethnicity, incoming GPA, size of incoming class, international status, etc.) are warranted and will be investigated in future studies.

On the other hand, the relatively high post-survey results in the F2018 semester suggest that the changes made between the F2017 and F2018 semesters in the CHE 150 course structure could be contributing positively to students' skillset shifts. However, the course structure remained generally unchanged during the F2019 semester from the F2018 semester, so the low normalized gain for F2019 students brings course structure as a complete explanation for the relatively large gain in F2018 into question. Future work will explore how the individual course assignments and other differences between semesters influence students' perceived skillset shifts.

In terms of the post-course skillset trends, students attributed all changes in their perceptions to CHE 150 to at least some extent. The skill for which changes were least attributed to CHE 150 was managing one's personal life (i.e., "I am effectively managing the various aspects of my personal life, such as interactions with family and friends, personal finances, and outside workload."), but even this skill was perceived to have been impacted by CHE 150 to some extent. In all four semesters, students highlighted positive feelings toward the University of Rochester (i.e., "I feel good about the University of Rochester and about the educational experience I am receiving.") and the perceived importance of setting clear academic goals (i.e., "I recognize the importance of goal setting and I have clear academic goals.") as post-course skills that they agreed most strongly with. On the other hand, students much more weakly agreed (or even disagreed) with statements about their contact with professors (i.e., "I interact regularly with my professors in positive, beneficial ways, both in and out of the classroom."), their preparation before class (i.e., "I prepare for each lecture by reviewing my notes, reading ahead in the text, attempting some problems, and writing down questions."), and their review after class (i.e., I keep up in my classes by mastering the material presented in the last class meeting before the next class meeting."). These skills are vital for success not only in college-level engineering courses, but also in the engineering profession as a whole, and future work will include how the weekly workshops can better target these skills.

Conclusions and Future Directions

In summary, pre-post semester normalized gains of agreement with specific statements about academic success skills indicate that a weekly workshop targeted at improving students' perceptions of those same skills may contribute to positive skillset shifts for future success in engineering. Further, the particular skills that students are most and least likely to agree with provide direction for future offerings of CHE 150. In particular, while students express positive feelings toward the University of Rochester and agree that they see the importance of setting clear academic goals, they lack follow-through on preparing for their classes and in making strong connections with their professors despite noting at least some impact from CHE 150 on all of the academic success skills included in the survey. Thus, in the F2020 offering of CHE 150, more of the assignments should emphasize interactions with professors and potential mentors as well as the value and practical implementation of preparing well both before and after each class session.

Consideration of the impact of course activities on students' skillsets is an ongoing topic for investigation. As mentioned above in the "Results and Discussion" section, future work will explore how the individual course assignments and differences between semesters influence students' perceived skillset shifts at the individual skill level (rather than as an aggregate score). These comparisons and new data from the F2020 semester will help to further refine the best practices for CHE 150 in regard to improving students' perceptions of their academic success skills. Qualitative data from F2019 (in preparation for a future publication) about students' favorite and least favorite assignments as well as which assignments they found most helpful can be used for triangulation purposes to increase the likelihood that the course will be both valuable and enjoyable for future students. In addition, comparing across cohorts (e.g., demographics such as pre-college engineering exposure/coursework, gender race/ethnicity, incoming GPA, size of incoming class, international status, etc.) can provide context for determining to what extent factors outside of CHE 150 are related to these skillset shifts. With the addition of demographic information, comparisons between men and women, racial/ethnic majority and minority, and international and domestic students may elucidate differential gains for these identity groups. Of particular interest are the potential differences in perception between women on project teams with other women or those on project teams where all the other members are men. All of these topics are in process as future studies and publications.

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Appendix A: Academic Success Skills Survey

1. I interact regularly with my professors in positive, beneficial ways, both in and out of the classroom.
    - Strongly agree
    - Agree
    - Neutral
    - Disagree
    - Strongly disagree
2. I make effective use of my peers by regularly engaging in group study and collaborative learning.
3. I schedule my time, utilizing time and priority management principles.
4. I would give myself an A+ on the amount of time and energy I devote to my studies.
5. I prepare for each lecture by reviewing my notes, reading ahead in the text, attempting some problems, and writing down questions.
6. I keep up in my classes by mastering the material presented in the last class meeting before the next class meeting.
7. I am aware of the importance of being immersed in the academic environment of the institution and spend as much time on campus as possible.
8. I practice good study skills in areas such as note-taking and preparing for and taking tests.
9. I am aware of the best methodologies for reading for comprehension and practice those methodologies during my learning process.

10. I recognize the importance of goal setting and I have clear academic goals.
11. I am effectively managing the various aspects of my personal life, such as interactions with family and friends, personal finances, and outside workload.
12. I am highly motivated through a clear understanding of the rewards graduating in my chosen major will bring to my life.
13. At my university, I know other students in my classes and feel part of an academic learning community.
14. I am aware of and make optimal use of campus resources such as the writing center, counseling center, student health center, library, and career center.
15. I feel good about myself and about my situation, and I am confident about my ability to succeed academically.
16. I feel good about my institution and about the educational experience I am receiving.

The Advancement of Autonomous Vehicle Navigation

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Abstract

As technology advances, the interest in fully autonomous vehicles has been a major focus for the automobile industry. These vehicles are becoming increasingly intelligent and for simple tasks such as highway driving, driver assistance can already operate with minimal interaction with a driver. It is anticipated that in the next decade, fully autonomous vehicles will transport humans in a more efficient, cost-effective, environmentally friendly, and safe manner. Most car manufacturers are focusing on public road transportation, but an intermediate proving ground may be large industrial, government and academic campuses. This paper discusses the design and integration of an autonomous golf cart vehicle called the Autonomous People Mover (APM) as part of a multidisciplinary capstone project for engineering seniors. The APM has been through prior capstone projects which firstly made the vehicle remote control, and then added advanced sensors such as LiDAR, computer vision, and GPS. The focus of this research is on navigation, localization, and obstacle avoidance on a large college campus. Through the implementation of a particle filter algorithm combined with A navigation and image segmentation, a reliable autonomous vehicle system can be obtained.*

I. Introduction

The Autonomous People Mover (APM) was conceived as a vehicle to transport people around a college campus. A user selects their on-campus destination, and the vehicle would automatically take the passengers to their destination via waypoints. Unlike current autonomous vehicles on the market, navigating a college campus requires a different approach. These changes include having to traverse campus pathways with pedestrians, not having roads with defined lines, and being able to move alongside pedestrian traffic. For these reasons, refined methods and sensors will be applied to overcome these challenges. The APM is a platform for researching new methods to efficiently transport people around college campuses. Currently, in the seventh phase of development, the goal is to implement a more robust system for localization of the APM. In the previous phases, an ordinary golf cart was modified to allow a computer-controlled steering, braking, and throttle. Aided with various sensors such as Light Detection and Ranging (LiDAR), cameras, and wheel encoders, full autonomy is now possible. Advanced computer vision technology involving a camera aided by machine learning software, enables the capability to distinguish drivable areas from obstacles. This technology was improved further in this phase with upgraded software and additional training data. Two particle filters were implemented to help with localization of the vehicle. These particle filters help to correct localization estimates when sensor data is inaccurate or hard to determine. The software structure was refined to allow for the future implementation of additional sensors. These additional sensors could add further robustness to the current sensor array.

II. Background

Robotic Operating System: The following section defines key sensors and functions essential for vehicular autonomy. The APM requires an array of sensors and software programs to communicate with one another to comprise an autonomous system. Robotic Operating System (ROS) is an open-source operating system that allows for such communication. At its core, ROS based software is comprised of nodes and topics. A node represents a software program such as a program that runs a sensor or does a calculation on sensor data. A topic is essentially a data bus in which information can be transported to and from nodes. This transportation process is defined by subscribers and publishers. A node can subscribe to a topic thus allowing the program to receive any data being published from that topic. A node can also publish to a topic, thus allowing other nodes to access the data by subscribing to that topic. The software that runs the APM is structured around this node-topic framework. Autonomous vehicles often require some form of localization, odometry, path planning, object detection, and object avoidance. These functions require an array of sensors to support them.

Localization: Successful localization is achieved when the entity of interest is able to identify its fixed location with a reasonable degree of accuracy on a map. An accurate and stable form of localization is fundamental for any autonomous robot to be capable of navigating in a foreign environment. Failure to achieve a reliable source of localization can limit the abilities of autonomous navigation altogether or result in large degrees of error. These errors can form into inaccurate measurements, relative to the position of the robot and its environment; having the potential to result in a cascading of error. Autonomous navigational decision making is heavily reliant on the accuracy and precision of the robot's incoming sensor data. The introduction of noise can have dramatic, sometimes unexpected effects upon the navigational system [6]. It is for this reason that the particle filter plays a vital role in filtering out noise from incoming data.

Odometry: Odometry is defined as an object's change in position over time. This allows for the location tracking of the object once it has localized. Once localized to a specific x,y position, and heading angle, an object can receive live position and heading data through odometry. This data can also be used to determine the speed of the object.

Path-planning: Path-planning is the function in which an autonomous vehicle can determine a path from its current position to the desired destination. There are several methods for doing so with varying trade-offs. Dijkstra, A*, and Bellman-Ford algorithms are popular algorithms that form the basis for path-planning. These algorithms focus on finding the optimal route between two points given multiple paths.

Object Detection & Avoidance: Another main component of autonomy is object detection and avoidance. An autonomous vehicle must be able to detect between drivable and non-driveable geography such as the distinction between roads versus sidewalks. It must be able to detect obstacles within a drivable path. Once an object in the path of the vehicle is detected, it must avoid that object. This is key to the safety of any passengers as well as bystanders whether they be obstacles within the path or otherwise.

An advanced sensor array is vital to any functioning autonomous vehicle design. The most popular sensors currently used in the industry for autonomous vehicle development are a variety of LiDAR, camera, GPS, IMU and radar units.

Global Positioning System: Global Positioning System (GPS) utilizes a number of satellites to identify an approximation of the robot's positioning. Although this technology has been refined over the years, it has its limitations. These deficits become apparent when traveling underground, or beside a wall or building which can sever the satellite's link and interfere with the ability to reliably communicate with satellites.

Inertial Measurement Unit: Inertial Measurement Unit (IMU) sensors are especially useful when used in conjunction with other sensor data, as it is independent of outside sources of error. This device operates by utilizing a combination of magnetometers, accelerometers, and gyroscopes to independently calculate the linear and rotational acceleration of an entity in relation to known heading. These positional changes are best used when other sensors are incapacitated or deemed unreliable. The shortfall of solely using an IMU is that the calculated positional changes are only relative to its previous state at an earlier time. Without information relative to its environment, it is incapable of identifying changes occurring in the outside environment.

LiDAR: LiDAR is short for light detection and ranging. These sensor units function by emitting pulses of light, in the form of lasers and measuring the return of the reflected light. This technology boasts the capability to perform precise measurements in a fraction of the time of rival sensors. Although LiDAR can provide perceptual benefits that the other sensors are incapable of, it has its limitations. These limitations are pronounced in harsh weather conditions, where for example light can reflect off of snowflakes or rain drops.

Radar: Radar, or radio detection and ranging are very similar to the functionality of LiDAR except for radars use radio waves instead of light. Radio waves are emitted from the radar device. Once those waves hit an object, those waves are reflected back to the device providing information about the object's distance and/or speed of the object the radar is mounted to. The main benefit of radar over LiDAR is usage in unstable weather conditions as radio waves can travel through rain and snow.

Computer Vision: Computer vision cameras have the benefit of being low-cost and effective at distinguishing structure and colors present in the environment. The shortfalls of cameras appear in the computations required to interpret and distinguish input data. These computation heavy algorithms can take time, which is of the utmost importance when it comes to implementing safety initiatives and immediate path planning. Another shortfall of cameras is their vulnerability to being blinded from direct light or misinterpreting captured shadows.

Particle Filter Algorithm: The Particle Filter algorithm is a localization algorithm based upon weighted particles. Each particle consists of x, y, and θ data, or in other words, a position and heading. First, a Gaussian distribution of particles is placed upon a 2D environment of interest. Using sensor data, each particle is then assigned a weight based on the probability that the particle in the location of the object you want to localize. This weighting process is called the sensor update. The more robust the sensor array, the more accurate the weights are. Once the object has moved, odometry data would be used to transport each particle the same distance and direction that the object moved. This process is called the motion update. The particles are then redistributed closer to the previously higher weighted particles. These updates continue in a cycle. This allows the particles to converge closer to the object's location after each cycle.

A Algorithm*: With the use of A* path planning, the vector for the desired trajectory of the cart is determined. This is done by taking the output of the sensor-fused cart heading and location and compares that to the desired path. The calculated difference between the next destination point and the current position is how the trajectory vector is generated.

III. Methods

The APM contains five functions that allow for autonomous traversal. First, the APM must localize on a known map. Path-planning is then used to chart an optimal path to the desired location. Odometry allows the APM to keep track of its movement and follow this path. The object detection and avoidance system ensures that the cart detects objects within its path and can maneuver around them safely.

Localization: For our application of localization, the APM is able to accurately identify its location within the campus setting of RIT. Prior to our phase of the capstone project, localization was achieved through the sole use of a Kalman filter. By utilizing the research of similar projects at RIT, a particle filter was developed for achieving a more accurate form of localization. It is hypothesized that by integrating two independent particle filters (one for heading and the other for handling GPS coordinate data), localization can be achieved with improved stability and accuracy [5]. Accurate localization with minimal noise is fundamental to the development of any successful autonomous vehicle, and these particle filters are integrated with the goal of achieving a localization error of under one meter.

A particle filter was chosen over a Kalman filter for a Bayesian estimate because we desire the properties of a state estimation and not a linear system [4]. Since we are using a nonlinear system we will obtain better results at the cost of higher compute power because of the particle filters randomly chosen location instead of the Kalman filters fixed algorithm. The higher accuracy is needed for our situation due to factors that can affect GPS accuracy such as tall building and overhead structures. Having a reliable location is important in order for navigation to work.

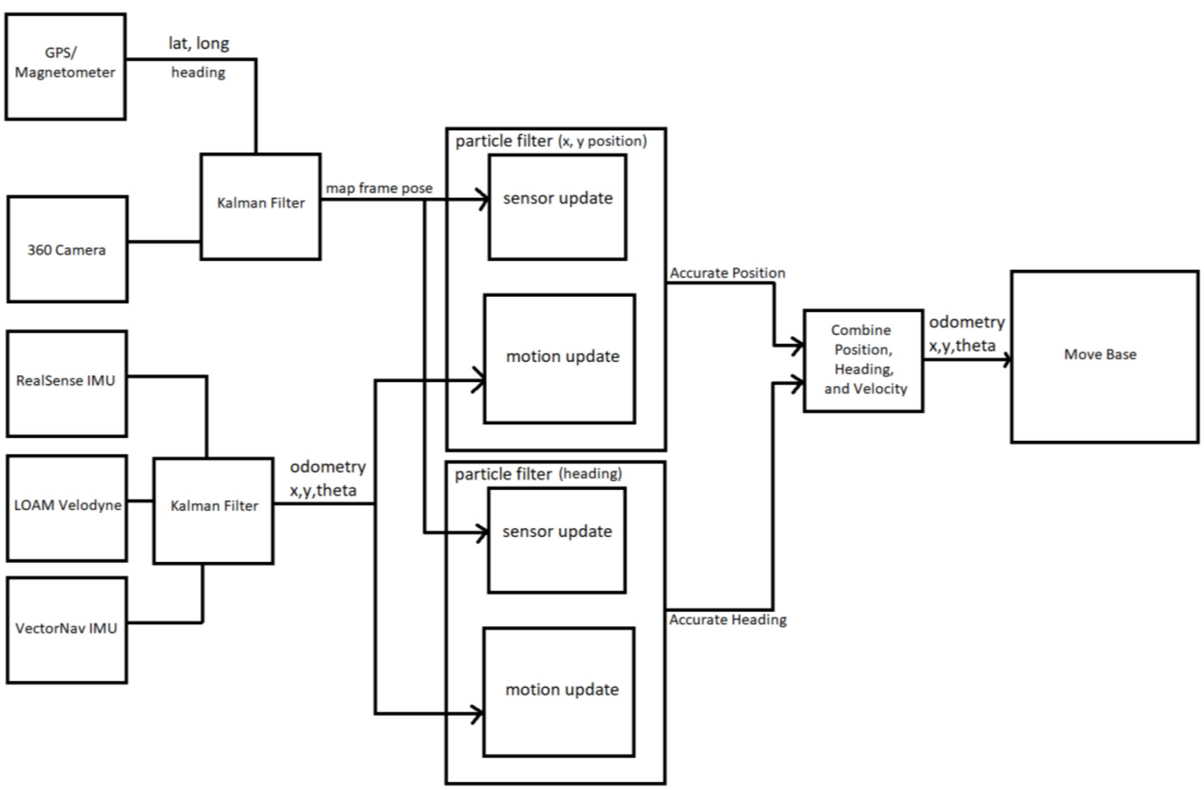

Figure 1: Software Block-diagram overview.

Sensors: Proper localization is a critical problem in creating an autonomous vehicle. For this particular application, the autonomous vehicle will be outdoors in relatively open areas, making GPS/GNSS a simple and viable option for localization. For an unassisted GPS, horizontal position accuracies can vary from a few meters to tens of meters depending on the conditions in the current environment (i.e., next to tall buildings or during a cloudy day). Additionally, accurate heading information is required for robot localization. These sources of error pose a problem for localization, but can be mitigated through the use of assisted GPS technology and Kalman filtering with other sensors such as an IMU and magnetometer. The Vectornav VN-200 is one such GPS aided IMU with a built-in Kalman filter that satisfies the need for a more reliable position estimate as well as a reliable heading estimate. The device is capable of reaching an accuracy of 2.5m RMS for horizontal position estimates and an accuracy of 2.0° RMS for static heading.

Integration of additional sensors such as Intel's RealSense tracking camera and a 360^o view camera could improve the accuracy of the particle filter. The RealSense utilizes two camera lenses which provide live odometry data and mapping. With two sets of odometry data from LiDAR and RealSense camera, the motion update of the particle filter will become more accurate. With the addition of a 360 view camera data to the GPS data, the sensor update portion of the particle filter will also become more accurate [Figure 1].

Odometry: The APM's odometry provides information about its position and heading. This is done by inputting 3D point clouds or a collection of points in 3D space, into an open source ROS program called laser odometry and mapping (LOAM). LOAM takes in LiDAR point clouds and outputs live odometry data.

Path Planning: The static map [Figure 2] is a Google earth map of the RIT campus. The APM will localize and determine paths based on this map. A GPS coordinate to static map pixel conversion allows for the location of the APM on the static map to be identified.

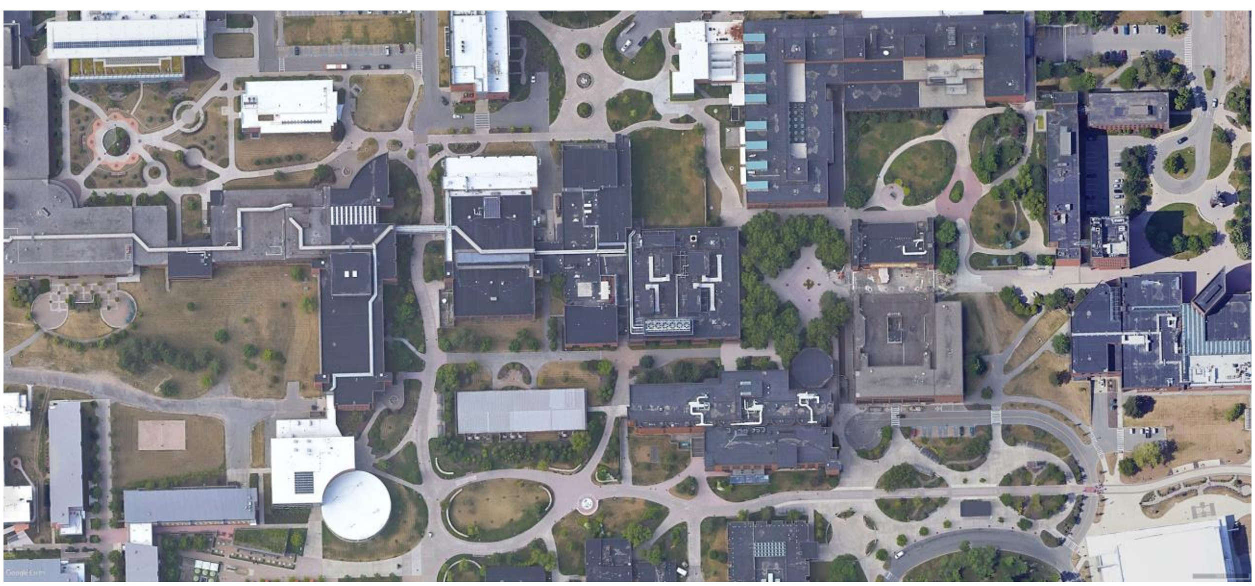

Figure 2: Static Map Overview.

Dijkstra's algorithm is used to determine the lowest cost path. This is done by calculating the cost of each intermediate waypoint and determining the optimal route. The cost of the path is directly correlated to the length between the current location and the intermediate waypoint.

Obstacle Detection: Obstacle detection is based off of data from two sensors, a front monocular camera and a single channel LiDAR. During pre-operation testing, hundreds of images were taken with the monocular camera mounted on the roof in the front of the APM. Each image was individually annotated pixel by pixel. Each pixel gets an associated object type through the process of image segmentation. Using these annotated images and deep learning methods, the APM's computer is trained to identify objects in view of the front camera. A Hokuyo single channel LiDAR system provides another layer of object detection beyond the front camera detection. The Hokuyo is mounted below the bumper in the front of the APM which allows it to see small objects in close vicinity. A radar unit could also be integrated by future teams adding another layer to object detection.

Obstacle Avoidance: The key technology powering the new vision system was the high-speed deep-learning model ERFNet. ERFNet is an encoder-decoder convolutional neural network that performs image segmentation [Figure 3] at real-time speeds. Given a large training dataset composed of camera images and pixel-level labels, image segmentation networks learn to generalize the classifications on unforeseen images. ERFNet was trained on hand-labeled images to segment existing roads, sidewalks, and undrivable terrain in camera frames. It was also trained with Cityscapes, which is an existing dataset that has thousands of trained images.

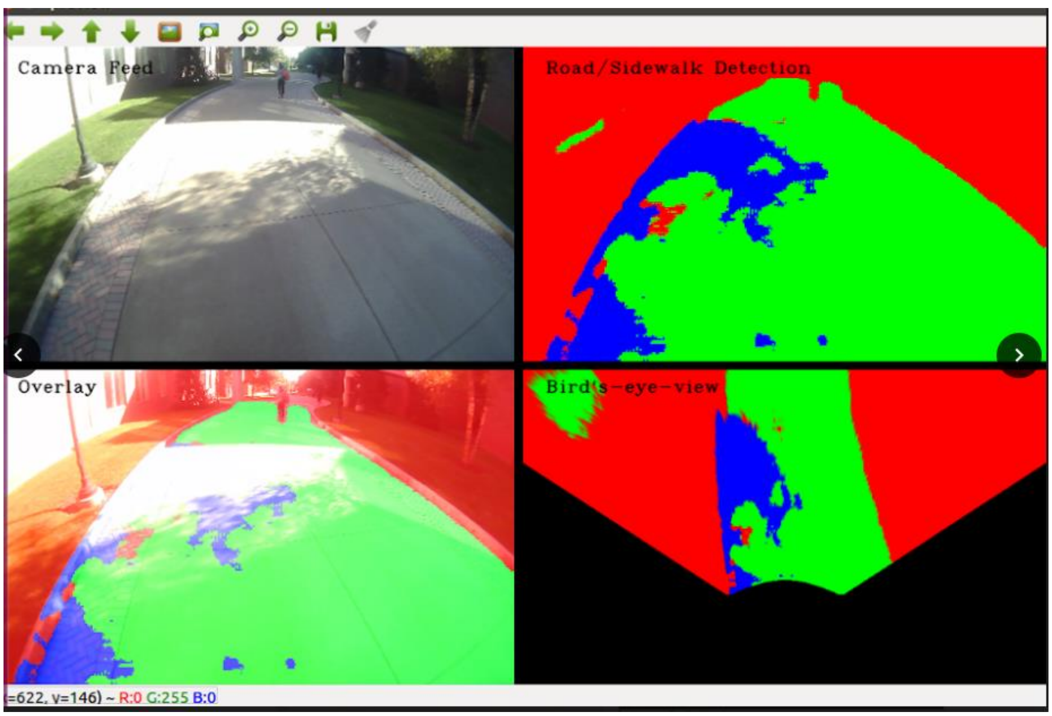

Figure 3: SafeZone Image Segmentation.

In order to train ERFNet to detect campus roads and pathways, a large dataset of the RIT campus pathway images was collected. This dataset consisted of camera frames with corresponding hand-generated road, sidewalk, people, and other unsafe parameters. These images were labeled using a tool called Supervisely. The resulting segmented images were transformed into a bird's-eye-view image which is visible from the front touchscreen monitor of the cart, displayed using Rviz. This provides accurate mapping of segmented image pixels to measure distances in front of the cart through inverse perspective mapping.

This perspective mapped image was published as a PointCloud with a set of data points in a coordinate system. This point cloud could then be used for integration with other ROS modules.

IV. Results

An integral addition to the APM was an updated road and sidewalk detecting camera system. This new system provides valuable information about the surrounding world to the cart. By integrating vision, the APM was able to accurately distinguish between roads, sidewalks, and objects/regions that were considered not safe to drive on. The pre-existing vision system consisted of a less robust training network due to its lack of training images. Using a new software program called Supervisely it allowed images to be manually labeled in a faster way. Supervisely uses computer vision assisted labeling to help the user label objects. Although it was not perfect, it allowed the user to go back and fix some of its mistakes. This was a key breakthrough because it could provide more learning data for the neural network.

Improved localization was achieved through a number of factors. First the statics map utilized to illustrate the RIT campus was improved to a resolution of 4800×2605 pixels. By assuming a linear conversion from GPS coordinates to pixel dimensions, an accurate equation was developed. Independent of the particle filters, an error of +/- 1.5 meters was achieved through this linear equation. By further integrating two distinct particle filters to handle the GPS coordinates and heading of the vehicle, the error was further minimized.

While striving to obtain a fully operational Autonomous People Mover, there have been several opportunities to learn topics taught outside the classroom. A new experience for much of the team is learning to navigate in a Linux environment and integrating new ideas via ROS. Although this has its challenges, the steep learning curve was easier to overcome by working with peers who have an established background in Computer Engineering.

In addition to the software challenges encountered while working on this capstone project, there were a number of team dynamic and hardware challenges encountered throughout the academic year. Some of these hardware challenges include the integration of advanced sensors, and rapid prototyping techniques to support these sensor systems. By utilizing the diverse skill sets that our team brought forth, we were able to overcome both the hardware and software issues, by maintaining a balanced approach to team dynamics.

V. Conclusion

The Autonomous People Mover has a fully functional obstacle avoidance system that depends on the utilization of both the front monocular camera and Hokuyo single-channel LiDAR for obstacle detection. To support the hardware features that comprise the obstacle avoidance system, proven software in the form of ERFNet was successfully integrated to visually distinguish undrivable regions. In addition, an accurate and stable form of localization has been established with the use of the Vectornav GPS assisted by a built in IMU and Kalman Filter that respectively established reliable heading data and improved accuracy.

Remaining issues include the expanded use of some features such as the complete integration of the 16-channel LiDAR into the obstacle avoidance system. An additional remaining issue is the battery charging issue, where a foul odor and condensation build up appears on the battery array when left charging for prolonged periods of time. The recommended solution for this issue is to have the batteries examined by an expert and replacing any damaged battery units.

Currently there are a number of newly developed components that function independently of one another. Future teams can further improve the object detection features by integrating hardware such as the Kodak 360 camera and D3 Radar for additional sensor inputs. These hardware features could be used to further expand the possibilities of the obstacle avoidance and detection systems.

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Use of Flow Visualization Projects to Personalize Introductory Fluid Mechanics For Students

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Introduction

Introductory Fluid Dynamics classes are often viewed by engineering students as one of the most challenging courses in the curriculum. The course is content heavy with a strong reliance on complicated equations which can make the material appear dry and distant to many students. Beyond that, introductory fluids is a required course for many engineering disciplines and has a wide range of student interest levels. At Clarkson University the introductory fluid mechanics class includes students from the Mechanical and Aeronautical, Civil and Environmental, and Engineering and Management departments. Engaging students by making the subject personally relevant is challenging given these boundary conditions. Personal connection is needed to actively engage the students in their learning. This paper describes a flow visualization project that is designed to personalize fluid mechanics by having students take and reflect on a picture of a flow field that they find "interesting". The results of this project is assessed and the outcomes described based on four criteria: 1. Originality of the picture; 2: aesthetic Quality of the picture; 3. Clarity of the flow visualization; 4. seriousness of the Reflection.

The Navier-Stokes Equations are the fundamental equations of motion for a fluid. These can be expressed in variable form for an incompressible Newtonian fluid as:

$$\rho\left(\frac{\partial}{\partial t}\left(\vec{V}\right) + \vec{V}\cdot\nabla\vec{V}\right) = -\nabla P + \rho\vec{g} + \mu\nabla^2\vec{V} \qquad (1)$$

These equations are 2^{nd} order, non-linear differential equations, which is conceptually overwhelming. Even when these equations are simplified, it is difficult to translate the mathematical expression into a mental picture of the physical reality. This is true even for many faculty who have worked with these equations over the course of a career. Alternate analysis methods that are taught, such as integral analysis, are useful engineering tools but they too often remain just equations, with mysterious variables and meaning to the students. These mathematical and engineering descriptions are critical to problem solving, but what is often lost is an understanding or appreciation of the fluid motion. This is unfortunate because the very nature of the fundamental equations allow for the rich and beautiful motion of fluids in the world around us. It is also unfortunate because students, especially those who do not see the personal relevance of fluid mechanics, often fail to connect the course material to their own lives and experiences.

One way to make the subject of fluid mechanics more accessible is by using flow visualization. When a flow field can be seen, the complexity and beauty becomes apparent. This in turn moves the subject from mathematical to aesthetic allowing for students to make not only personal but also emotional connections. It is these personal and emotional connections that provide critical intrinsic motivation for students. This paper describes a flow visualization project given to students in an introductory undergraduate fluid mechanics class. This project was designed to promote a personal connection with the broad subject of fluid mechanics and thereby encourage students to become engaged in the course material.

Project Description and Metrics

Students were asked to take a picture of a fluid flow that they found personally "interesting". The requirements for the picture were that: 1. The fluid phenomenon must be visible in the picture; 2. It was a picture they took, or that it was a picture they were in; and 3. The picture should be interesting to them. The project description and discussion of the project in class emphasized that "interesting" was a value judgement left to each student. This was done purposely to give the students space to personalize the project. Examples of flow visualization images were included in the course content throughout the semester. This was done first to motivate each lecture and demonstrate concepts, but also to provide examples to the students on what "flow visualization" was or could be. Some of the example images were scientific (e.g. visualization of experimental or computational flow fields) while others were from daily experiences (e.g. vortices observed in sauce while cooking). A variety of example images were chosen to purposely give examples of "staged" flow visualization where one might work purposely to see a flow phenomenon, and natural/opportunistic flow visualization where one might notice something in the world that is interesting, beautiful, etc. in the moment. Students were told that both approaches were acceptable as the real criteria was that they found the picture interesting.

The students were asked to provide a two page report and an original copy of the image at the end of the semester. Within the report the students had three tasks. First, students were asked to describe the flow field in the picture, including a sketch of the flow field (e.g. schematic vectors or streamlines). It was stressed that these were sketches and they were interpretations of the flow shown in the image. Second, students described how the image was staged and flow was made visible. For example, images of environmental flows may have natural seeding like water vapor in clouds, while experiments may have had dyes added. Finally students were asked to reflect on the picture and answer two questions. Why did they find the picture interesting? And, what question did the picture raise in their minds? Students were told that either technical or personal answers to both reflection questions were acceptable. The reflection was structured with this openness so that students who were not naturally excited about the topic could tie it to some personal experience. For example, a picture taken while hiking with a friend or sibling might be personally relevant because of the personal nature of the experience and may also contain some interesting phenomenon (e.g. a waterfall). The purpose of the second question was to encourage the students to expand their reflection beyond what was directly shown in the image. This reflection was also modeled during the semester when the example flow visualization images were presented to the class. Examples of both technical and personal reflections were given by the instructor.

The project was assessed using four metrics: *originality* of the flow, aesthetic *quality* of the image, *clarity* of the flow phenomenon, and quality/seriousness of the *reflection*. Each metric was assigned an integer score of 0-4 in those categories by the course instructor. The originality score was based on how unique the subject of the image was. For example, common subject that students see frequently in their daily lives are rivers and streams. These projects score low in originality. A subject that was shown as an in class example may score midlevel in originality if only one or two students recreated this example. However, if a student added to or changed an in class example their project scored higher in originality. Quality was assessed based on aesthetics of the image. Was it in focus? Was the image well composed? Was the image carefully staged and taken? Clarity of visualization was determined by how well the intended flow phenomenon was shown in the image. Could the flow feature be seen clearly or at all? Finally, the reflection score was based on how deeply and authentically the students answered the two reflection questions. The category assessment scores were made independently. For example, a student may have chosen a common (scored low on originality) flow, say milk being poured into coffee to show mixing. However, that student make have taken a well composed, artistic picture resulting in a high image quality score. That same image may have also scored low on clarity because the coffee obscured the details of the mixing but scored high on reflection. The assessment of the project described in this work is focused on the correlation between those metrics, as well correlation of those metric with final course grade. Note that the metrics were assigned without knowledge of the course grade so that bias was avoided. Course grades were added to the analysis after project metrics were assigned. A total of 157 students were enrolled in two sections of the class during the 2019 Fall semester. Both sections were taught by the author.

Examples of Student Work

In this section of the paper examples of student images are presented. The images were chosen to illustrate the variety of images that ranged in originality, quality and clarity. Figure 1 shows common subjects (low originality) that students staged to complete the project. By far the most common staged subject this year was a magnetic stirring rod in a beaker. The submission date of this project coincided with a laboratory that was being conducted in the Mechanical and Aeronautical Engineering lab class that utilized a magnetic stirring rod. This presented an easy, last minute subject for the flow visualization project that required very little preparation on the part of the students who chose it. In general the images were of low to moderate quality in terms of the aesthetics, and the seriousness of the reflections followed this general trend. Another common theme for the flow visualization images was, unsurprisingly, coffee. The two samples of this topic in Figure 1 show the range in image quality. The image of the coffee pot was poorly composed and the flow was difficult to observe from the image. In contrast, the image of the coffee cup with the spoon was more esthetically composed. The background was interesting, the spoon added depth to the image, and the instabilities caused by the stirring were clearly visible due to the contrast between the dark coffee and white cream. Mio jets were another popular, easily accessible subject. Again the two example images in Figure 1 show the range of image quality, and ease of viewing flow patterns. Finally, a more thoughtful common image type is flow from a faucet. The example shown in Figure 1 is the use of a spoon to deflect the stream and turn it into a sheet that breaks up into drops. That image was moderately well composed. The sponge on the back of the sink could have been removed, and the flow could have been in better focus to improve the aesthetics.

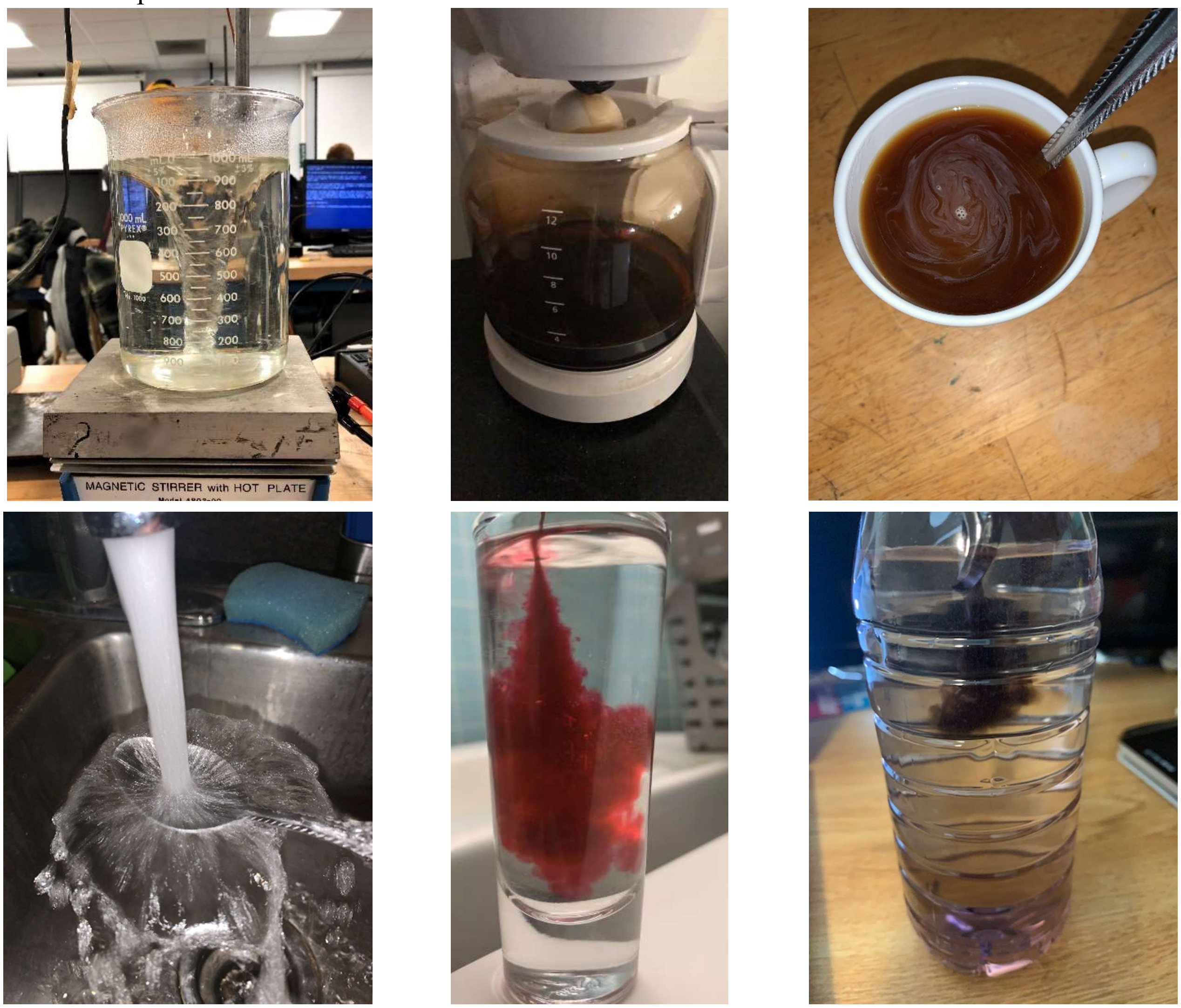

Figure 1: Common Staged Image Subjects

Many students chose to take use pictures taken from observation of the world around them, rather than from staged experiments. These images commonly focused on flow in streams, waterfalls and dams. While the topical areas of these images were common, the subjects and composition of the images showed variety. For example the three images of waterfalls included one that is a local hiking and swimming location (top middle), one from near the students home (top right), and Niagara Falls (middle left). The image of the dam in Figure 2 is one of the local dams near campus in Potsdam, which was a fairly “easy” subject, but the image was well composed and thoughtful. Typically these images score low on the clarity of the flow phenomenon due to the lack of control over the flow and the reliance on natural visualization. This trend was not always true. The included image of the rock in the stream was nicely composed and the flow phenomenon was clearly shown by the surface waves upstream of the rock.

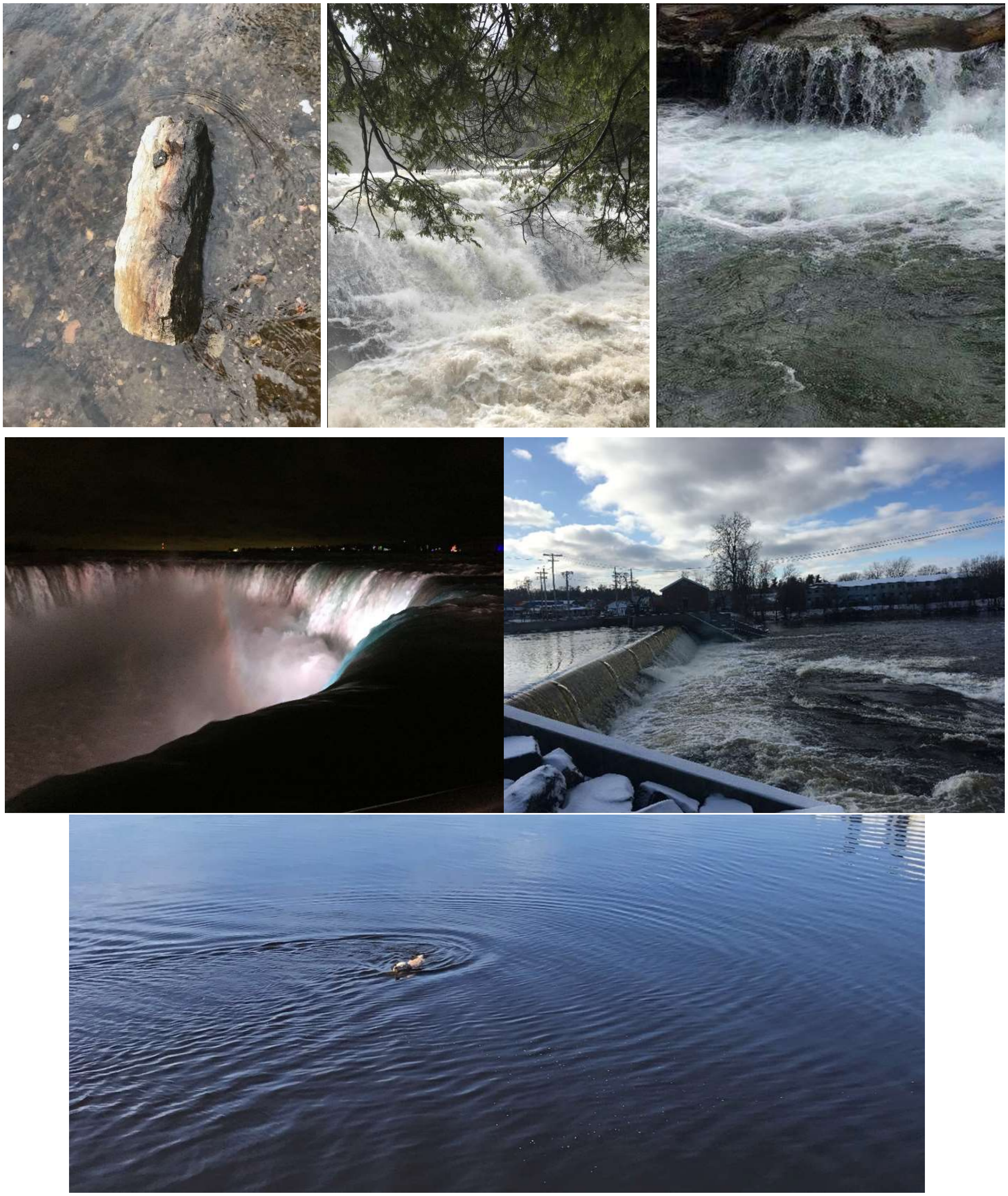

Figure 2: Common Natural Image Subjects

Examples of student images with high originality scores are shown in Figure 3. Students whose images scored high on originality tended to fall into one of two categories. First, they observed a flow that was naturally formed, was interesting to them and they had the opportunity to take the picture in the moment. For example, the image in the upper left hand corned of Figure 3 was taken when a student was having their car washed in an automatic car wash. The student noticed the sheet of water running off the hood and the ripples that formed in the sheet and then was able to capture the image in the moment. Secondly, the students had a definite subject for their image either based on a personal experience, or based on something that was shown or discussed in class. The middle left image in Figure 3 shows "needle ice" where ice forms upward by drawing liquid from the ground. The student who took this image is an avid hiker and had seen these formations. That student, motivated by past observations, used this project to learn more about that phenomenon. Examples of ideas that were taken from material discussed in class were the crown splash (middle top), hydraulic jump (right top) and jumping liquid jet (bottom left). The jumping liquid jet image was intriguing in that the student had a pencil in the lower right side of the picture with the words "see something" printed on the pencil. The author does not know for sure if this was purposely done, but the coincidence would be remarkable if it was not. The bouncing ball (bottom middle right) was a students rework of the classic "bouncing milk drop" experiment. They remaining example images were independently generated by the students. Of particular note are the tear drop bubble (lower right) and the water into soap (middle) which were images that had never been turned in by students during all of the years this project has been run.

Finally, images taken by students that had personal meaning or connection. The three landscape images were of Denali in Alaska (upper left), Mt. Daniel in Washington (middle right) and a waterfall in Ireland (lower left) were taken on trips that the respective students had taken with family or friends. Reflections were consistent that the images were chosen because of personal importance placed on those trips. The picture of the bubble ring in the pool (upper right) was taken by a student who was a competitive swimmer. This student's reflection stated that the subject of the image was chosen because of the connection between a personal passion and the course material. The image taken on the middle right was of vortex rings created during the start-up of a John Deere tractor on the student's family farm. The reflection here indicated that the student had seen these vortex rings and noticed them, but now had technical understanding to put them in context. The bottom middle image was taken at that student's family hunting camp in the Adirondacks. The project inspired that student to come to office hours and talk about ideas the student had about improving the fresh water supply at the camp. Finally, the middle left image is of soap film across the opening of a travel mug. That student was a non-engineering student who had chosen to take the fluids class because the material was interesting. That image was taken when the student saw the soap film while cleaning the bottle and was inspired by the colors and structures shown.

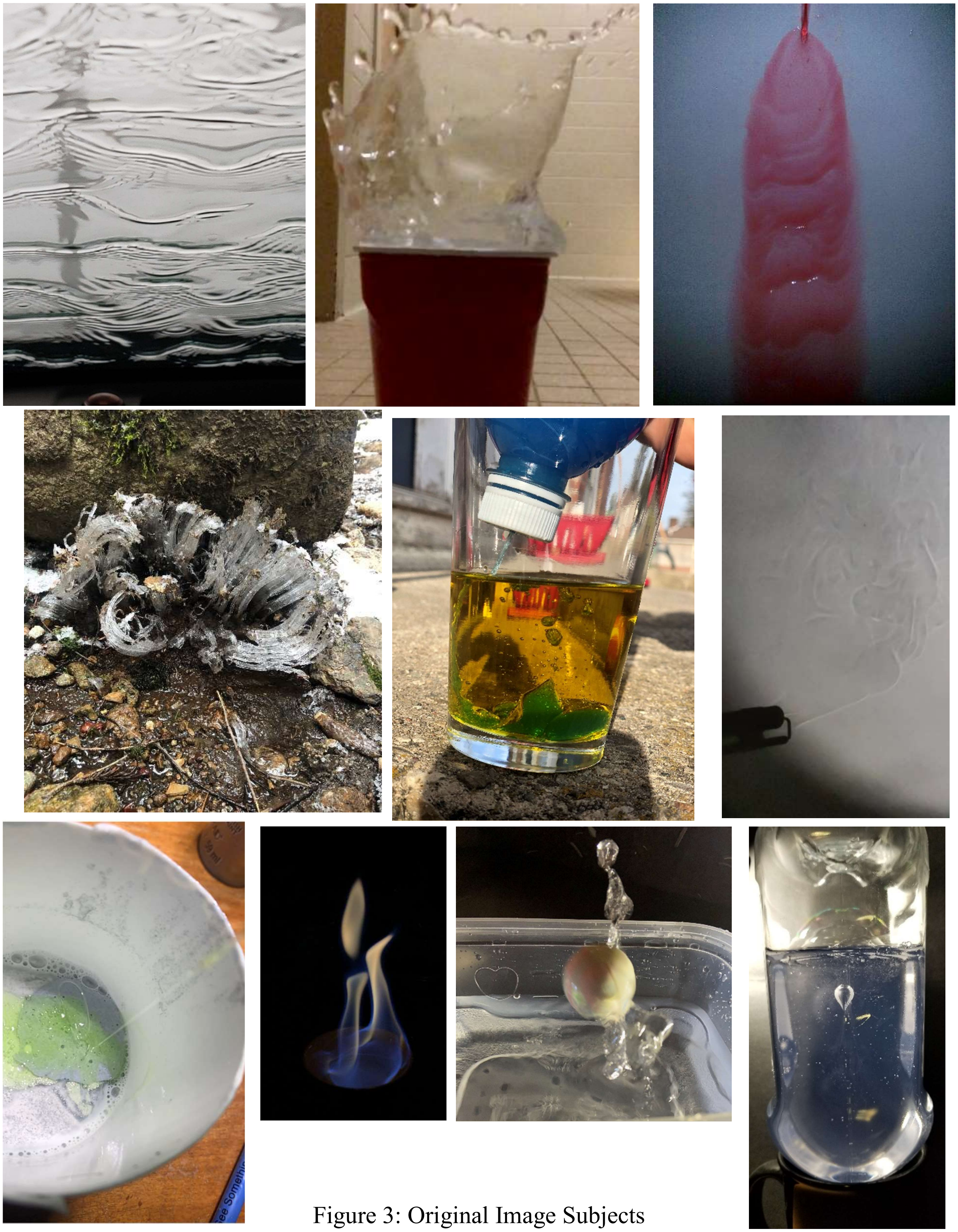

Figure 3: Original Image Subjects

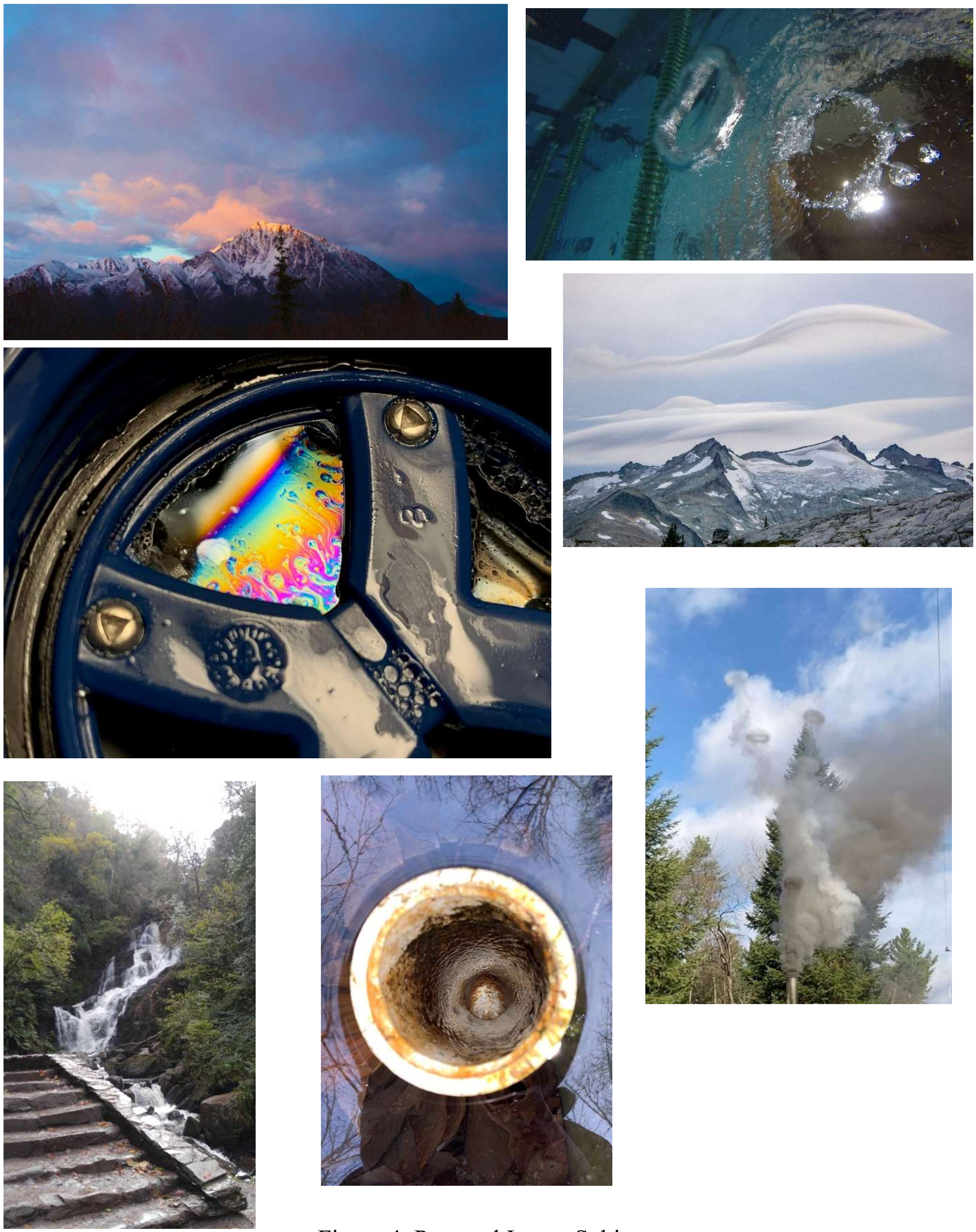

Figure 4: Personal Image Subjects

Assessment of Project Outcomes

Assessment and analysis of the project outcomes are now considered. Figure 5 shows the breakdown of the natural versus staged images. Roughly 66% of the students staged or purposely set-up the scene they imaged while 33% of the students used natural settings. Broadly speaking the natural setting were chosen due to a personal experience while the staged images were chosen because of a personal interest. The average and rms values of the metric scores are presented in Figure 6 for all students and also broken down based on natural and staged scenes. The originality score was found to be the lowest of the four metrics investigated. This was not surprising given that the students were new to the subject and did not have sufficient background to find original ideas. However, the average score of 2.8 was still well above the numeric average of 2 indicating that the majority of students came up with original or somewhat original subjects. The variation in the originality score for the staged projects was significantly higher than for natural subjects indicating students pick both easy and original phenomena to image. The highest mean score was found to be for the reflection metric (3.4) indicating the students were able to express why the image was interesting to them personally and that they were able to form a question based on the subject they chose. The most significant variation between the natural and staged subjects came in the image quality which showed a mean value of 3.2 vs 2.8 in that category. This was likely because the student who chose to stage images would have had to put effort into composing the image to score high in this metric, whereas the natural images subjects required less purposeful composition. Further, the natural images tended to be inherently more aesthetically interesting.

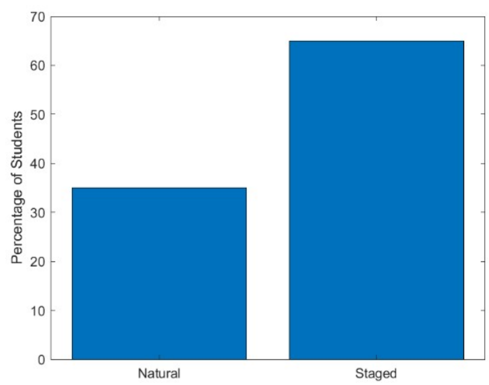

Figure 5: Breakdown of Project Subjects

The data were then sorted by each metric score to investigate relationships between metrics. For example, the data were sorted by the originality score and the mean scores for the other metrics (quality, clarity, and reflection) were determined. It is noted that the sample sizes for each mean as the distribution of scores were not equal, Figure 7. These distributions show that the only metric with a statistically significant number of students with a score of 1 was found for originality. The number of students whose images scored lowest for originality was still relatively low and indicative that relatively few students picked “easy” or “obvious” subjects. In fact, approximately 30% of the students picked highly original subjects. Image quality showed a peak at a score of 3 indicating that the majority of students turned in images that were well composed (quality score of 3 or 4). The distribution of students for these two metrics, which could be interpreted as "effort", indicated that the majority of students put effort into choosing a subject and executing the image. The clarity of the visualization of the flow was evenly distributed showing a wide range of success in this category. This was not surprising given the students were novices at fluid mechanics in general and flow visualization in particular. Approximately 80% of the students received a 3 or 4 on the reflection metric. Again, most students appeared to take the project either seriously or somewhat seriously.

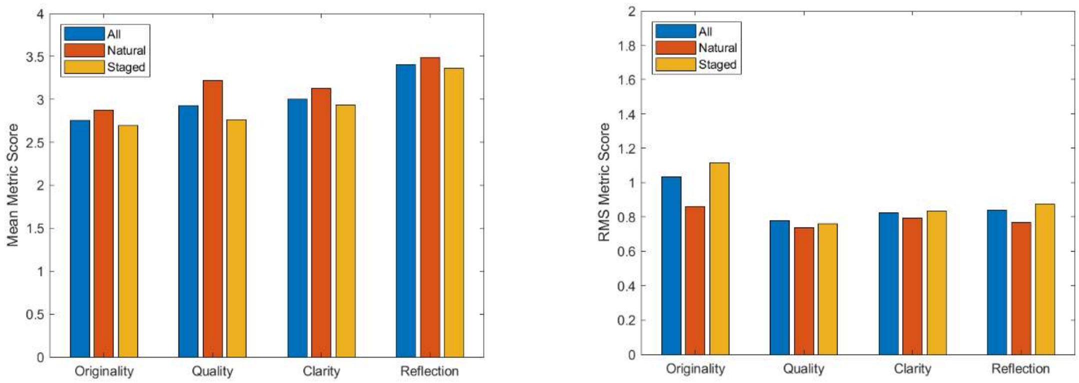

Figure 6: Average and RMS Metric Scores

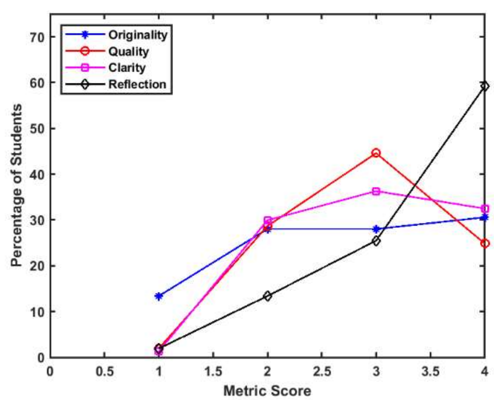

Figure 7: Metric Student Distribution

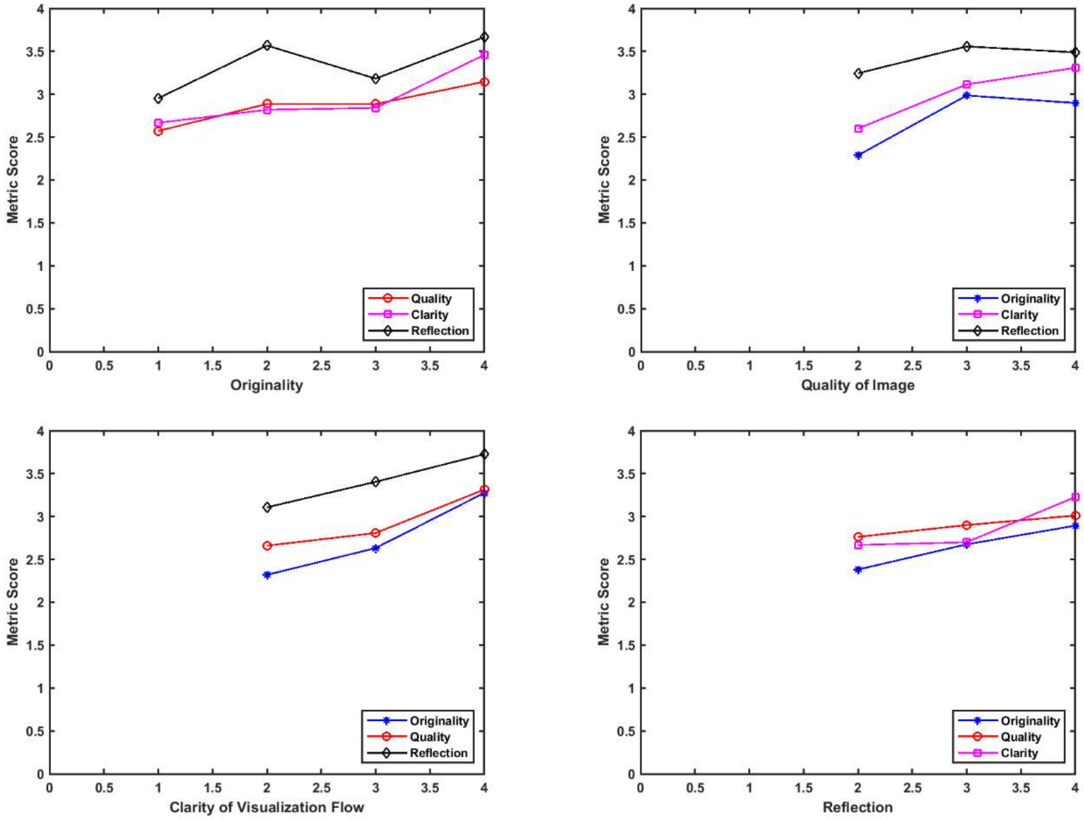

Figure 8: Metric Sorted Average Metric Scores

The mean sorted data are shown in Figure 8 to show relationships between metrics. Note that the data for metric scores of 1 were eliminated for all cases except originality due to the low number of students in those bins which made the mean statistically unreliable. The data show a general trend of an increasing relationship between the metrics. For example, students that scored low in originality generally also scored low on quality, clarity, and reflection. This was observed most strongly when the data were compared based on the clarity metric. This result indicated that the students who were most successful at staging a subject in which the flow was successfully visualized were most likely to score well in all metric categories. Finally, metric scores were considered with respect to student's final numeric grade for the course, Figure 9. This relationship was investigated to determine how well the project was able to reach students, particularly those with low course performance. Students were sorted in to bins of 100-90, 90-80, 80-70, 70-60 and <60. Means scores for each of the metric values were then calculated for each bin. The bin data for students with a course grade <60 were omitted again due to low number of students in this bin (4/157). These data indicate an increasing relationship in each metric value with the course grade. It was clear that students who were performing well in the class were the most likely to develop original ideas, execute the imaging well (both in terms of photographic quality and ability to see the flow), and had the most in depth reflections. This was not surprising given that students who were performing well in the course were mostly likely also highly engaged in the course. It was at first somewhat disappointing that the reflection metric tracked with course grade as well. It had been hoped that the student engagement and performance in the project would be more uniform. However, the scores on the reflection metric were always significantly above the other metric scores and ranged between 3 and 4, even for the students with lower course grades. This indicated that the students were able to find a subject for the project that was interesting to them, which met the goal of the project.

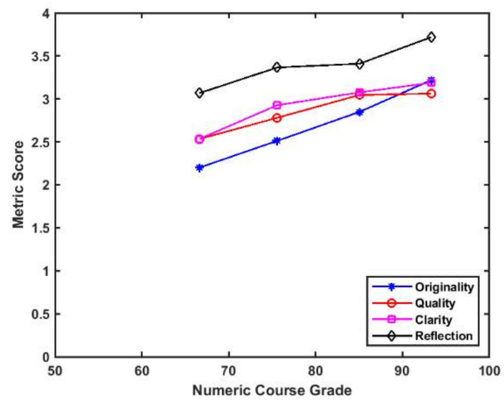

Figure 9: Mean Metric Scores versus Course Grade

Conclusions

This paper details a flow visualization project in an introductory undergraduate fluid mechanics course. The project asked the students to find a fluid dynamic flow field that they found personally interesting and could see a fluid phenomenon, and then take a picture of it. Students were asked to reflect on the image and communicate why they found the image to be interesting to them. The definition of “interesting” was left open to the students interpretation. The goal of the project was for students to connect the broader subject of fluid mechanics with their own personal interests to better engage them in the material. Project outcomes were assessed by assigning scores in four metric categories: Originality of project subject, aesthetic Quality of the image, Clarity of the flow visualization, and seriousness of the Reflection. The metrics were not used to assign the project grade. Metric scores were then correlated with each other and with the final course grade to assess the success of the project to meet the goal.

Students presented a broad variety of flow fields that included both natural (33%) and staged subjects (66%). The large number of staged projects indicated that the students were actively choosing flow fields to image. The projects that used natural settings tended to be motivated by personal experiences or interests. Both of these indicated that students were actively engaged in the project. Originality of the project subject was a weak indicator of project success. Some projects that score low for Originality were chosen because they were “easy”. For example, many projects used a magnetic stirring rod to generate a vortex in a beaker. Students had easy access to this device as it was being used in another class near the project due date. Other project subjects (e.g. flow in streams or waterfalls) scored low in Originality because they were historically popular with students. However, these projects tend to be chosen because of a student’s personal connection with the picture and therefore other metrics like Reflection scored high. Many students chose highly original subjects that were not discussed or shown as an example in class. These projects, unsurprisingly, scored high in all metrics. Similarly many students chose subjects for the project that were highly personal. Again, these projects typically presented high quality images and reflections due to the personal connection with the subject.

The metric scores gave insight into the success of the project to achieve the goal of connecting the broader topic of fluid mechanics with the student's personal lives. The metrics that directly indicate effort (i.e. quality, clarity, and reflection) all had mean values above 2.5/4. This result showed that the students were engaged in the project. In particular the metric scores on reflection were always 0.5 points higher than the other metric scores. This showed that students were engaged in the project sufficiently that they were able to pick a flow field that was personally interesting and communicate that. This was true even for students who has lower final course grades. Overall the project appeared to be successful in meeting its goal of having students connect the course subject to their personal lives.

Going forward several changes to the project will be made. First, the project description will be changed to better describe the requirements for the reflection section of the written report. The expectations for the scope of the reflection were not well described, and it is felt that the quality of the Reflections can be improved by clarifying the expectations. Second, the students will be asked to more clearly describe the flow phenomenon they are imaging. Currently the students are being asked to describe the image and many projects lacked a clear description of what is being shown (separation, sheet break-up into drops, etc.). This will enable a better assessment of the clarity metric and allow for the addition of a description metric. Finally two additional assessment tools will be added. Other faculty will be asked to look at the projects and provide assessment scores. This will make those assessment scores less subjective by adding additional independent observations. Students will also be given a survey to assess their level of engagement and ability to see the relevance of "fluid mechanics" in their personal and professional lives. This will be done at the beginning and end of the semester to quantify changes in attitudes.

Mid-semester Course Feedback Surveys
Extend the Reach of an Engineering Teaching Center

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Abstract

Formative mid-semester feedback to faculty can be used to improve a course before the summative end-of-semester teaching evaluations run by a college or university. The James McCormick Family Teaching Excellence Institute (MTEI) has changed the culture in Cornell University's College of Engineering such that the norm across most of the departments in the college is to incorporate mid-semester feedback accompanied by actionable suggestions from MTEI. Faculty taking specific individualized action on student-identified problem areas each semester, when carried out by many professors across multiple semesters and in many courses, increases the impact of MTEI far beyond the handful of "regulars" who would attend a teaching development event.

The mid-semester survey MTEI uses was created in collaboration with faculty in one department and across the last seven years has been modified and fully adopted in seven additional departments and partially adopted in several more departments. The surveys can be customized according to individual departments and instructors' preferences. The mid-semester feedback is conducted via anonymous, adaptive Qualtrics surveys deployed to the students enrolled in each participating course.

The survey design and implementation has been mindful of both student and faculty time. Students first select aspects of the course they feel need improvement and are only asked detailed survey questions about those areas. Then students respond to multiple select questions to identify what is going particularly well in the course, both in class and on assignments. A third block of questions, suggested and vetted by Cornell’s Diversity Programs in Engineering Office, asks students about feeling included in the course. Using drill-down and multiple select options organizes student's responses, making it more efficient to identify themes in the data. When the students' responses have been collected, MTEI personnel read through each course's report, highlight key pieces of student feedback, and send the report to the instructor in an email including a summary and actionable suggestions to address significant student concerns. Faculty then have the option of reading the full report for themselves or focusing just on the MTEI analysis. They can spend their time, effort, and focus on improving the course, not on the logistics of creating and running feedback surveys.

While the feedback and responses are at the course level, across the college we see improvements in how often strengths of courses are cited by students. The process is labor-intensive for MTEI, but it is efficient for both students and faculty, and is a key component of improving the general level of teaching effectiveness across the college.

Introduction and motivation

As a teaching center, MTEI's goal is to assist **all** faculty in improving their courses and teaching skills. For faculty at the beginning of their teaching careers, we provide information, support and feedback for a strong start in teaching so they build confidence and identity as good teachers. For highly skilled teachers, MTEI offers assistance with planning and assessment of new approaches, or technology, or learning activities they created. Both of these groups of faculty are highly motivated and seek out and welcome assistance. For teachers needing significant and more specialized support, their departments frequently encourage them to seek assistance to increase their teaching skills. For various reasons (research, too many classes, high service load, etc.), there is a large population of teachers between the groups described above who could use help increasing their teaching and communication skills as shown in the middle levels of the teaching skills hierarchy in Figure 1. This population of teachers may not attend MTEI programming, but will frequently respond well to information tied to their specific course(s) that is timely and time efficient to implement. Reaching all faculty, including in this last group, has guided the design and implementation of the mid-semester course feedback program.

MTEI is supported and mentored by very successful alumni and we value the insights and external perspectives they share with us. They have strongly supported this effort to reach all faculty. Alumnus James McCormick, founder First Manhattan Consulting Group, has served as a program consultant since MTEI's founding in 2008 and based on his experience in driving change in businesses, he has continually advanced the idea of reaching all faculty, not just those who typically participate in our programs. This has led to a strong focus on reaching the broad and middle range of teachers and has been a driving force in MTEI programming, especially for the department-wide mid-semester feedback surveys. Figures 1 and 2 reveal how we have deliberately looked at different categories of teachers and built programs to support them and reach them where they are.

The work described in this paper has three motivations:

1) **Provide nearly all engineering teaching faculty with a time-efficient method to incrementally improve their courses and engage with MTEI,**
2) **Provide students with an efficient, anonymous, routine way to provide feedback on courses before the end of the semester, and**
3) **Provide an "early alert" for courses that might have diversity and inclusion issues.**

To accomplish these goals, MTEI created a carefully designed mid-semester student feedback survey that reaches nearly 200 courses and provides most of our faculty with timely, incremental, time-efficient suggestions of steps they can immediately take to improve their course and teaching. Developing the feedback survey required extensive effort. The next sections will briefly explore the literature regarding the development of mid-semester feedback surveys followed by a discussion of the development of MTEI's implementation.

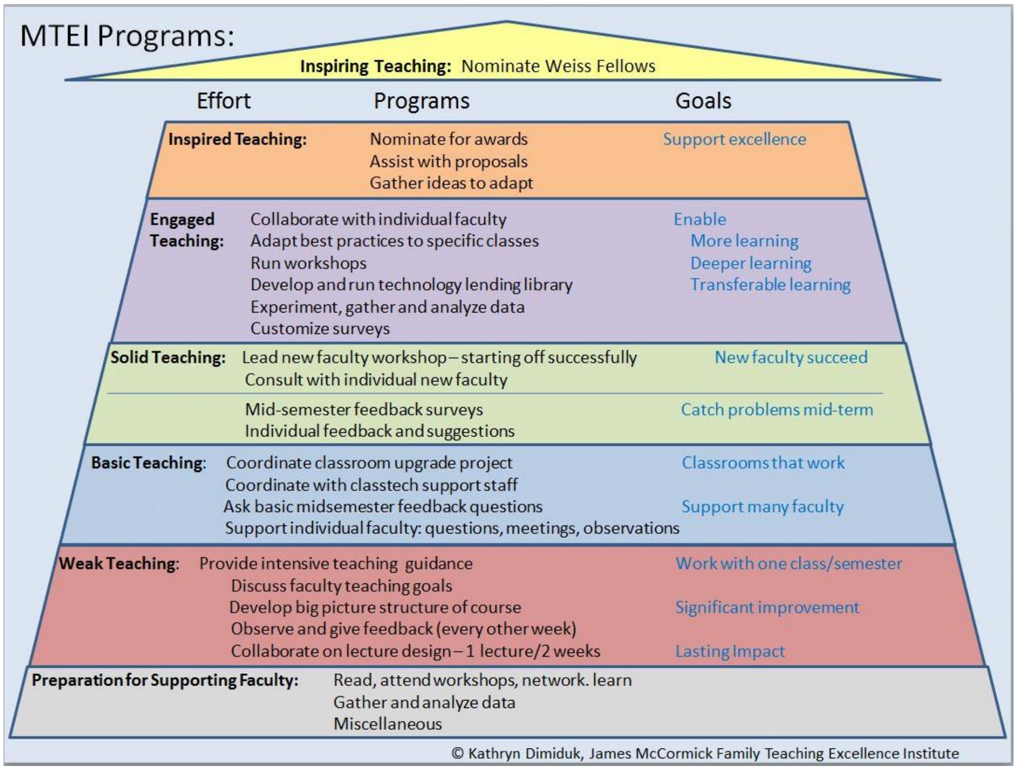

Fig. 1. Teaching skills hierarchy

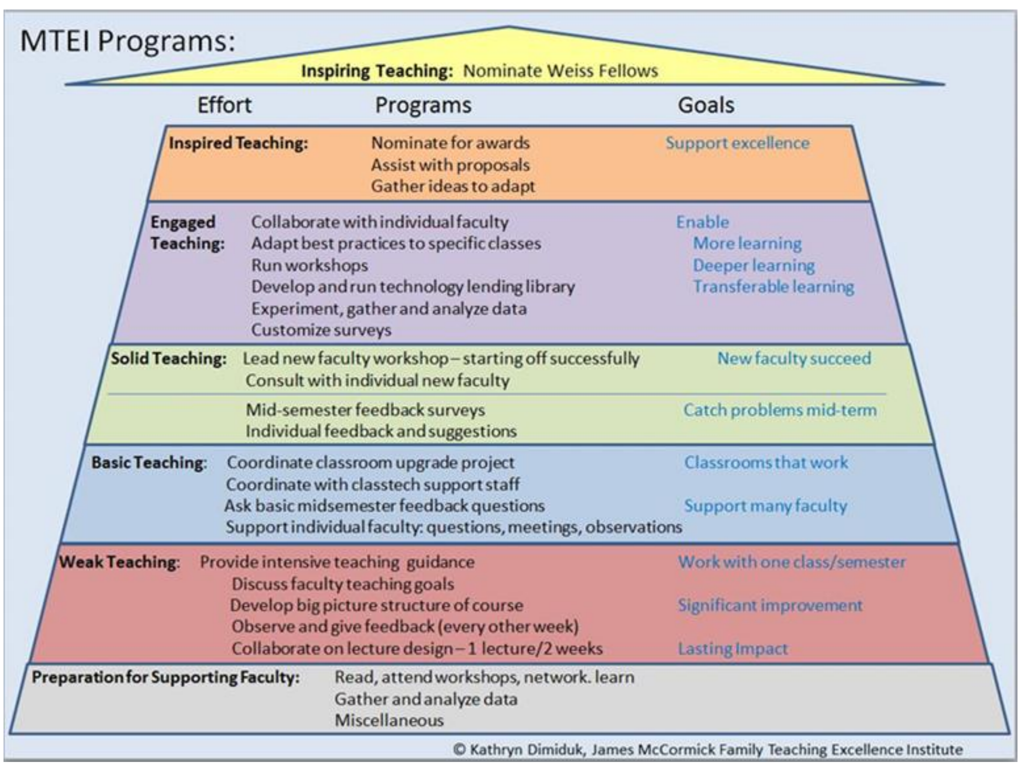

Fig. 2. Mapping MTEI programs to the teaching skills hierarchy

Literature review of mid-semester evaluations

Formative assessments (mid-semester evaluations) have proven valuable in providing student feedback [1] [2]. Mid-term student evaluations have long been fertile ground by which faculty growth and development has been re-examined and reassessed [3] [4]. In 1970, a teaching center at the University of Washington created an assessment tool, Small Group Instructional Diagnosis (SGID), which provided an opportunity for faculty and lecturers to obtain a better grasp of course structure and course materials and to better understand student feedback while the course was still in progress. Changes could be made to various aspects of departmental courses and students and faculty in turn saw more powerful and positive summative evaluations. SGID quickly gained faculty interest due to increased student motivation in courses, and faculty saw concrete and immediate ways to make changes to help students and potentially change future courses [5].

One challenge with SGID early on was to increase the number of faculty involved in mid-semester evaluations. Many faculty who participated with this assessment tool were already well established, motivated and skilled teachers. Strategies such as making it mandatory for new faculty to evaluate the process after their first year, making the questions more course specific and assisting faculty in understanding the benefits of mid-semester evaluations to their courses proved to be compelling methods in gaining more faculty interest [6] [7] [8]

Formative assessments have significantly changed over years. Key studies using formative assessments illustrate the importance of continuously thinking about mid-semester evaluations [9] [10] [11]. Kulik's study focused on teaching center facilitators who followed up with faculty as a crucial intervention after implementing mid-semester evaluations [9]. The results confirmed that faculty who received teaching center "consultations" (comments, suggestions, and feedback) had significantly higher progress than those who did not receive "consultations". Many studies have used facilitators to administer formative assessments [9] [10] [11] [12]. These studies used multiple disciplines, departments, and various class sizes and levels.

Technological advances have opened new possibilities for how the assessments are administered and also enhanced the possibility of questions becoming more applicable to students and more course specific. One use of technology was an online collaboration assessment. Students, in small groups, were requested to use Google Docs, an online tool which allows students to interactively respond to the evaluations. All students were able to view each other's comments and respond to the comments. Google Docs is familiar to many students and requires no software purchase [13]. This study was successful with many students. Despite this success using Google Docs, there remains questions of anonymity and the willingness of some students to share information when peers have visible access to their responses.

Many studies [12] [14] recognize the importance of teaching center or facilitator intervention in the mid-semester evaluative process. Diamond's study [15], for example, used a longitudinal study with SGIDs, where facilitators were central to the mid-semester evaluation process. They asked key standardized open-ended questions: "1) What aspects of this course/instruction enhance your learning? 2) What aspects of this course/instruction could be improved? 3) What could you-as the student-do to make the course better for yourself, your classmates, and the lecturer?" [15] The facilitator gathers the top responses and shares them with faculty. The facilitator would offer suggestions and resources on how to address these concerns with students.

Two key aspects differentiating the MTEI mid-semester feedback surveys from Diamond's are student anonymity and scalability to a large number of courses. MTEI uses Qualtrics surveys to allow students to participate in the evaluations outside of class with complete anonymity. Scaling is enabled by MTEI's approach of efficiency in the surveys. Survey logic adapts the questions students see based on the topics that students say need improvement, thus gathering pertinent information while reducing the number of questions the students see. In addition many questions are multiple select based on MTEI's experience with student answers, with an "other" for anything else students want to add. This reduces the number of free response comments and enables automatic tallying of results.

After gathering student data from the surveys, MTEI is able to identify which courses need specialized and focused intervention. Similar to other studies in the literature review, once issues regarding courses have been identified, MTEI makes suggestions through individual emails that accompany the reports sent to faculty, and follow-up telephone and in-person discussions and classroom observations. Faculty have been motivated and open to making necessary adjustments to their courses mid-semester and for their future courses.

Discussions and training/workshops at many universities and within mainstream society have heightened awareness and consciousness around issues of diversity. The literature is inundated with data discussing either diversity or mid semester evaluations, but there is little data on the impact these entities have on one another. However, in 2015, African American students at Emory University demanded that faculty include "open-ended micro-aggression questions" on teacher evaluations in order that they have a safe and anonymous space to share their feedback. [16] Micro-aggressions, according to psychologist and leading author on the subject, Derald Sue, are: "The everyday slights, indignities, put downs and insults that people of color, women, LGBT populations or those who are marginalized experiences in their day-to-day interactions with people." [17] Micro-aggressions are often subtly expressed and often without malicious intent. Cornell has incorporated diversity and inclusion questions into the mid-semester surveys that exposes micro-aggressions and other issues facing classes.

Creation of the surveys at Cornell

The idea for the department-wide mid-semester feedback surveys grew out of a discussion requested by a graduating senior. He pointed out that students had no way to anonymously provide feedback while a course is in progress, neither to the professor, nor to the department. He felt this was a significant failure that should be addressed. At that time, mid-semester feedback was typically only done by individual instructors who wanted to excel in teaching, not the courses of greatest concern to the students. To address the issue**, mid-semester feedback surveys would have to be normalized in the department and given to all students in all courses. This would need to be done in a way that had faculty support, wasn't burdensome to students or faculty, and that also provided an "early alert" for courses that were having difficulties.**

The resulting survey was designed with an adaptive, multiple-select, drill-down-to-problem-areas approach. Students initially rate the course as quite good or needing improvement in one or more areas. This defines the path through the survey, either to a pair of open-ended questions asking what is good and what needs improvement or to a deeper dive into problem areas, first selecting problem areas and then providing more detailed information. This allows easy tallying of responses to identify problem areas, some free-response questions to capture details and students not seeing irrelevant questions. The result was detailed information on problem areas from a small set of questions that each student saw. The multiple select answers were based on MTEI's extensive experience with course evaluations and recurring concerns. Faculty input was sought on the exact wording of questions and potential responses so that the resulting survey reports would resonate with them. This careful question and answer choice phrasing minimized the number of students who selected "other" which made the surveys efficient for students to take and for MTEI to tally results. Figure 3 and 3a show the survey flow for the first block of questions. If a student selected "needs improvement in one or more areas" a multiple select question showing potential problem areas was asked next. Depending on the answers selected, additional questions on the specific areas were asked, drilling down for more detailed information on those problem areas. Questions related to topics not selected were skipped.

The survey was adopted for all courses in the pilot department, with an opt-out option if a professor had his or her own mid-semester feedback system that was more tailored to a specific course. Word spread between faculty and two more departments immediately adopted the survey and additional departments were added across the following semesters.

As the survey adoption grew, there was strong faculty interest in also reporting on the strengths of courses in a systematic way and not just with open-ended comments. This led to a second block of questions that asked about strengths in the lecture component of the course and in assignments using multiple select questions. See Figure 4.

The results were presented as a bar graph so faculty could quickly see which strengths students saw in their course and which ones weren't as present. As one faculty succinctly stated – "but all of these are important strengths, shouldn't I be doing well at all of them? I'm going to try for more next semester." A question was also added to measure whether students saw active learning happening in their classes. Figure 5 compares student responses concerning strengths for a particular course where the professor worked on increasing strengths over several years.

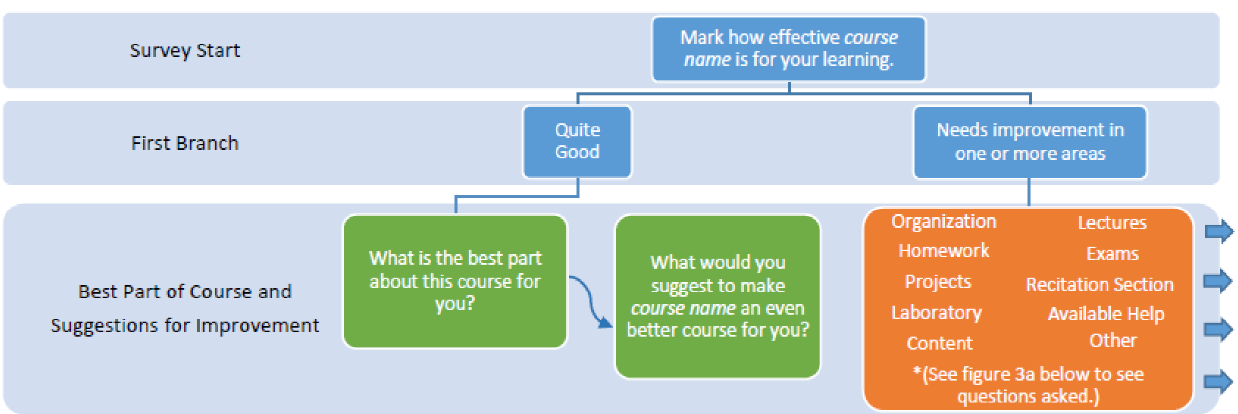

Fig. 3. First block of questions showing survey path (Green background indicates open-ended question; orange background indicates multiple select question). Continues in Fig. 3a.

Topic	Question	Answers
Organization	Which of the following change(s) to the course organization would help you learn more? (check all that apply)	• Better organize the content across the course. • Use a textbook. • Make the organization of the lectures more apparent. • Make the workload more even, less sporadic. • Modify the homework due dates. I would suggest... because.... • Assign homework earlier so we have more time before it is due. • Don't assume we know material that was only briefly mentioned in earlier courses. An example is • Don't repeat large parts of earlier courses. An example is • Try to make fewer mistakes. • Start and end on time. • Other
Lectures	I could learn better from lectures if you would (check all that apply)	• not cancel multiple lectures • write larger • improve your handwriting • speak louder or use a microphone • organize the lecture better • make lectures more interesting • include more examples • make the explanations clearer • use clickers • use clickers differently, elaborate • engage students more by • other, please elaborate

Fig. 3a. Examples of additional targeted (drill-down) questions that were included based on the identified problem areas (see the orange block in Figure 3)

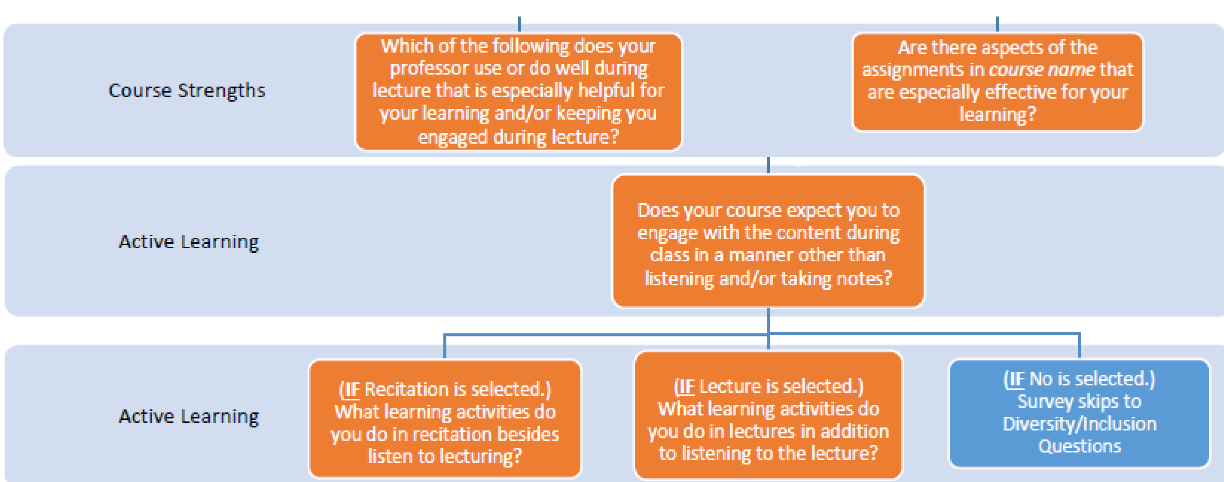

Fig. 4. Question block 2 seen by all students: strengths of the course, and active learning

Survey Question: Which of the following does your professor use or do well during lecture that is especially helpful for your learning and/or keeping you engaged during lecture? Select all that apply, if any.

Example Class (F17 vs. F19)

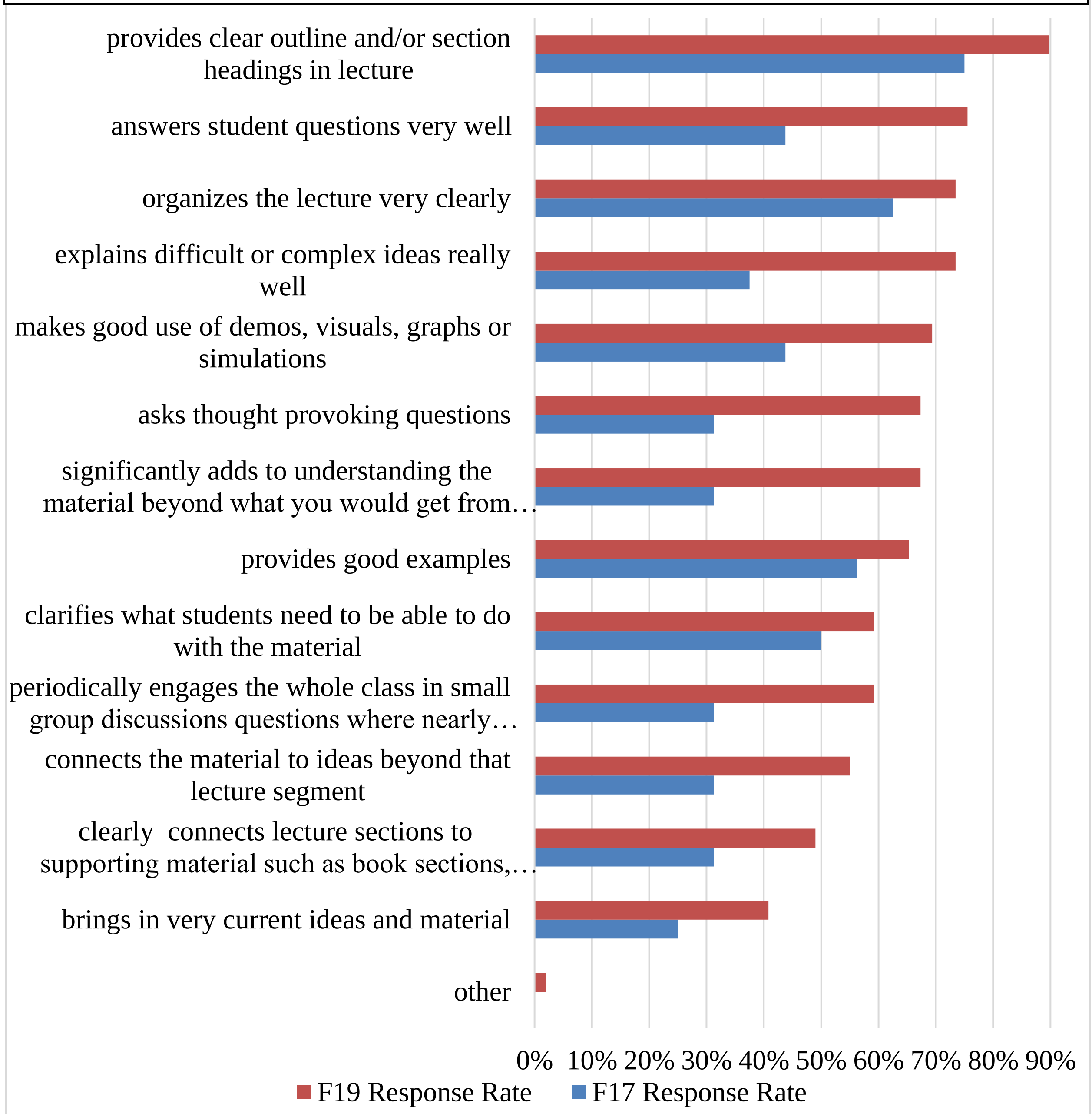

Fig. 5. Example bar graph showing how the lecture strengths responses has changed over time for a particular course. This emphasizes that the survey itself can serve to suggest and motivate areas to improve year to year, even for an already good course.

The third block of questions, Figure 6 and 6a, was created in response to student concerns around diversity and inclusion and how to easily report things that made them uncomfortable in a class but didn't rise to the level of filing a formal report. These questions were developed by authors Dimiduk and Carter in coordination with Cornell's Diversity Programs in Engineering, and were worded with an intent to capture diversity or inclusion concerns in a broad sense. This provides a way to identify not just larger issues, but also micro-aggressions, which course staff might otherwise be unaware of, and bring them to the attention of faculty. The surveys were not intended to, nor do they replace formal reporting of serious issues.

The next section will briefly explain how MTEI implements and processes the mid-semester surveys. Currently the survey fully reaches 8 departments, includes some courses in several more departments, and covers nearly 200 courses each semester.

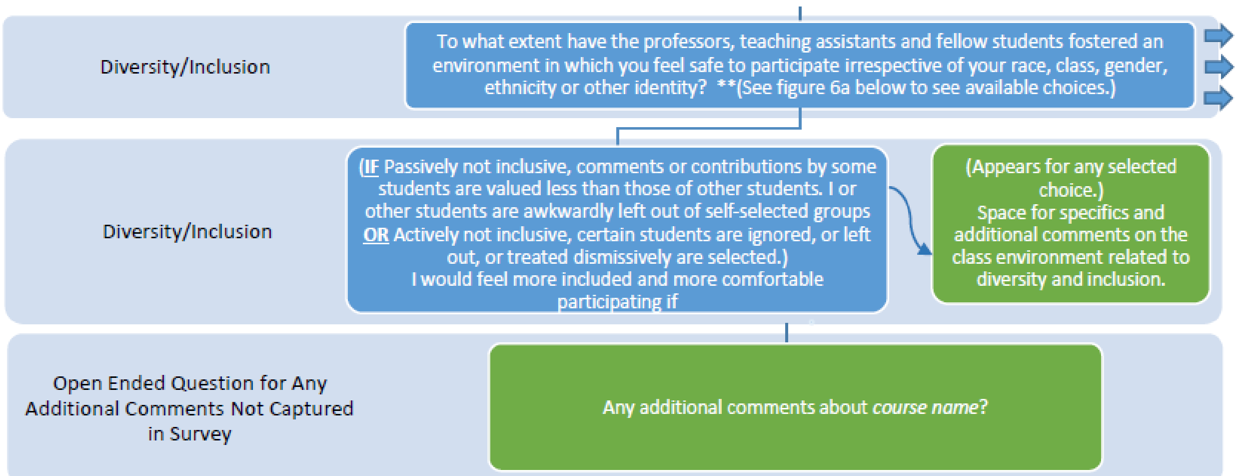

Fig. 6. Diversity and inclusion questions

Answers
Actively inclusive, all are fully encouraged to participate and are supported.
Passively inclusive, everyone is welcome to participate. Nothing specific to encourage or discourage anyone.
Passively not inclusive, comments or contributions by some students are valued less than those of other students. I or other students are awkwardly left out of self-selected groups.
Actively not inclusive, certain students are ignored, or left out, or treated dismissively.

Fig. 6a. Available choices for the first diversity and inclusion question (see the top blue block in Figure 6)

Survey implementation and processing

Each semester, MTEI works closely with each department to ensure that all courses are included and that co-listed courses appear only in the parent department's survey so students are not surveyed multiple times for the same course. Timelines are set for faculty input for additional questions for specific courses and survey dates. Part time (seven weeks or less), special topics, research, independent, seminar, and colloquium type courses are typically excluded from the mid-semester survey. Surveys are created in Qualtrics and shared with participating departments.

Departments communicate any changes (classes cross listed, removing or adding classes, or course name changes). Departments alert students to the survey process and usually give a brief overview of the purpose of the surveys, how the surveys should be taken, their anonymity, and the dates the surveys will close. MTEI tests each survey to alleviate any malfunctions in the system before the final launch. Student enrollment data is turned into a Qualtrics email list. Students who have not yet completed the survey receive reminder alerts every other day to complete the survey.

Once the surveys close, MTEI generates reports for each course which MTEI faculty then read, comment on, and share with faculty and departments. This whole process takes considerable MTEI effort, but very little effort from most faculty. Faculty focus and effort is reserved for considering and making changes to their teaching and courses after they receive their reports.

Mid-semester feedback reports

Each mid-semester feedback report is read by the MTEI director or a faculty teaching fellow at the center. They then write an individual email to the course instructor highlighting something that is going well in the course, something actionable that the students would like improved, and suggestion(s) on potential improvements. The suggestions focus on something straight-forward that the faculty member can try in the next several classes. Because the suggestions are directly tied to student concerns and are written in terms of straight forward actions, faculty have been remarkably receptive to feedback and willing to try something slightly different. Faculty don't feel singled out as all faculty in the department get the emails. Some faculty pore over the reports themselves and some comment that they really like the summary and suggestions as that is easier both in terms of time and angst of reading negative comments. For more complicated suggestions or courses with multiple, significant issues, a meeting with the professor and potentially sitting in on a class is suggested. Occasionally, a suggestion is included for the next time the class is taught as a way to avoid the problem in a later semester. Table 2 illustrates frequent responses from students and strategies MTEI implemented to address the issues.

These are all straightforward ideas and standard teaching center fare. The impact comes from sending an individual email to faculty tying specific suggestions to student concerns brought up on the feedback survey for their course. By leveraging what students report and that all classes in a department are included, we are providing next step suggestions to most of the faculty each semester. Small steps each semester adds up to noticeable progress over time.

Table 2. Student concerns/ MTEI actions

Student Concern	Action(s) Suggested by MTEI
Can't hear	Suggest using the microphone and information on its location. If the professor is already using the mic, a ticket is sent to the AV support group to adjust the sound levels.
Lecture is disorganized	Suggest starting lecture with a brief outline, 3-4 lines. Add headings in the lecture as well. Add a summary or take-away slide at the end or write on the board.
Confusion on the course project	Suggest next lecture reviewing project information and then using a muddiest-point- minute-paper to identify remaining points of confusion. Suggest a rubric.
Students concerned they don't know what the exam will be like	Point students to learning outcomes. Potentially go over some high-level review of the course showing how the ideas are connected and what you consider important. This focuses students' review efforts on what you think is important
Homework is out of pace with the lecture	Suggest rather than staying off cycle, moving a problem or two to the next assignment to get back in sync
Content is just lots of bits and pieces.	Suggest spending part of a lecture to go over at a high-level what has been covered and how it all fits together and/or where the material is going for the rest of the class.
Students are confused.	Suggest muddiest-point-papers to learn where they are confused. Send the information to recitation leaders or go over a few points in the next lecture.
Class is boring.	Suggest active learning such as think pair share. Include information on implementing the suggested active learning method.
Need more examples.	Point out the request and ask if more can fit in the class. If not, suggest making a video of an additional example worked in detail for particularly hard topics. Make 2 or 3 a semester and over time you build up a library.
Lectures move too fast.	Suggest moving some material out of class, via posted readings or short videos. Those videos can be either video lecture capture or tablet-based screen and voice capture.
Homework grading too slow.	Suggest clarifying expectations of TAs or homework graders. Suggest simplifying the homework grading rubric to focus primarily on completion with fewer problems graded in detail.
TAs unprepared for discussion sections and office hours.	Suggest making explicit what has been covered in most recent lectures and what TAs need to cover. Require TAs to have fully worked all problems for discussion sections, not just read over provided solutions. Have homework solutions available for TAs well ahead of office hours and explicitly require them to familiarize themselves with the solutions beforehand.

When the mid-semester surveys were first introduced, the dominant complaints were around organization. That concern is much less frequent now and most classes now have a strong showing in the lecture strengths question for using outlines and headings. This was not the case when strengths were first included as a question. More recently, lack-of-engagement in lecture has been increasingly brought up by students, so suggestions have been including simple active learning approaches. A few semesters later the active learning questions are now showing more positive responses.

Every semester MTEI does further follow-up with a few courses including observing a class and meeting with the professor. For example, one semester, in a particular course, students reported the male professor was giving the women students a hard time if they answered or asked a question. They perceived that he was making faces at them while they answered and he would come stand right over them. The MTEI director, female, met with the professor, observed the class and saw exactly this behavior. Following up with him after class, he made faces at her too. When pointed out, his response was he was trying to clear his ears as she was very soft spoken, as were all the women in his class. From the classroom observation, all the women were not soft-spoken; this was the clue to the underlying problem. The professor had lost some hearing and couldn't hear the women students. He was moving close to them and trying to clear his ears in an attempt to hear them. Once this was identified, he treated it as an engineering problem to be solved; he needed data so he went for a hearing test, and was fitted for hearing aids. He was open with the students about the underlying issue and having initially lost some hearing at an engineering internship years ago working with a pile driver. The hearing loss was exacerbated now that he was older. The following semester there was no evidence of the problem in the student feedback. Thus, what could have been a serious bias complaint instead became a teachable moment on many levels – as an engineering problem, as a hearing protection issue, as a communication issue, and as a role model for addressing a disability directly to remediate and resolve the underlying problem.

In another example, one class had many students report "lecture not organized" while at the same time many students selected that lectures made good use of an outline and headings. This discrepancy was quite unusual. A classroom observation made the underlying issue apparent. The instructor was starting the class with a brief outline of the class and connecting the lecture to the previous lecture. However, this was an early morning class, and half the students arrived late – after the outline and connection building had already been presented. The problem was resolved by writing the outline on a side board and leaving it up across the lecture. Students were reminded to come on time but for many, the class was earlier than they could arrive on time. The outline on the side allowed them to more easily pick up on the lecture at whatever point they arrived and also to know what they had to review on their own. In this case, it was valuable that the MTEI director had been reading the feedback for many semesters and recognized the out-of-character feedback indicating there was a problem with this particular course.

For the diversity question in Fig. 6 and 6a, nearly all students choose the answers actively or passively inclusive. For any classes where even one student selects passively or actively non-inclusive, the text answers to the diversity block and other text answers in the survey are carefully read. Faculty are alerted to issues and encouraged to address the issue themselves, or with the TAs or in a discussion with the whole class depending on the source of the issues. While this represents less than 1% of classes and responses in any semester, we take these student concerns seriously. Some specific issues for faculty and TAs that leave students feeling excluded include: presumed common experiences not being common, political bias, gender insensitive examples in class, international students treated as "foreigners", and English speaking students feeling excluded if the TA switches to the TA's native language rather than English in office hours. Women students feeling excluded in group work or lab groups has come up multiple times and faculty are encouraged to address this in class. Faculty can only address these issues if they know about them. A few students write to say they resent this question and more write to say they appreciate the question being asked. Because the surveys are anonymous, we cannot follow up with individual students, so the question does have information on where to report incidents or to get support through the Diversity Programs in Engineering Office.

Departmental use of the mid-semester feedback

A summary table is created for each department that gives the percentage of students who said each course was quite good. This information is shared with the appropriate person in department leadership and gives a quick view of which courses might be experiencing difficulties. In some departments this is the only information given to the chair and the rest of the survey only goes to MTEI (who create the reports) and the individual faculty members. Individual faculty can share the results further if they wish and can include information in their performance reviews at their choice. In other departments, the culture is that all the reports are shared with departmental leadership. Some departments add questions to surveys for all their courses to address broader curriculum development.

Conclusion

We have met the following goals:

- Students now have an anonymous method to provide feedback for many (nearly 200) courses mid-semester.
- The surveys reach nearly all the courses in eight departments so this feedback is an accepted part of the department culture for all instructors in these departments, weak or strong.
- We send a signal to students that we are paying attention across the college to the course environment and whether students feel included or not. This sometimes identifies micro-aggressions that can be addressed. Usually these are unintentional and the faculty were unaware they were happening in the course. Faculty then make changes and usually the issue doesn't show up the next time the course is taught.
- Faculty receive individualized teaching tips for their specific course.
- Faculty teaching strengths are also recognized thus encouraging the growth of teaching strengths.
- MTEI now routinely interacts with over three quarters of the faculty in the college in any given semester.
- Teaching tip emails and teaching discussion lunches can be targeted to issues that show up across multiple courses.
- Across multiple semesters we see an increase in the strengths reported in teaching and a decrease in basic teaching problem areas which can be measured.

Because MTEI faculty read all the comments, they develop a sense of teaching strengths and issues across departments and the college. This informs topic selection for other MTEI programming such as periodic Teaching Tip emails that go out to all teaching faculty and periodic small group Teaching Discussion Lunches. In addition to general invitations to the lunches, individual invitations are sent to faculty for whom a topic might be particularly relevant. For example, when students raised concerns about lab courses across multiple departments, a discussion lunch around lab courses was organized and all lab instructors were specifically invited and encouraged to attend. Ideas and potential solutions were shared across departments that might otherwise have been siloed.

This mid-semester feedback program requires a significant effort from MTEI, but is very efficient with faculty time. It is incrementally improving teaching across a wide range of courses. We have seen an increase in the use of active learning as reported by students following several semesters of tips including active learning suggestions and instructions. In conclusion, we believe that the mid-semester student feedback surveys paired with individual emails with targeted teaching tips have been effective at extending the reach and impact of MTEI to a much broader pool of faculty and courses than we could reach with other methods.

This mid-semester feedback process, and the individualized observations on strengths and improvement opportunities, is a win/win: students are better served, and faculty self-confidence in delivering a superior educational experience is bolstered.

Next steps

There are several directions for next steps. A version of the survey for large CS coding classes is being developed and piloted. MTEI is also creating a Python program to take the Qualtrics data from a department-wide survey and automate generating drafts of the reports. With the new reporting tool, we will also be able to sum responses across a department or type of course and look for trends in problem areas that can then perhaps be addressed more generally rather than just at the course level.

Measuring the results of our diversity initiatives by identifying micro-aggressions and larger issues in classes is the first step towards addressing them. This is an ongoing process we are working on to make our classes more inclusive and increase student success. The data revealed will be used to inform trainings and workshops and share with academic circles.

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Prof. Wolfgang Sachse in Mechanical and Aerospace Engineering at Cornell was especially helpful and vested in making sure the questions were just right.

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Extended Abstracts

Making an Olin Grand Challenges Scholars Program: Co-Creating with Students

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[1]Olin College of Engineering

Olin College established its Grand Challenges Scholars Program (GCSP) in 2010, one of the first three programs in the country that created a set of curricular and co-curricular experiences intended to motivate and empower engineering students to address pressing 21st century global issues [1]. Olin's original program was designed collaboratively by students, faculty, and alumni, and was intended to be primarily student driven. Over time, the needs of the student body changed as Olin grew into a more established institution. Thus when a new GCSP director took over, a group of faculty, staff, and students took the opportunity to reinvent the program. The goals of this redesign process included increasing student engagement with some of the GCSP competencies and adding scaffolding to further support students' deep reflection and synthesis of lessons learned through distinct experiences [1]. (For more on this reinvention process, see [2].) Olin's "GCSP 2.0," launched in fall 2018, was again created by faculty and (current) students working together to design educational engagements that deliver a valuable GCSP experience attuned to the specific context of Olin, such as the curriculum and the culture.

While the original program design process was entirely collaborative, the redesign was a hybrid approach, with the program director providing a more centralized point of decision-making while still working closely with colleagues and students. This process was better suited to the changing circumstances at Olin and is perhaps more easily replicable at other institutions than a fully collaborative co-design. Students were highly involved in generating ideas, co-designing program components, and providing feedback on revamped program elements--all means of engagement that could be carefully scaffolded to succeed in a variety of environments [3].

A cornerstone of the revised GCSP is the course "Change the World: Personal Values, Global Impacts, and Making an Olin GCSP." This course was created and taught by a Professor of the History of Science and Technology and an Assistant Professor of Environmental Engineering (who is also Olin's GCSP Director), with significant input from students. It was another example of a co-creation process in which a few faculty leaders made final decisions based on engagement with students. The resulting course, taught for the first time in spring 2019, used a combination of individual and group projects, analytical and reflective assignments, readings, and discussions to address learning objectives of critical thinking and reflection, identity development, communication [4], and pluralism (i.e., embracing many ways of knowing and being, inspired by [5]). To continue the cycle of student co-creation, one of the small projects within the course asked students to reinvent portions of the course itself or the larger GCSP program at Olin; aspects of students' submissions are being incorporated into the second offering of the course for spring 2020. For example, one suggestion proposed modifications to a group project--in which students explored various grand challenge-like frameworks, including the NAE's report and the UN Sustainable Development Goals--to incorporate some individual components, allowing students to benefit from collaborative learning while creating space for them to dive deeper into their own ideas and priorities. In addition, student feedback on the course was solicited at several points during the semester to allow for iterative, ongoing improvement. Some suggestions were implemented almost immediately while others are being applied for the second offering of the course. This feedback not only resulted in important improvements to the course, but also fostered a highly positive, collaborative classroom environment and culture that made the students aware of their own cognitive preferences and processes, and encouraged them to proactively take steps to maximize their engagement and learning.

In this talk, we'll introduce the salient pedagogical and structural components of this course, such as major projects, learning objectives, and classroom activities, and explain what makes them effective. We will also analyze the impacts of the semi-centralized co-creation process used to develop the course and to revise Olin's GCSP. We'll share lessons learned on how co-creation of educational experiences with students can be a learning experience as well as a productive design activity, resulting in increases in student motivation and student management of their learning processes, valuable course content creation and revision, and an enriching engagement for everyone involved.

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Catapult Design Experiences for Deaf Engineering Technology Students at NTID

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Introduction. Courses that introduce engineering concepts to first-year students are now including more hands-on activities to help engineering and engineering technology students to better understand fundamental engineering concepts. At Rochester Institute of Technology's (RIT) College of Engineering Technology and the National Technical Institute for the Deaf's (NTID) Department of Engineering Studies, deaf and hard-of-hearing (D/HH) engineering technology students are introduced to engineering technology in the NETS-101 Fundamentals of Engineering course and are taught directly through American Sign Language (ASL). This course introduces the profession of engineering/engineering technology, ethics and safety, engineering specialties and career opportunities, educational requirements, design, teamwork, and technical communications skills. Also, D/HH students learn other tools such as SolidWorks (i.e., CAD application/software), Excel and Matlab (i.e., computations and graphics), 3D printing (i.e., CAD outputs), decision making, and documenting engineering notes (i.e., Cornell method, Free-Body Diagrams). This course exposes D/HH students to design opportunities and leads them to consider undergraduate research experiences before transferring to the baccalaureate Mechanical Engineering Technology program at RIT. One of these design experiences involves the planning and building of a catapult system to support students' understanding of several of introductory engineering concepts such as potential energy, gravity, mechanism of catapult construction, and free body diagram of changing forces.

Project Description. D/HH students were selected through a lottery to put students on specific teams, provided with basic engineering technology theory, tools, components, considering different mechanisms, and asked to design and build a catapult. Design criteria such as budget, materials, the acceptable dimensions of the catapult, and the method of projectile release were provided to students. The functioning catapult was expected to pitch a bean bag into a corn-hole target. Students were graded using a rubric that assessed each of these project areas.

Methods. The sample size for this class was six (n=6), and all identifiers were removed. The methods of data collection, data analysis, and data management methods were considered as well. The data collection involved the design project for each D/HH student were evaluated on their participation, instructor observation, engineering documents, final presentation, final design, and final lab report. Data analysis involved review of aggregated data, simple descriptive statistics, and academic records of engineering notes, final design, and final report of the design (i.e., rubric assessment). Data used in this study were stored and retrieved from the University's MyCourses platform and the instructor's backup storage locked in a file cabinet.

Result. From the sample size of six students, five were male (83%), four (67%) classified themselves as culturally deaf, four (67%) were white/Caucasian, and all were freshmen. From the instructor's observation, both teams (Team A and Team B) designed a functioning catapult that could project a 6-inch x 6-inch bean bag to a corn-hole target 22 feet away with the expectation of throwing overhand and underhand twenty times. When catapulting overhand, Team A achieved 16 targets (80%), and Team B made nine targets (45%) because their catapult throwing stopper (i.e., a ½ inch rolled wood dowel) broke and accuracy became an issue. Team A used multiple tight loops of surgical tubes with ties and hooks for adjustment, a brilliant design! When catapulting underhanded, Team B tried to repair the damage and could not fix the damage in a timely matter. Team A, with their adjustment capability design, they could readjust and threw an accuracy of 35% (7/20). During the interactions with faculty, staff, and their peers, students expressed their experiences as being very positive but exhausting because of the redesign, retesting, communication and time invested in the project. Also, from the SRS qualitative feedback, the students showed that they liked the teaching and the concept of engineering project (i.e., catapult project), but struggled on writing a formal lab report or final report. Finally, students showed that troubleshooting through the engineering design process was the most crucial teaching element for the success of this course. All six students passed the design project, and four expressed interest in undertaking potential future design research.

Discussion. Many of the D/HH students in each group found creative solutions to the catapult design project through discussions with each other. As a result of their hearing loss, D/HH students have less access to incidental learning opportunities than hearing students. Freeman-King (2017) indicated that incidental learning is "what a person learns through informal communicative interactions with others in public and educational settings" (para 1). Also, Hauser, O'Hearn, McKee, Steider, and Thew (2010) indicated that "deaf individuals are deprived of incidental learning opportunities" (p. 488) since a large amount of information is lost to deaf while hearing people have full access to the data. This class and the design project offered D/HH students an opportunity to have informal conversations about design or troubleshooting skills that do not occur in a traditional classroom (with hearing students), thereby enhancing D/HH students' interaction during their design project experience and allowing them to overcome, at least in part, their generally reduced access to incidental learning.

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Designing the Precision Manufacturing Technology Sub-baccalaureate Program for Future Deaf Students at NTID: A SWOT Analysis

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Introduction. The National Technical Institute for the Deaf (NTID), one of the colleges of Rochester Institute of Technology (RIT) was established in 1965 through an Act of Congress, Public Law 89-36 (PL 89-36), also known as the NTID Act. The goal of this legislation was to "[provide] a residential facility for post-secondary technical training and education for persons who are deaf in order to prepare them for successful employment" (PL 89-36, 1965, p. 1). Therefore, NTID serves as a national leader in science, technology, engineering, and mathematics (STEM) education for deaf and hard-of-hearing (D/HH) students, a reputation that is enhanced by RIT having one of the oldest and largest cooperative educational programs in the nation (RIT, 2019). In response to NTID's Strategic Decisions 2020 plan, the Department of Engineering Studies Strategic Plan 2017, and discussions with an Industrial Advisory Board (IAB) during the Spring 2017-2018 term, a case study was developed to examine curriculum developments for an undergraduate engineering technology program for D/HH students through a SWOT (strength, weakness, opportunity, and threat) analysis. The decision to make significant curriculum changes included the removal of general education courses for AOS programs, modification of technical classes, a reduction in total number of credits for the degree, and a program name change, which resulted in a program modification of 29%. The question is: How can feedback from the faculty and IAB members be used to enhance the program's curriculum?

Methods. The sample size for the department faculty members was eleven (n=11), and the Industrial Advisory Board (n=8) and all identifiers were removed. The data collection, data analysis, and data management methods were considered. Data collection involved a simple survey of 12 questions sent to faculty members and three questions for the IAB members. The study was undertaken to investigate the effect of a proposed curriculum change on a degree geared toward the machining trade. The investigation approach was the SWOT analysis (i.e., strength, weakness, opportunities, and threats analysis) about the department and program and the responses came from faculty members. The second survey went to IAB members and employers (i.e., D/HH alums and repeated employers) who often hire our formerly Computer Integrated Manufacturing Technology (CIMT) D/HH students. The data analysis involved interpreting the qualitative data that was collected as well as the resulting descriptive statistics. Data collected and used in this study were stored and retrieved from the University's survey administration platform. Document analysis, supported by secondary qualitative-quantitative data, was used to assist in the decision making.

Results. The results of this study indicated that seventy-seven percent of faculty members recognized our department members have a unique character because faculty possess longevity in an academic environment with many years of teaching, significant experience working in/with industry, and the ability to communicate through sign language (Laury, 2017, Q1#5). Seventy-seven percent of the faculty members acknowledged that the department's offering of limited options of career-focused programs for D/HH engineering studies students who cannot qualify for higher-level associate degrees (Laury, 2017) is a significant weakness and an opportunity to create new programs. Last, eighty-nine percent of the members are concerned about faculty retirement. The primary consideration is "where [will] new faculty [be] found?" (Laury, 2017, Q4#1) who can teach, bring in industry experience, and can communicate through sign language? The IAB results indicated that blueprint reading (85%) and CNC machining (57%) were the top two essential skills to possess. The IAB survey indicated that our program did not do well in providing students with an understanding of inspection techniques (45%), a topic about which the program offers only one course (Precision Measurement). However, 90% of the employers were satisfied with graduates' preparation (Schwenzer, 2018, See Appendix C). Other qualitative feedback showed the machining program's strengths included recognition by employers of our students' skills and also the ability of students to obtain successful and high-wage internship and permanent employment opportunities. On the other hand, program weaknesses that were identified included a lack of space and the cost of equipment necessary to support the program. Opportunities include continuing connections with employers, equipment support and student placement to increase enrollment. A significant threat is finding replacements for faculty who retire.

Discussion. After learning the results through document analysis, during the 2018-2019 academic year, the Department of Engineering Studies and the Department Curriculum Committee (DCC) unanimously approved modifications to the CIMT program to address the new directions. The decision to make significant curriculum changes included removal of 9 credits for general education courses for AOS programs, modification of 15 credits in technical courses, changes in the total number of credits and to the program name, resulting in an overall program modification of 29%. Ultimately, DCC approved the name change from CIMT to Precision Manufacturing Technology (PMT). During the following academic year, the department proposed offering an AAS version of the degree. Overall, this program modification and development has been undertaken to enhance the workforce readiness of D/HH students with an eye toward enhancing student retention and strengthening their cooperative work experiences.

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STEAMing Textiles Smart through Classroom Research and Teaching

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The project "STEAMing Textiles Smart" aimed at teaching science, technology engineering, art, and mathematics (STEAM) to an audience of multi-disciplinary college students in a collaborative and experiential learning environment. The overarching goal was twofold. First, to draw an audience that was more creative, and less STEM inclined into the domain of STEM. The second was to expose STEM students to Design Thinking. Students from all domains collaborated and participated in soft skills development while learning STEM subjects and Design Thinking. The innovation of the project resided on the integration of the disciplines to create unique technology-enabled incorporation of imagery and functionality into clothing. In their collaborative work, students incorporated aesthetics, functional performance, and materials performance required by the product. This presentation will discuss methods and outcomes for the incorporation of innovation in the classroom and experimental work with students across disciplines.

The three faculty members have diverse experience and expertise, each brought a different set of skills and knowledge to the course. Prior to this course, the faculty worked together as a research group to support graduate and undergraduate research in smart textiles and to design and produce smart textiles projects. One project executed by the team was the Women of Rochester Dress. The dress fabric lists the names of over 100 women from Rochester, NY who had a significant impact on the world and displays special panels for several of the more well-known examples of highly accomplished Rochester women. Many of the panels have functionality such as electronics or functional inks to provide another dimension and expression of the woman's achievement. The panels were attached with a 3D printed button in the form of an icon of the achievement of that woman. The dress is on permanent display at the Women's Rights National Historical Park. This experience aided in the development of the Smart Textiles course and its course model.

Students were recruited for the course entitled, Applied Topics in Media Arts, Sciences & Technology: Smart Textiles, through word of mouth and email. This resulted in a total of ten students, six undergraduate students and four graduate students, from seven unique majors taking the course. The learning objectives of the course were: 1) to create a learning environment to foster students in critical thinking, project planning and problem solving; 2) to identify means of cultivating creativity for innovation and experimentation in the classroom through project-based learning; 3) to devise opportunities in the classroom to engage students in research activities; and 4) to teach individually partitioned STEAM topics.

The project separated the course curriculum into units of Components and Integration. The Components focused on topics of STEAM. The Integration concentrated on the process of fabrication and a final show of the pieces. The Components were weekly three-hour workshops with topic-focused hands-on projects. The Components covered the topics of 2D and 3D design software, design for production, programmable electronics, interactive inks, printing technologies, sewing, production workflow, and project planning and management. Each topic has its own associated hands-on project. For example, simple electronic circuitry was taught through a project called “Snap-People”, where panels of heads, bodies and legs were constructed and the connection of them completed the circuitry for the powering of LEDs.

In the course, students produced fabric or fabric-like artifacts that were “smart”, interactive or dynamic, by using a variety of inks with different attributes, such as, photochromic ink which reacts to UV, or thermochromic ink which reacts to changes in temperature. Students acquired skills in designing appropriately for hybrid printing to incorporate different inks, for assembling basic electronics, and knowledge of the skills needed to produce professional results. The course was experimental in nature and students learned the limits and concerns that should be considered when printing on fabric and when implementing electronics. For example, the students had to consider how and where the volumes and weights of the electronic components, such as batteries, could be incorporated. They learned to test ideas and to trouble shoot problems and find solutions. Students tested a variety of inks using a several different fabrics. Some of the experiments were more successful than others.

The course outcomes, in addition to the underlining knowledge gained, were to create show-case artifacts. Students were required to plan and execute a project using combination printing methods, 3D printing and circuitry to solve a problem or create an impression. The resulting garment needed to showcase functionality. Students followed design thinking methods and collaboration to develop and execute their projects. In their collaborative work, students incorporated aesthetics, functional performance, and materials performance required by the product.

At the completion of the course, students reported through the course evaluation survey and an open class discussion that the course was successful in its model. They felt the course was well balanced. They appreciated the component modules which provided structured learning, but most enjoyed the opportunity to integrate the skills and techniques together to develop their own solution and object. There were significant barriers to the course which would need to be addressed in order for the course to run regularly. The course required significant facilities and GA support, had three faculty instructors, and came with significant costs. While some of this would be relieved as the course could reuse materials and research already developed, the course would still require a higher level of support than most courses. While grant funding supported the initial run of the course, subsequent runs would require students to finance some of their project materials. The school would need to invest in the specialty inks which are expensive and do not have a long shelf life.

This presentation will discuss methods and outcomes for the incorporation of innovation in the classroom and experimental work with students across disciplines. The presentation will discuss the research, the course model, reflections on student learning, and demonstrations of the projects’ outcomes.

The effects of recitation classroom environment on attendance and performance in an introductory mechanical engineering course

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Introduction: Persistence in the STEM majors continues to lag behind other majors, with less than 40% of intended STEM majors completing their degrees [1]. Introductory course performance is closely linked with retention rates [2,3], and can set the stage for the development of both technical expertise and the study skills needed to be successful. In many engineering courses, problem-based recitations provide students the opportunity to work on course material in a smaller class setting. Although attendance is often non-mandatory, there is compelling evidence that recitation attendance is linked with overall class performance [4-6]. In courses with multiple recitation sections, student learning experiences may vary due to many factors, including whether or not the classroom physical space where the recitation is held supports collaboration and discussion. In this study, we observed an introductory engineering course with two recitations, one which was held in a modern, active learning room (ALR) with tables and moveable chairs, and a second in a more traditional room (TR) where individual chairs had personal desks. Although there are many reasons why students may choose not to attend recitation, in this study we were interested in assessing whether the classroom itself affected recitation attendance, thereby affecting course performance.

Hypothesis: We hypothesized that students in the ALR would have higher recitation attendance, with better course performance than students in the TR.

Methods and Results: This study was reviewed and approved by our university's IRB (Study #03624). Students were recruited from Engineering Mechanics I, an introductory required course in mechanical engineering, in the spring of 2019. After reviewing and signing a consent form, participating students completed a questionnaire and agreed to the release of their demographic data and course grades. Demographic data that were collected included: gender, IPEDS ethnicity, international student status, and first-generation status. Following the completion of the semester, de-identified responses and coded demographic data were shared with the course instructor for analysis. As the study is ongoing, demographic data has not yet been decoded. Of the 69 students enrolled in the course, 51 chose to participate (74%), with n=28 from the ALR recitation and n=23 from the TR recitation. After the semester ended, survey responses were linked with demographic information and course performance.

No significant differences in final grades were found between recitations. Weekly percent attendance was evaluated with a paired t-test and found to be significantly higher ($p=0.005$) in the ALR (66% ± 11.8%) compared with the TR (52% ± 17.8%). When asked to rank the value of recitation in the context of other course components (e.g. lecture, homework, office hours), with lower scores being more valuable, students in the ALR ranked recitation as significantly more valuable (p=0.036) than those in the TR (3.6±1.8 vs 4.7±1.9).

Qualitative analysis of student responses reflected differences in the classroom environment as well. Here are some representative comments from students in the ALR recitation:

- *"The environment was very open to allow you to work efficiently with a few peers."*
- *"Being able to be collaborative and not have individual desks benefitted my experience drastically."*
- *"The fact that there were tables as opposed to individual seats allowed me to work together with other [sic]"*
- "*The way the tables are set up allows for working together in groups you feel comfortable with, or working alone."*

Compared with feedback from students in the TR recitation:

- *"I didn't feel comfortable in the recitation classroom and thus my attention span was lowered."*
- *"It always felt like there were too many people. Not enough board space."*
- *"Room was crammed and chaotic. Hard to work in groups/too many desks. Hylan is in the middle of nowhere. No windows."*
- *"The room is too crowd [sic] and seats are too small. It will be better to have a big table with students sitting around."*

Conclusions: The results suggest that the recitation classroom environment affects student attendance and valuation of recitation as a course component. In addition, qualitative analysis of open-ended survey responses suggested that the classroom environment shaped students' experiences around collaboration in recitation. Surprisingly, grades were not affected by recitation room, but this may relate to the low number of participants (n=51) and potential interactions between student demographics and recitation enrollment choices. It remains to be seen if recitation classroom experience in this introductory course affects long-term recitation attendance and course grades. In this continuing study, we are following the same cohort of students into the subsequent semester to assess whether recitation attendance, students' valuation, or course performance are affected long-term.

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Food Waste – to – Energy: Teaching Students about Waste Disposal Options and the Science of Resource Recovery

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Faculty and students from Clarkson University (CU) are in the second year of a grant-funded partnership with a local K-12 school district to institute a school-wide resource recovery program and teach accompanying project-based lessons in selected science classrooms. With assistance from CU students and educational staff from the nearby Cornell Cooperative Extension Service (CCE), middle school (MS) and high school (HS) students at Canton Central School separate their cafeteria food waste (FW) into collection bins. The FW is transported to CCE's nearby Learning Farm, where it is processed in a small-scale anaerobic digester operated by CU faculty and students. Student ambassadors from the HS Environmental Club and MS Green Team work with the CU team to educate the student body about resource recovery, and encourage them to participate in the cafeteria FW collection program. The collaborative project intends to increase K-12 and CU students' knowledge and understanding of issues related to organic/FW management and options to create clean, renewable energy resources.

Like the majority of the general population, most students lack awareness of what happens to items they 'throw away'. Most don't know, and don't think about, where 'away' is. Exposing young people to best practices in waste management will help them develop lasting habits, and may also inspire them to share what they've learned with family and friends. Particularly when it comes to organics in the waste stream, and food in particular, our habits need changing. Americans discard 41 million tons of FW annually, making it the single largest fraction of material (22%) disposed in landfills in the U.S.[1] Sending FW to the landfill contributes to multiple pressing issues including gaseous emissions, leachate generation, and diminishing landfill capacity. Many states in the U.S. are in the process of revising waste disposal regulations to more closely control the disposal of organic wastes. New York State has mandated that as of 2022, facilities producing an annual average of at least 2 tons of FW per week will no longer be allowed to landfill their organic wastes.[2] Although the regulation does not apply to private residences, nursing homes, hospitals, primary and secondary schools, the village of Canton, NY, where our partner school is located, has proactively instituted a village-wide resource recovery program that allows Canton residents to drop off FW and later pick up compost for their yards and gardens. Residents bring their organic wastes to centrally-located collection bins, for treatment at the municipal compost site.[3] Clearly, the time is ripe for educating students about the importance of diverting organic materials from the solid waste stream!

Waste organics can be treated aerobically (i.e. compost) or anaerobically. While both produce valuable fertilizer, the biogas produced by anaerobic digestion contains approximately 60% methane and can be used in a variety of energy systems as a substitute for fossil fuels. Biogas produced by the anaerobic digester treating Canton Central School's FW is used to heat a small greenhouse where seedlings are started in early spring. Digestate, the liquid effluent from the digester, retains most of the nutrients and is used instead of commercial fertilizers at the Learning Farm. This process can be implemented in individual FW digesters, or as part of FW co-digestion at wastewater treatment plants or dairy manure digesters. Food waste is an energy-rich feedstock that, when added to municipal wastewater or dairy manure anaerobic digestion systems, increases energy production and improves process economics. This economic gain can be realized only if the costs for providing ‘clean’ waste, free of inorganic contaminants, are low. Thus the feedstock must be void of contamination that would require pretreatment to separate non-biodegradable substances (e.g. plastics, metals, glass) prior to being added to the anaerobic digestion system.

Diverting FW from the waste stream on a large scale requires a *cultural shift* so that organic waste streams of high enough quality can be generated. Our experience with educating college students on the merits of FW separation indicates that it is difficult to “undo bad habits” even with extensive outreach efforts. It is well known that long term behavioral change originates in early experience.[4] Thus, exposing K-12 students to source separation will engage them in good practices before those bad habits develop. The underlying hypothesis of our project is that that the earlier we expose students to FW separation and resource recovery the more likely they will retain proper waste disposal habits, generating a feedstock suitable for anaerobic digestion. Thus, a successful K-12 source separation program will facilitate long-term resource recovery.

Project-based educational experiences have been developed to complement the cafeteria FW program, so that students can learn the science behind resource recovery and anaerobic digestion. Evidence has shown that project-based and place-based learning experiences enhance student motivation, engagement, and learning.[5] Open-ended projects challenge students to operate at the higher levels of Bloom’s taxonomy, and students tend to be more engaged in the learning process because they see the relevance of what they are learning to their lives outside of school. The method deepens students’ understanding of principles that link concepts together, and enhances students’ ability to retain and apply knowledge.[6] The CU team developed and taught 2 science experiments whereby HS students built small anaerobic bioreactors using glass bottles and balloons or Tedlar gas sampling bags. Various organic FWs were added and students measured the variation in gas production as a function of organic substrate composition over time. Teachers in various classes adapted the lesson to meet class-specific learning objectives (for example, chemistry students worked out the stoichiometry of the anaerobic digestion reaction; environmental science students predicted potential biogas produced from a typical dairy farm and the resulting impact on electricity-related CO_2 emissions).

Results from a student survey indicate significant gains in students’ knowledge about energy in general and resource recovery specifically, their knowledge about anaerobic digestion, and their willingness to talk with their families about proper FW disposal practices. Compared to their high school counterparts, middle school students were more committed to the program, and had a greater sense of self efficacy when it comes to being able to contribute toward solving issues related to energy and the environment.

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Multiple Choice Learning Assessment for Intermediate Mechanics of Materials: Insights from Think-Aloud Interviews

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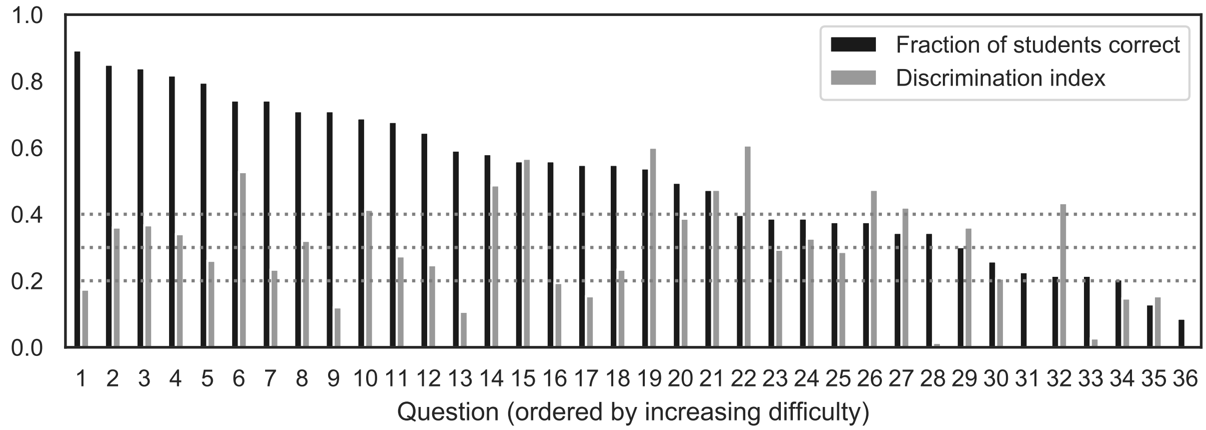
Concept inventories (CIs)—validated tests based on carefully articulated models of conceptual knowledge in a field—have been developed for many introductory STEM courses such as Physics / Mechanics, Statics, Chemistry, and Electricity and Magnetism [1, 2, 3, 4]. CIs can be powerful research tools for measuring students' progression towards expert-level thinking, but they often do not match well with the learning objectives in intermediate courses where domain-specific knowledge, problem-solving strategies, and technical fluency are as important as conceptual frameworks. For such intermediate courses, it is still valuable to develop high-quality, multiple-choice tests to gauge students' progress towards course learning objectives or to assess the efficacy of instructional interventions [5].

We developed a multiple-choice learning assessment (MCLA) for a junior-level mechanics of materials course. (A previous effort to develop a strength of materials CI [6] resulted in a draft version but no follow-up publications to our knowledge.) We began by identifying 34 learning objectives for the course covering a broad range of topics and cognitive skills. Next, we developed multiple-choice questions that demonstrate the abilities listed in our learning objectives. (Not all learning objectives can be appropriately measured with an MCLA. Skills requiring synthesis or design, for example, were not addressed in our instrument.)

We conducted think-aloud interviews [7] with undergraduate students who had previously taken the course. During each interview, we asked students to complete the assessment while vocalizing their thoughts with minimal prompting, which yields rich qualitative data. We found that students use a variety of problem-solving strategies including application of memorized formulas, identification with personal experience, mental simulation, strategic elimination, and reverse psychology of the presumed test author. Think-aloud interviews can also highlight potential problems with questions such as false positives (correct answer despite flawed or undesirable reasoning) and false negatives (incorrect answer despite correct reasoning).

The assessment was delivered after instruction in a lecture-based course at a private R1 university. Results from the sample ($n = 93$) show that many of the student-held misconceptions identified during the interviews are widely held even after instruction. The assessment score is moderately correlated with the final exam score ($r = .44$, $p < 0.001$) and final grade ($r = .40$, $p < 0.001$). The mean assessment score was 51% with a standard deviation of 12%.

The discrimination index D is a measure of how precisely a particular question separates high- and low-performing students and is defined as the difference between the success rates of high-



and low-performing students (often the top and bottom quartiles). A value of D above 0.3 is generally considered acceptable, while some authors recommend 0.2 or 0.4 [8]. Only 17 of 36 questions have $D \geq 0.3$. While low D can indicate problems with the questions, there may be other reasons for poor correlation with the rest of the assessment. For example, only one question on the assessment requires numerical evaluation (finding the maximum principal stress at a point). This question has an adequate difficulty (55% answered correctly), but a low discrimination index ($D = 0.15$), possibly because the skill required is sufficiently different from the conceptual questions comprising the bulk of the assessment.

Data collected from think-aloud interviews, along with statistical evidence from pilot-testing, will be used to improve the assessment in the future.

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Outcomes of a Grand Challenges Regional Collaborative Workshop

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As a response to the 2008 National Academy of Engineering (NAE) report detailing 14 Grand Challenges for Engineering in the 21st Century, three pioneer academic institutions—Duke's Pratt School of Engineering, the Franklin W. Olin College of Engineering, and the University of Southern California's Viterbi School of Engineering—created the Grand Challenges Scholars Program (GCSP). The program outlined a new paradigm for engineering education intended to prepare undergraduate students with the information, skills, attitudes and behaviors necessary to take on the grand challenges and ensure the NAE's goal of "continuation of life on the planet, making our world more sustainable, secure, healthy, and joyful." All GSCP scholars are expected to gain experience in five competencies as they explore one or more of the Grand Challenges: talent, multidisciplinary, multicultural, entrepreneurship, and social consciousness. The GCSP was endorsed by the NAE in 2009 and has now expanded to more than 80 academic institutions. In upstate New York, a regional alliance of NAE approved GCSPs includes the University of Rochester (U of R), the Rochester Institute of Technology (RIT), and the State University of New York College of Environmental Science and Forestry (ESF).

In fall 2018, the U of R, RIT, and ESF GCSP directors joined forces to plan a regional event for their student scholars. This ***Grand Challenges Regional Design Thinking Workshop***, held January 26, 2019, was advertised to students as a way to 1) network with scholars and faculty from RIT, U of R, and ESF and community leaders working on grand challenges; 2) learn a basic design thinking problem solving process to use on any challenge (even less grand ones); 3) get a primer on project planning; 4) learn about local housing issues; 5) practice design thinking and planning skills along with grassroots leaders; 6) earn a certificate in Design Thinking; and 7) earn a low-level Grand Challenges credit in the entrepreneurship or social consciousness competency. The regional GCSP workshop centered around addressing the issue of *Affordable and Sustainable Housing for All* under the "Restore Urban Infrastructure" Grand Challenge. The event was held at the U of R iZone collaboration space and attendees comprised 21 U of R students, 16 RIT students, 3 ESF students and 9 community representatives. It began with a welcome from the Dean of Engineering followed by ice breaker activities and a 90 minute design thinking sprint which set the stage for the design thinking activities around sustainable and affordable housing in the afternoon. A Voice of the Customer workshop led by the AIN Center for Entrepreneurship prepared participants to interview community partners from the Rochester City Wide Tenet Union, the Rochester Homeless Union, REACH, St. Joseph's House, and the City Roots Community Land Trust in small groups over lunch. Teams, including their community partners, then used a Point of View (POV) exercise to frame the problem and springboard into ideation and prototyping. Project Management 101 and Business Plan Canvas activities followed to help the groups think critically about how their ideas might be implemented. The day finished with brief team presentations a networking dinner.

After the workshop, participants were asked to complete feedback forms. Responses were submitted by 38 of the 40 student participants and from 4 out of 9 community partners. The most frequent responses from student participants were grouped into common themes, quantified here:

"What was the best part of the workshop?" Only two respondents did not include one of the following areas and some listed more than one:

- Interacting with community partners: 32% (12/38)
- Ideation/Prototyping: 32% (12/38)
- Learning overall Design Thinking process: 26% (10/38)
- Networking/meeting new people: 20% (8/38)

***"What tools would you use again*?"** Four people responded "all of them" and other respondents reported they would use the following, some including more than one:

- Brainstorming/Prototyping: 42% (16/38)
- Design Thinking generally: 26% (10/38)
- Interviewing/VOC: 24% (9/38)
- Business Plan Canvas: 18% (7/38)

"What can we do better next time?" All student participants said they would recommend the workshop to others, and had the following suggested areas for improvement:

- Too long, too much sitting, or not enough breaks: 24% (9/38)
- Community partners need better preparation: 11% (4/38)
- Activities were rushed: 8% (3/38)
- Better prototyping materials are needed: 8% (3/38)

"Do you think this event helps you advance completion of your grand challenge competencies?" One student said, "Not really, I have already done most of this stuff, but it was fun!" Eight were blank. The rest said yes and some specified a competency: Entrepreneurial: 24% (9/38); Talent:18% (7/38); Social:11% (4/38); Multidisciplinary: 3% (1/38).

Based on the student feedback, we plan to reduce the length of the workshop and include more breaks. Survey responses from community partners also suggested the need for more preparation. Although we reached out a month in advance and provided background materials, some participants did not join until the day before the event and others had not seen the materials. We will add a briefing for partners preceding the event and a specific time for partners to present.

As GCSP directors, we (the authors) also qualitatively assessed the impact of the event. Directly, it provided a means to meet the entrepreneurship competency, networking opportunities, and interaction with community partners actively working on local challenges. Longer term impacts include better student understanding of the entrepreneurial competency, an enhanced sense of community among scholars in each school and regionally, and increased engagement and completion of the program among those who attended. We consider our first Regional Event a success and are planning another for September 2020. We hope our model might serve other GCSP directors working to grow student engagement and sense of community.

Development of an Interdisciplinary Grand Challenges Course

Sarah Brownell, Rochester Institute of Technology

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Background

In developing the Grand Challenges Scholars Program (GCSP) at RIT, we pursued an approach that emphasizes the importance of the Liberal Arts in preparing students from STEM programs to become Grand Challenges Scholars. Though the Grand Challenges demand significant technical competencies, they are also entangled in many factors rooted in the Liberal Arts, including social, cultural, and economic considerations among many others. The GCSP [1] provides a platform from which to impress upon engineering students the importance of Liberal Arts to their overall education and their preparation, which is a priority at RIT and beyond [2].

One important aspect of the GCSP at RIT has been the development of a course called *Grand Challenges* that is team-taught by an engineering and liberal arts professor who share interest in a particular Grand Challenge. The Grand Challenges provide a rich context for introducing broader concepts such as ethical decision making, cultural contexts, project-based approaches to course work, collaboration, interdisciplinary research, and communication to diverse stakeholders, to name a few. The RIT course has been taught four times by two instructors (an engineer and a philosopher) who share interest in the Grand Challenge of providing the world with clean water. The course includes case studies and essay writing on topics such as the Flint crisis, Great Lakes water levels, and the Green Revolution in Bali, as well as an extensive team project on a team-selected water topic. The project is executed in phases as students learn skills related to understanding a problem and proposing solutions. The objective of this presentation is to share preliminary assessment data as well as student and instructor reflection on the course.

Methodology

Students in the course complete a self-assessment at the beginning (PRE) and the end (POST) of the course to evaluate the extent to which they report development toward achievement of an inventory of competencies supporting the learning outcomes. Broadly defined, the outcomes relate to a number of the GCSP competencies, and include: 1) evaluating information from multiple sources, 2) identifying and analyzing a problem and proposing solutions, 3) presenting to an audience, 4) writing, 5) understanding ethical issues, and 6) working collaboratively on a team. Students rate themselves on how often they utilize each competency (always, often, sometimes, rarely, never) and provide specific examples to support their survey responses. The self-assessment instrument was administered in 2017 and 2018 to a total of approximately 50 students at the beginning and end of the course, and a t-test was used to compare the proportion of students who indicated “often” or “always” for each learning outcome.

Results and Discussion

Of these 27 competencies, students reported significantly increased usage in 11 of them, with all but the *presenting to an audience* learning outcome represented among these gains, most likely due to the high baseline (PRE) reported for that outcome relative to the others. Table 1 lists the 11 competencies for which a statistically significant improvement ($\alpha = 0.05$) was observed in comparing the pre-course survey results (PRE) to the post-course survey results (POST) for the percentage of respondents who reported “Always” or “Often” for each.

Table I
Student Self-Reporting of Learning Outcome Competencies

Learning Outcome	PRE	POST
In the past year, how often did you use the following approaches to evaluate information from multiple sources?		
Compare the strengths and weaknesses of different explanations or arguments	62.5%	90.2%
Weigh the overall importance of the information	64.6%	75.0%
In the past year, how often did you use the following approaches to identify and analyze problems and propose a solution?		
Seek advice from experts or review expert material or data to help understand the problem	27.1%	56.1%
Identify the similarities and differences between alternative approaches to the solution	43.8%	78.6%
In the past year, how often have you used the following approaches to writing?		
Use a variety of sources directly related to a purpose or problem	52.1%	81.0%
Organize and synthesize information from sources to achieve a specific purpose	51.1%	88.1%
Integrate evidence from and cite or document sources	52.0%	81.6%
Revise a written piece to make improvements	31.3%	53.7%
In the past year, how often have you used the following approaches to understand ethical issues?		
Identify a potential position on an issue and consider the ethical implication(s)	43.8%	69.0%
In the past year, how often have you used the following approaches when collaborating on a team?		
Listen and consider different points of view and perspectives	87.2%	100.0%
Respond to conflicts in a helpful way	83.0%	81.0%

Though student self-reported outcomes need to be interpreted cautiously, these gains are consistent with both faculty observation and testimonials provided by the students. These will be discussed further as part of the presentation. Also notable among the feedback we receive from students has been the appreciation they have gained about the importance of the humanities to addressing the Grand Challenges. For example, one student commented, “[The class] helped me broaden my understanding of engineering, to realize that not all problems are a matter of math and science,” while another indicated, “I discovered that every engineering project involves people, and anything with people involves ethical issues.” With respect to problem identification and proposal of solutions, one student remarked, “I enjoy the open discussion and that most of the class we taught ourselves since we needed to research about our specific challenge.”

The course was designed so that future iterations focus on different Grand Challenges, or a combination of challenges, but the learning outcomes will remain the same. We will discuss some of the challenges we have faced in expanding the course beyond the original team of instructors teaching the clean water course as well as ideas around best practices for teaching this type of interdisciplinary, team-taught course.

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Extended Abstract

Title: Ensuring Student Success - Developing Intangible Skills in the Technical Workplace

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Objective

The authors' data indicate non-technical, intangible (soft) workplace skills can be assessed and improved via an appropriately properly designed Capstone course with relevant projects.

Background

It is common knowledge that intangible (soft) skills are vitally important in the technical workplace. Because of the difficulty in methodically addressing soft skills, they are often not included as a component of technical education. According to surveys and interviews of employers that hired our NTID students, employer feedback regarding the technical skills of our students was generally positive, but soft skills needed improvement. Some of the soft skill concerns of our students included: "took little initiative to research solutions before asking for help"; "is not independent"; "had no self-initiative to go beyond assigned tasks"; "does not recognize and define problems"; "does not demonstrate the ability to transfer theory to employment situations"; "does not express ideas clearly on email or in writing"; "does not expresses ideas clearly in group discussions or presentations."

Deaf and hard-of-hearing students receive technical education in computer support, networking, security, and troubleshooting at Rochester Institute of Technology's National Technical Institute for the Deaf (RIT/NTID). These classes address technical skills but do not adequately address soft skills that are needed in the workplace, however. The authors learned one of the best ways to test students' ability to apply soft skills in a world-of-work situation is through the use of a project-based capstone course. In 2012, we implemented the ICS capstone course after the fourth semester of the program, just before the required co-op experience. The course was implemented with student project roles and responsibilities specifically designed to address some of the expressed supervisor concerns. Projects throughout this study included technically challenging tasks that put students in positions of leadership and required teamwork, research, self-initiative, innovative thinking, and more. Some examples of the projects were:

1. IoT - Security Camera/System research and implementation at several area businesses
2. Computer repair business operations for local clients
3. Raspberry Pi activity implementation for D/HH students in summer camps
4. Arduino controlled devices for D/HH water sports
5. Biometric and video feedback for D/HH water sports

In 2014, we analyzed the supervisor evaluations from 2007 – 2014 to see if there was any significant change in the ratings of those students that took Capstone after co-op compared to students that took Capstone prior to co-op.
Student: The feedback received by the students about their capstone course performance proved to be helpful as they progressed through each project.

After offering the Capstone course and reviewing the supervisor data periodically over the past eight years, the authors found that students were able to hone their soft skills as well as their technical skills on a capstone project as predicted.
Employer: The supervisor evaluations of students' soft skills improved in a few key areas with statistical significance.

Earlier Findings: Our early findings were presented at the April, 2015 ASEE conference, where we found the following significant improvements on the job if the students had completed the capstone course:

- Chi-Square = 7.083, DF = 2, P-Value = 0.029 (Seeks new responsibilities, shows initiative & leadership
- Chi-Square = 7.233, DF = 2, P-Value = 0.027 (Implements solutions and evaluates outcomes)
- Chi-Square = 6.111, DF = 2, P-Value = 0.047 (Expresses ideas clearly with email or in writing)

Note that in the above data, a Chi-Square result with a P-value of 0.05 or less is significant.

Evaluation Methodology
Student: For student soft skill improvement during the capstone class, soft skill development included requirements to demonstrate leadership, professionalism, significant writing and documentation, teamwork, and more. The capstone evaluation process included peer evaluations, customer evaluations, professor evaluations, and evaluations by the supervisor within the business where large, medium and small projects were implemented. This course also included an audience evaluation of the students' final capstone presentation.
Employer: The employer evaluation process included supervisor assessment with both open-ended and specific questions at the end of the co-op work experience.

Results
Recent Findings: Supervisor evaluations since 2015 provide evidence that students continued to improve in additional areas that will be discussed and shared during the authors' presentation. This presentation will also review the course expectations, methodology in course design, and how the data was collected. Comprehensive results will be shown using current visualization tools.

Mapping the Technical Knowledge and Skills requirement of the Electronic Manufacturing Industry using Topic Modeling

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Background

Electronics Manufacturing (EM) is a fast growing industry with the potential to lead the reinvigoration of the nation's manufacturing sector and the economy [1]. The industry supports technology-aided manufacturing from defense, aviation, consumer durables, to electronic components [2]. The trillion dollar industry **employs the highest number of engineers within the manufacturing sector from at least 20 STEM and engineering disciplines** [2]**.** However, the need to employ engineers from a plethora of disciplines presents a unique problem to the industry.

Problem Statement

Recently 63% EM employers reported that finding graduates from various engineering disciplines with the required technical knowledge was a major challenge and this led to multitudes of engineering positions being unfilled [3]. Employers claimed that engineers graduating from generic disciplines (quality control, process, mechanical etc.) do not come with a foundational knowledge of EM [3]. Lack of **core technical knowledge required by EM industry**, renders them unsuitable to enter and contribute to this industry [3]. Nevertheless, there is no research yet, that codifies the core technical and conceptual knowledge and skills required across the EM industry. Lack of a readily available set of core technical competencies required by the EM industry debilitates workforce preparation across engineering disciplines that feed into the industry and exacerbates the shortage of industry ready skilled workforce [3] [4].

The electronics manufacturing industry has seen significant change from the 1990's, 2000's and 2010's. Each decade has evolved it's manufacturing practices to keep up with modernization of the consumer electronics market, this also poses an educational challenge. Primarily, **Electronics Miniaturization** has driven the evolution of the electronics manufacturing process. Electronics Miniaturization is the concept that our consumer electronics products are continuously shrinking in size. As Electrical Design Engineers push products to smaller size with increased electrical functionality the complexity of the product manufacturing process, as well as the opportunity for manufacturing defects, increases. This has led to the adoption of more complex automation and the inclusion of smart manufacturing practices also known as, Industry 4.0.

Graduates implementing Industry 4.0 are typically not Electrical Engineering students; rather their academic training is in either Industrial, Manufacturing, Robotic, Computer or Mechanical Engineering. Manufacturers are looking to new graduates with knowledge in programming and statistics to elevate their current practices. Existing employees have little to no experience in these areas therefore on-the-job training is ineffective. Employees with more than 10 years industry experience lack knowledge in modern manufacturing practices and therefore are not suitable mentors for the adoption of Industry 4.0 and Advanced Manufacturing innovation. This study intends to evaluate recent graduates in advanced manufacturing factories to identify key areas of educational needs to better prepare future students for modern manufacturing practices.

Objective

The **objective** of the proposed study is to map the technical needs and skills requirements for engineering positions in the modern Advanced Electronics Manufacturing factories. The purpose of the study is to establish a need to **develop inter-disciplinary modules** that provide a wide range of engineering students a foundation in the technical knowledge and skills required by the Industry 4.0 movement in the EM industry.

Significance of the Study

This project will codify hitherto uncodified conceptual knowledge and skills required by entry-level engineers within the EM industry. It will create a baseline for future studies on technical competency requirements intending to update emerging workforce needs of the EM industry. The findings will **inform STEM workforce preparation in at least 20 disciplines** that feed high skilled workforce to the EM industry. This research will help engineering education programs **determine the technical competencies to focus on** in order to meet the needs of a high-growth industry such as EM. It will also lead to **development of inter-disciplinary modules** that provide a wide range of engineering students a foundation in the technical knowledge and skills required by the EM industry. It will help professional associations that provide technical training to EM industries to **narrow** down on content/ topics they need to focus on. The findings will equip the associations to inform policy makers and accrediting bodies on technical competency needs/challenges of the EM industry.

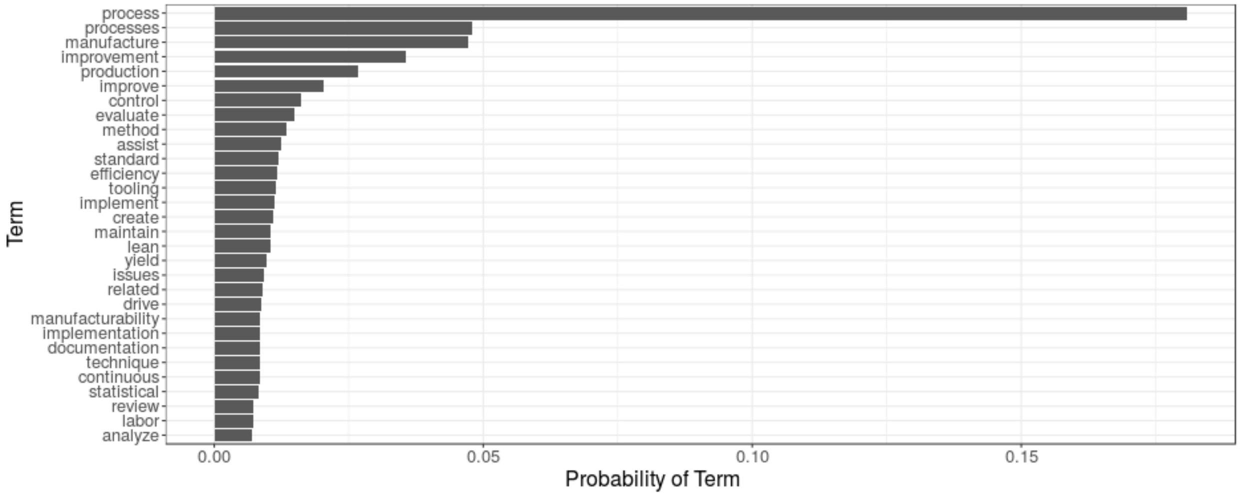
Method

We conduct a content analysis of 1500 job postings collected over a ten year period from the EM industry, using topic modelling. Job postings are critical indicators of employer needs. Therefore, by scientifically analyzing the evolution of job postings for jobs within the EM industry, we will be able to cull out the advanced and Industry 4.0 technical competencies required by the EM industry. Topic modelling is a statistical analytical tool that allows text mining for specific purposes. The study is in the data analysis stage and we intend to present some of the results at the conference.

Example Result

1,478 job postings from a non-profit organization that focuses on EM education and networking from November 11th, 2007 to November 27th, 2017 were used in the model. Terms like “Control”, “Improvement” and “Improve”, “Evaluate”. “Efficiency”, “Statistical” and “Analyze” appear commonly in job postings for Process Engineering positions as shown in Table 1.

Table 1: Process Engineering Topic Model Outcomes



Results like those shown in Table 1 suggest that EM companies are looking for Process Engineers to possess more than manufacturing best practices knowledge, rather, they would like them to be able to control and improve the efficiency of the manufacturing process using analysis and statistical techniques.

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Preparing Future Human Factors Engineers for Developing Ergonomic Products using Computer Aided Design and Prototyping

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Keywords: Ergonomics, Product Design, Computer Aided Design, 3D-Printing.

Background: Engineering relates to the application of scientific postulates and theorems to improve the quality of human life. Human factors engineers, in particular, try to achieve this goal by enhancing the interactions between human, equipment, and processes towards optimized efficiency, safety, comfort, and health. While knowledge of statistical anthropometry and biomechanics can facilitate the mentioned interaction, the real-life product development needs aesthetics and ergonomics to complement each other by integrating engineering and design disciplines [1]. An engineer may see a system through a mathematical binocular vision, however, design and art can facilitate the exploration of new concepts and ideas to create unique product features [2]. The current curriculum in engineering ergonomics is mostly focused on human body size/shape variations without considering the implications of these variations on product development. To achieve this learning objective, students need to explore the concepts from both engineering and design fields for example through experiential laboratory-based assignments. We believe that the inclusion of at least one detailed laboratory assignment covering both body size principles and design aspects can improve students' creativity. The original lab exercise includes an ergonomic assessment of a workstation, in which students provided design recommendations based on the geometric measurements. Although the lab exercise included design content, it was more inclined towards geometric modeling and lacked organic design features, which are widely observed in modern ergonomic products. To enhance the design-related content, a new lab exercise was designed consisting of freeform Computer-Aided Design (CAD) modeling, 3D printing, and usability assessment.

Methodology: Most Engineering CAD courses consist of parametric modeling and the students possess less knowledge relating to freeform surface modeling, which is the basis of comfortable handling of products. Students from the Industrial Design course, which is usually taught in the College of Arts are comparatively more familiar with such modeling and prototyping. Moreover, the students from an art background possess an improved perspective upon creating foam/clay models, which makes freeform modeling easier to learn. However, students from such a background could lack the engineering knowledge required to perform ergonomic analyses. To achieve this goal, our new exercise includes the fundamental ergonomic principles of anthropometrics, adjustability, and comfort that are common between the new and the original exercises. However here, the students will be experimenting the product with the final deliverable being an improved physical model through usability testing.

Figure 1: Procedure for Lab Exercise

In the newly designed lab exercise, the students would be given a pre-modeled variant of a computer mouse, which was selected as a product after a brief survey of ergonomic products in the market and considering the level of surface details, knowledge of students and the popularity of the product. After 3D printing the model, the students would measure key anthropometric dimensions and conduct usability tests using the group members as human subjects, for which a questionnaire will be prepared by the students based upon the existing literature. The testing of the product will include an analysis of discomfort-inducing surfaces of product, reach of interaction buttons and the ease of use of the product. Moreover, statistical analysis will be performed based on the collected anthropometric databases and similar existing databases. This analysis will be used to create reach envelopes for the designs of interfaces on the computer mouse. Next, the design will be modified using sculpting techniques in the CAD environment. This part will provide flexibility in the design content to allow for the exploration of ideas and design thinking of the students. The students will then re-conduct the tests and present their results as a part of the deliverable report.

Conclusion: Through this exercise, students will learn to come up with a design recommendation, and how to assess the effectiveness of their design. One of the challenges in designing such new lab exercises is related to understanding the transdisciplinary technical needs and the pre-requisite knowledge between design and engineering domains, for example students completing the assignment especially undergraduates may not be familiar with intricate details, thus the exercise should inherently acquaint them with the tools especially if the domain varies from their background. Conducting this exercise will likely increase the students' interest in the human factors and ergonomics discipline and provide them with the experience of developing new and innovative products, which may further prepare them for their future careers.

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ROCHESTER INSTITUTE OF TECHNOLOGY

Engineering at the Intersections of the Design, the Arts and Technology

April 3 - 4, 2020

Student Poster Abstracts

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Food drying is a form of preservation and has been refined over many years to make the process more efficient and effective. It is a necessity to dry packaged food to avoid mold growth and increase storage time. Food drying processes typically involve energy intensive processes such as air dehumidification and velocity that will be forced over the food. Electrohydrodynamic drying (EHD) is a process that consumes less energy than the typical forced convection drying. This team expanded upon electrohydrodynamic drying (EHD) as an alternative to high energy systems. The system used at Grove City College (GCC) is a replica of the one used at Oniris (Nantes-Atlantic National College of Veterinary Medicine, Food Science and Engineering) to continue partnered research. This experiment hypothesised that damp sponges could be used instead of high moisture content foods during the experiment. Instead of being able to conclusively test this hypothesis, troubleshooting the EHD system became the predominant goal. An error analysis protocol along with methods for data collection was developed while the problem with the system persisted. This protocol and testing kitchen sponges as alternative material for dehydration will continue once the system is working.

Thinking Aloud: How do Biomedical Engineering Students Solve SV Tasks

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Spatial Visualization (SV) is defined as the ability to mentally manipulate two-dimensional and three-dimensional objects. STEM students, in this case specifically engineering students, with a strong foundation in SV have a higher chance to succeed in engineering based courses as they have the cognitive abilities to easily adapt to concepts that are introduced in engineering design (1,2). The goal of this project is to understand how first year biomedical engineering students perform at certain tasks that involve SV. This information will help understand the level of SV skills these students already have as well as how they process these tasks. By identifying these areas, the curriculum, specifically the Introduction to Biomedical Engineering course, can be adapted to incorporate activities or lessons that could improve students' SV skills (3). The students that participated were actively enrolled in their first semester of biomedical engineering which included the one-credit Introduction to Biomedical Engineering course. The students volunteered for one-on-one interviews. These sessions were "think aloud" interviews which were recorded with a camera to allow for post-interview analysis. The different activities that the participants were asked to perform included drawing two-dimensional and building three-dimensional objects as well as taking part in a mental rotations quiz (4). The protocol allowed for observation of strategies, gestures, and timeliness of the students during the activities. These interviews occurred after an initial introduction to SV concepts in the course. What was found from initial interviews was that most students have a strong understanding of what orthographic and isometric drawings are but lack some skills with being able to draw a two-dimensional representation from a three-dimensional structure. This shows that though students may know conceptually what SV is that does not mean that they have developed the cognitive skills needed to apply it. The results also show that students who have had previous training in SV through high school programs were able to complete the rotations quiz faster whereas students with no previous experience did struggle with performing this activity. This supports the idea that more training and practice with SV will improve the skill. In addition to these interviews, in order to assess if the current curriculum improved SV skills, the PSVT rotations quiz (4) was administered as a pretest the first week of classes and posttest at the end of the semester. What was found was that on average the score at the end of the semester slightly increased from the pretest. This is still an ongoing project, but from what has been seen changes can be made to the introductory Biomedical Engineering curriculum that allow students to have more practice with orthographic drawings and different hands on activities. By the end of the course all students should have had adequate exposure to SV to allow them to excel in future engineering courses as well as the engineering industry.

Impact Reducing 3D Printed Running Shoe Midsoles

Bennett Wong
Rochester Institute of Technology

Running is a very easy sport to get into, but has been notorious for being a joint impact heavy sport. Specifically for the knee, the impact forces can reach up to three to six times the force of gravity, causing the most amount of injuries in that area. The goal of this research is to design a running shoe to reduce impact loads during running, more specifically to design the heel section of a running shoe to reduce peak impact loads during running. Studies have shown that running on grass and soil during trail running has a lower peak impact forces than running on concrete and hard surfaces. Many might not have access to a park, or a large section of grass where they can exercise their bodies without doing more harm to them. A shoe that reduces peak impacts will allow individuals with certain injuries or knee pain, who like to run but don't have access to trails, to continue to run on hard surfaces. Rear foot, or heel strike running, is the most common way the general population runs, which is why this study focuses on the heel section of the midsole. The end product will be a running shoe midsole tailored to a single individual that can be printed cheaply using very accessible FDM 3D printers. Using current additive manufacturing technologies, different geometrical shapes will be printed to reduce the peak impact loads seen in heel strike running. Finite element analysis (FEA) will be used to explore and simulate how those different geometries react to deflection in order to quickly explore the many different possible geometries. Past accelerometer tests have confirmed peak loadings up to 4 g's on hard pavement with the goal of these new 3D printed heel midsoles to reduce the impact loading to 3 g's. Success of the design will be tested using 3D printed samples on a drop tester that will represent the running forces seen of a 150 lb man running.

Optimal Stencil Cleaning Process for Consistent Solder Paste Deposition for Ultra-Fine Components

Romit Kumar Nag, Martin Karl Anselm
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Printed Circuit Boards (PCB) are foundational components for any 21st-century electronic device. Increase in industrial automation required integration of complex electronics with sensors on reliable PCBs for on-field device installation. Research indicates 50- 65% of defects for PCB manufacturing occur in the solder paste stencil printing process. Stencils can get clogged over repetitive usage and essentially needs to be cleaned for consistent solder paste deposit or Transfer Efficiency (TE). Low volume of solder paste transferred to any PCB pad is a printing fault, which can lead to a circuit board failure and substantial repairing cost. Troubleshooting poor printing problems occupy almost 40% of the production time. An optimized Surface Mount printing process would ensure minimal reworks and eliminate Cost of Poor Quality (COPQ) as well.

The primary goal of this project is to maintain consistent TE of solder paste printing, which can lead to increased first pass-yields of printed circuit board assemblies (PCBAs). The hypothesis for this study is that stencils with ‘ultra-fine pitch apertures require more frequent in-process cleaning for accurate paste height and volume deposition.’ Preliminary research conducted at RIT’s Center for Electronics Manufacturing and Assembly (CEMA) on BGA printing, showed the TE remains consistent for at least ten prints for large apertures and deteriorates quicker for smaller ultra-fine pitch applications. The minimum paste deposit for a few pads were significantly low compared to the average solder paste deposit. This prompted the need for an optimized stencil cleaning process.

The research study was conducted at RIT’s CEMA lab on a 3-mil stencil with multiple apertures for 0.35mm pitch BGAs and 01005 passive components based on DOE. An Indium 8.9HF, SAC 305, type 5 solder paste has been used. The results generated by Solder Paste Inspection (SPI) machine was analyzed on Minitab and visualized using Tableau. Loss of solder paste deposit were reduced with the implementation of the optimized process.

Further the results of this study can be used for Industry 4.0 optimization and machine algorithm development to reduce solder paste printing production defects. This research methodology can be implemented to determine optimal cleaning frequency for any stencil based on multiple printing parameters. An optimized monitoring system would increase hourly throughput of PCBs.

Automated Fluid Mixer

Amariah Barton-Harris
Buffalo State College

Consumers manually measure out fluids and pour them into their fluid mixer. The more fluids a consumer desires to mix, the less precision and more time consuming the procedure becomes. Manual measurements are limited to visual inspection giving room for error. We built an automated mixer that dispenses and mixes fluids together to produce a final solution. The dispensing and mixing rates are based off the Adriano's time clock. Our Automated Mixer is pre-loaded with four different fluids and recipes. The recipes are uploaded into the Arduino that will instruct the mixer to dispenses a precise amount of each selected fluid and pump the fluid into the mixer's container. 15.8-16.3 oz will dispense in 8 seconds. Our design includes the L298N chip that allows us to drive two solenoids at a time. Our mixer is automatic and can dispense up to four fluids at a time unlike other home mixers. We made an inexpensive product that can easily be used at home.

Sever Room Environmental Monitoring and Control

Thomas Wallen, Brandon Kohn, Farhanul Islam, Tre ‘Shon Black-Presley
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Data centers are locations where computing and networking equipment is concentrated for the purpose of collecting, storing, processing, distributing or allowing access to large amounts of data. These devices are highly sensitive and work best when maintained between a specified range of temperature and humidity. When they aren't within the specified range it could lead to decreased performance and or component failure. With companies being more reliant on data storage, it is imperative that these data centers and server rooms are environmentally controlled and monitored. The project will involve the monitoring and control of the temperature and humidity of a small-scale server room. The project will be tested on location in a small-scale server room located at Alden Highschool. The temperature and humidity data will be sent wirelessly for online viewing. The data will also be displayed on a local LCD screen inside the server room. Automated control of the temperature and humidity will be accomplished by a set of relays that will activate AC appliances when a certain temperature or humidity level is reached to adjust the environmental conditions back within normal limits.

Researching this project revealed evidence that only large-scale server room environmental monitoring systems exist and are exceptionally expensive. This is not cost effective for companies that have smaller scale server rooms. Our focus for the project is too build a cost-effective environmental monitoring and control system that can be used by these companies to help save them money as well as protect their assets. An Arduino microcontroller system drives the application programming to continuously monitor the humidity and temperature of a server room. This is accomplished by using a DHT22 sensor module available for the Arduino, which displays environmental data on an LCD screen. The readings will be available online using an ESP8266 Wi-Fi module to transmit the readings to a website called ThingSpeak. The Arduino will also control the relay switches for outlets used by AC appliances such as a dehumidifier and a cooling system to maintain environmental conditions.

The team chose the Arduino Uno R3 because it is a low cost open-source product that contains enough analog and digital pins for the needs of the project, which allows the project to be built in a cost-effective manner. The DHT22 is available for a reasonable price and it is designed to work with the Arduino for easy integration. An ESP8266 WI-FI module was used for remote data acquisition, which allows the user to view the data from anywhere, so long as there is an Internet connection via the ThingSpeak website which uses MATLAB and Simulink to display readings obtained from the Arduino graphically for the user in real time. Using the I2C LCD to display data is cost effective and can be easily implemented with the Arduino. It only needs two data pins to display data on the LCD, which will help save pins on the Arduino and make troubleshooting easier. Our LCD is a 20x4 version of the I2C which gives us enough room to display data clearly.

First Engineering Technology Classroom Design Experience on Catapult in a Deaf Classroom

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Rochester Institute of Technology-National Technical Institute for the Deaf-Department of Engineering Studies

At the National Technical Institute for the Deaf at Rochester Institute of Technology, us deaf/hard of hearing (D/HH) engineering technology students receive our first formal education in engineering technology in NETS-101 Fundamentals of Engineering course. The main exercise was a final design project, which was worth 30% of the final grade. The instructor provided the class with basic engineering technology theory, background information, tools, components, considering different mechanisms. We were asked to design, plan, and build a simple catapult which associates potential energy. The criteria for building the catapult were a limited budget of $100 for materials, limited measurement for catapult of 2 inches width x 2 inches length x 2 inches height and to be able to sling the projectile 20 feet and be able to make it into the corn hole. The class was exposed to a meaningful freshmen design experience that includes engineering ethics, decision making, communication, progressing through the Engineering Design Process framework, free-body diagrams, teamwork, time management, and creating an incidental learning environment for us new students. We have found creative solutions to the catapult to fix the design problems, and for example, team A found a solution of using latex tubing as an arm stopper cause the wood dowel is denser which means there is no elasticity to absorb the force, which causes it to break but ran out of time to change the stopper material. Team B came up with a solution of making a pull pin to prevent human error affecting the amount of potential energy that is being applied to the projectile. The final results were that team B were more successful than team A, because their arm stopper did not break during the corn hole competition and got around 16/20 (80%) shots. Team A had a human error caused by using our feet to push down the arm instead of using a pin-like what team B did. The catapult throwing arm was accurate but once the ½ inch wood dowel broke, we were not able to shoot the projectile into the corn hole which means that we got around 9/20 (45%) shots that made it into the corn hole. This experience will encourage us to consider Undergraduate Research Experience (URE) opportunities to support us to be able to transfer to the Mechanical Engineering Technology-BS program at RIT from NTID’s Applied Mechanical Technology-AAS program.

Smart-Grid 2020

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SUNY College at Buffalo

Buffalo State College is home to a live model of a modern electric utility grid. Over the last two semesters, we have begun taking the lab to a new level with the introduction of a RTDS (real time digital simulator). Early on in our involvement with the model, troubleshooting and technical work was performed to ensure a smooth reliable function of multi generation sources, a transmission network, distribution network and residential/industrial power utilization. The entire system has many points of interest for electrical engineers and technicians.

System operation and protection is achieved with SEL (Sweitzer Engineering Laboratories) relays and controllers. A section of the model emulates underground cable to a residential subdivision and allows students to configure feeder protection relays to monitor and protect this important line into the neighborhood.

SCADA (Supervisory Control and Data Acquisition) is a watchdog digital computer based system that controls power flow and performs automatic load shedding depending on the demands of certain areas of the lab and peak periods of the day.

Our nanogrid consists of residential homes that are pro-sumers. They have the ability to produce electricity via solar modules and/or small wind generation as well as still becoming loads to the electrical system if their sources can not produce. What we now have, is a vast network that acts as a very dynamic machine. There is a lot of parameters to measure and constantly control. The system has to still be something that is safe, reliable and easy for technicians to work on.

Now that the general description of the lab is established, we can discuss the addition of our Novacor RTDS. The simulator is a powerful computer that has computational capabilities that allow the smart grid team to perform electromagnetic studies at a transient level such as energizing a transformer or other critical devices. These measurements and plots can be examined for specific protection settings.
Creating a SEL settings file is done with these types of results.

The main focus with the new RTDS system is to use the software from Novacor called RSCad and model a control system that can provide the lab with power factor correction automatically. Having the ability to bring data into the RTDS from the lab will allow us to run the program in RSCad and examine how a reactive power compensation system would work. Stop by the Smart-Grid booth at the ASEE conference to learn about the project through our poster board, meet the team and check out the demonstrational video of the laboratory.

International Autonomous UAV Competition

Justin Payne
Monroe Community College

Monroe Community College has an exceptional engineering program that provides opportunity for students who strive to achieve more than a degree. The Drone Design Club helps these thriving students to advance their education in a promising field of engineering. The objective of this graduate level club is to build an autonomous multirotor quadcopter to compete at the SUAS competition in Maryland. This competition is intensive with ivy league and international schools competing. With such a prestigious competition the members take pride in developing a competitive system. The competition covers mechanical engineering aspects of aerospace, automotive, and general principles. Electrical aspects range from designing the communication system, the power distribution, and the compatibility of the components. The autonomous portion of the competition requires computer science and software programing. The UAV club uses top of the line technology to develop our systems. The growth of this club is due to the technology we use. Each year the team pushes for better results for our own reasons. That is what makes the team so special. We are self-motivated for our pursuit in an engineering career. By participating in a graduate level design team, our members receive skills that classwork is not designed to provide. We build strong networks, communication skills, and project management that allow us to thrive as we work to become professional engineers.

Technology of drones being fairly new requires members to become familiar with new ways of thinking. The club provides a new learning platform for students to develop alongside other students professionally. Students learn to contribute by fulfilling different roles within the team. Not only do the students learn to excel in learning, but they develop/improve character traits to better themselves. Each member learns to test and push their limits while also maintaining their grades. The team is well respected among the MCC association as well as the engineering professors.

Augmented Reality Maintenance

Tyler Lis, Zareya Moore, Ryan Lukowski, Aaron Dulniak
Buffalo State College

For our group's senior design project, we connected with representatives at Kaman Industrial Technologies to build an augmented reality application available for tablets and iPads. This application is being built for Westmatic Corporation who is a large vehicle wash system manufacturer and a customer of Kaman. Westmatic's main problems are with preventive and predictive maintenance of their vehicle wash systems. Preventive maintenance is executed on a fragment of equipment regularly to dilute the probability of failure and this is happening while the machinery is still running so there are no failures. Predictive maintenance is used to monitor the performance of equipment during activity to identify deficiencies and correct them before failing. Right now, Westmatic is functioning with reactive maintenance which means they are fixing failures as they surface. Currently there is no instruction as to when one of their systems may break down due to wear and tear, older parts, or fluke incidents. Unfortunately, they cannot afford to have any systems down because of the frequent day-to-day use. If one does proceed to fail, the process back to normal operating conditions usually isn't a quick fix. The faulty part or parts need to be found through time-consuming troubleshooting. Once found, new parts need to be ordered and installed once received. Resulting in a lengthy process that can be irritating for customers. With an augmented reality application, Westmatic will be able to prepare for faults in their systems and possibly prevent any from happening.

Using a picture recognition software designed by Schneider Electric, any operator can take a picture on a tablet or iPad of a Westmatic vehicle wash system, or a smaller section of it and be able to see following data at pre-programmed points of interest. Following data consists of the last service date, manuals of the components, a link to videos on how to replace said component, and any live data that may be pertinent in preventing a malfunction of the system. Westmatic's large vehicle wash systems have multiple control panels. The status and data accumulated from these control panels of the system are relayed to a programmable logic controller (PLC), also developed by Schneider Electric. This programmable logic controller is connected via wireless networking and/or Bluetooth to the application on the tablet/iPad. The application can show all the live data in the correct locations on the system because of the PLC and picture recognition software.

The Buffalo State team will be responsible for creating the scenes and data points for the Westmatic car wash which includes but are not limited to, schematics, video links, data sheets and live data. Materials will be provided by Kaman. The final project the team will deliver is an augmented reality program for Westmatic and a PLC that will be programmed by the team to simulate live data for a live demonstration of the capabilities of the augmented reality program. Not only will this project be beneficial in preventing vehicle wash system failures and downtime, but also in organizing all the parts, installations, maintenance, dates, and all other paperwork that should be filed for these unique systems. Also, technician and all other position training will be improved by this project as a result of the simplicity, time saving, and organized software.

Baby Car Seat Project

Omar Mohamed
Buffalo State College

If a baby is left unattended in a car for a long time, the baby could get harmed. Alerting someone to help them before they get in danger would be a great solution. Recent events indicate babies are left in the car unattended, in hot and cold temperatures and their inability to help themselves in these situations has led to approximately 50 deaths annually in USA. The "Baby Car Seat" project plans to solve this problem. The project plans to use a weight/ pressure sensor for weight detection. Arduino Uno is a microcontroller board that is programmed with Arduino IDE (Integrated development environment) software. Arduino is a flexible programmable hardware platform designed for artists, designers, tinkerers, and the makers of things. The Arduino is reliable and efficient. It uses less power and is inexpensive. Therefore, it is a good choice for this project. RF module will act as a wireless connection to transmit data from one Arduino to another through transmitter and receiver. The RF module will use is 315Mhz RF Transmitter and Receiver. This range is good for the project because it takes place in a closed environment (a car) and at a small distance.

Speakers and liquid crystal display (LCD) with night vision, are used to output audio and visual commands to the user following the written Arduino code. Switches are to simulate seat belt's closing and opening. The project will use a rechargeable battery as power source.

This proposal is for a lab-bench prototype

For the baby's components and connection.

- an Arduino Uno,
- a weight/pressure sensor,
- a switch,
- a RF transmitter module.

The weight/pressure sensor detects if the baby is seated, and a switch detects if the baby's seat belt is on, the information received will be checked through Arduino code and then transferred to the second Arduino which is on the driver's side.

The driver's components and connection.

- an Arduino Uno,
- weight/pressure sensor,
- switch,
- LCD display,
- speaker
- a RF receiver module.

The weight/pressure sensor and switch will detect if the driver is seated and seat belt is on or off, the information will be compared to the baby's received information. An output is then displayed on the LCD.

If the driver is not seated and the baby is seated, the LCD will display a warning, then it will wait up to 2.5 minutes before letting the speaker produce sound. The sound increases up to three levels with time interval.

If the alarm goes off because the driver is not seated but there are other passengers in the car with the baby, the passenger can press the push switch that will set the speaker off temporally for 5 minutes.

If the driver is seated in the car and seat belts is off, there will be no warnings, thus showing that the baby has not been left alone in the car.

The anticipation for the project outcome is, to use it such that babies who are left in the car for a long time unattended to, are not harmed or even die because of the hot temperatures in the cars during summer, freezing temperatures in the winter , as well as suffocation. We also hope in the future to upgrade this project so as it can communicate with multiple phones, send text messages.

A Case Study of Noise Reduction in a Salt Processing Facility

John Chambers
Rochester Institute of Technology

Morton Salt, a salt production company, contacted the Rochester Institute of Technology's (RIT) Mechanical & Manufacturing Engineering Technology (MMET) Department to request assistance with their processing plant located in Silver Springs, NY. Morton desired that their filter control room sound level be reduced in the hopes of easing the work experience of their technicians who spend most of their day in that room. The specific quantified value that Morton was hoping to achieve within the Control Room that oversees the operation of the Filter Room, was to reduce the production noise levels to or below 60dBA. The deliverable data that Morton requested be gathered toward the end of reducing the sound level was as follows:

- A noise and vibration survey of the effected and related areas
- Investigate design changes (cost inclusive) to mitigate the sound sources of greatest impact
- Investigate design changes (cost inclusive) to soundproof the Control Room from the Filter Room

The supervising engineer (Assistant Professor Brian Rice) and engineering master's student (John Chambers), were then left with the task of determining a methodology to identify the most impactful sound sources located within the Filter Room. The Filter Room contains three separate turbines to push steam through the duct network to the filtering drums in succession to produce salt, identifying the key equipment as the turbines, drums, and ducts. Due to the method of filtering and the necessary equipment, the Filter Room is loud, hot, and humid; thus, it makes for a very caustic environment for human ears and comfort. To separate the Filter and Control rooms, a cinder block wall with two entryways divides the two rooms, acting as a moderately effective barrier. Morton had pursued more effective noise isolation methods prior to RIT's involvement that had not proven effective enough.

The RIT engineering team performed a site visit to better understand the problem they were confronted with, leading to the identification of the likely sources as well as deficiencies in the existing measures to reduce the sound penetration from the Filter Room to the Control Room. After researching similar cases and source identification methods, the team determined that in order to understand the contributions of each possible source, they would need a full frequency content of the sound waves in both the Control and Filter Rooms. For preliminary room mapping and focus areas, a typical sound meter was used to locate the loudest areas, further data would be required as a sound meter does not provide specific information regarding frequency content. Instrumentation identified to specifically fulfill the goals set by Morton, as well as aid in source identification, included both a sound pressure sensor and accelerometer. The sound pressure sensor would collect data on the Sound Pressure Level (SPL) in the air at each location, while the accelerometer would collect vibrational data from the equipment or surfaces (wall/floor) relevant to each location. The probes would be connected to a Voltage Input Module that would then be connected to a laptop for data management and processing. The raw time signals provided by the two probes would be processed using Fast Fourier Transforms (FFT) performed using MATLAB. By collecting and processing data from throughout both relevant rooms, the greatest contributing frequencies to sound level could be identified at each location and then paired to the acceleration data from equipment sources or surfaces, leading to the identification of the source of the problem frequencies. This methodology relies on the fact that frequency of sound does not alter with medium, thus a sound created at a certain frequency can travel through a room and a wall and through the opposite room while retaining frequency.

The data collected and processed would identify key peaks to pair to their sources, but not all the peaks present within the FFT data would be the greatest problems that would require specific attention. The FFT of each data set doesn't alter the units of amplitude, but instead the domain of the content from time to frequency. The data from the sound pressure sensor would (on initial processing) have the output be in units of Pascals. Established formulas were then used to get to Decibels, a straightforward logarithmic conversion factor. To the human ear, not all frequencies are equal, and thus a curve is applied to convert the Decibels to A-weighted Decibels (dBA) to better ascertain their impact as the A-weighted curve better fits human hearing.

The walkthrough of the relevant areas and interactions with the Morton Salt staff revealed that the turbines and fans within the ducts were operated by a direct drive motor and would thus create the same frequency, which gave the team frequencies to particularly observe in the data. These drive and fan frequencies proved to be the greatest signals present within all the Filter and Control rooms FFT SPL data. Based on accelerometer data and observation verification, these frequencies were shown to be sourced directly to the turbines creating each frequency and their accompanying ducts, as the ducts were of a large surface area to better create sound waves. Based on the FFT SPL data converted to dBA to account for frequency, the frequencies sourced to the fans and ducts were indicated to be the most impactful sources.

As this project is still in progress, the identification of ideal solutions is well underway and approaching completion.

Thermal Reliability of Pb-Free Solder Alloys in SAC BGA Applications

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For many years the electronic industry relied on Lead based soldering as a feasible and reliable mechanism to attach components to Printed Circuit Boards. Lead-based solder alloys as Tin-Lead (Sn-Pb) provided great advantages like a low melting point, good wetting characteristics, low cost, and consistent reliability in a variety of stress conditions. Nevertheless, due to possible human health and environmental risks, companies were required to stop using Lead in their manufacturing processes and products. As a result, a strong industry-wide research effort has been on-going to develop and understand new Lead-free solutions. So far, SAC alloys (Sn, Tin; Ag, Silver; Cu, Copper) have been found to be a suitable replacement for Lead alloys as they can be adopted with minimal reliability risks. However, their significantly higher melting temperatures (217^{o}C vs 183^{o}C) presents many difficulties in managing manufacturing processes, including higher manufacturing costs, potential increase of defects, and the need of boards with higher glass transition temperature (Tg) to avoid board warpage.

Consequently, more studies are being done with solder alloys that contain elements that lower their melting temperatures. For example, Bismuth (Bi) containing solder pastes have been found to be a potential reliable and yet low-temperature alternative to lead-based and SAC solder alloys. By itself, Sn-Bi alternatives were somewhat discredited in the past because Bismuth is known to be a brittle element. However, it has been proven that by combining this element with small amounts of others, such as Silver, both the mechanical and thermal properties of Sn-Bi can be dramatically improved. Until now, most of the work has focused on improving the mechanical or drop-shock reliability of these alloys as this is an important characteristic for the growing portable electronics industry. Therefore, this study intends to pay more attention to the fatigue resistance under thermal stress, which becomes critical in bigger electronic applications that are not as exposed to mechanical stresses as portable devices.

The focus of this work was to determine how different factors influence the thermal reliability of solder joints from Ball Grid Arrays (BGA) and Bismuth solder pastes formed at low reflow temperatures. These BGAs, as the name implies, are composed by an array of solder spheres which, in this case, are 96.5Tin/3Silver/.5Copper (SAC305) balls. For this research, a proprietary Bismuth paste was used and, therefore, its exact composition is not known. The samples were exposed to two different peak temperatures 175^{o}C and 190^{o}C to evaluate the impact of reflow temperature as a controllable factor. Additionally, another factor was solder paste volume. Both of these have been proven to be critical factors on solder joint reliability as they play a significant role in the mixing of the solder paste with the solder spheres. Proper mixing between them is imperative to ensure the functionality and reliability of solder joints. Moreover, a control sample with SAC305 paste was also ran to provide contrast to the analysis.

This research includes the manufacturing of different samples as explained above, a thermal-cycling study, and a metallurgical analysis of the solder joints.

The Need for Modularity in Assisted Devices and The Corresponding Interface

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University of Buffalo

In the past, people in the disabled community were unable to achieve an equal level of independence as compared to their able-bodied counterparts. However, with the introduction of new technologies, such as sip-and-puff switches and eye trackers, those in the disabled community have the possibility of an improved quality of life. These and other devices have made it possible for those in the disabled community to achieve a greater level of freedom and independence than ever before. These technologies can enable a means of environmental control and communication for an individual who might otherwise find it difficult in these fields.

However, for the most part, computers are designed to be comfortable for able-bodied persons. As such, standard human interface devices, such as mice and keyboards, are not designed for those with physical impairments. When such a specialized device is provided to a physically impaired individual, it can improve the individual's quality of life. However, for degenerative disabilities these devices become more of a struggle; as the disabilities progress, the individual may be unable to continue using the same device. Therefore the quantity and variability of devices purchased must increase to continue to aid the community efficiently. This can be a challenge as the user will need to continue to learn new software to work with each new device. We set out to develop a modular user interface capable of interacting with a variety of devices, such as Brain-Computer-Interface (BCI), Iris Trackers, twitch sensors, button input, sip and puff switches, and touch and swipe actions. The devices can then be utilized to control the included software which is capable of text to speech communication, controlling televisions and Roku, nurse call light, and outlets. Our objective is to improve the quality of life for a physically impaired individual by returning some sense of independence through an ecosystem of devices and tools that can be modified to fit the needs of the individual even as a degenerative impairment progresses.

Teaching First Year Students the Engineering Design Process with a Tupperware Shape-O® Ball Toy

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Objectives:

This work will illustrate a method for introducing the engineering design process to first-year students with the following learning objectives:

1) List the steps of the engineering design process (Bloom Taxonomy Level 1)
2) Explain why the order of the steps in the engineering design process is important (Bloom Taxonomy Level 2)
3) Apply the engineering design process to an open-ended problem (Bloom Taxonomy Level 3)

Motivation:

The engineering design process (see Figure 1) is an engineer's most useful tool. It lists and orders the steps engineer's should use to successfully approach and solve any problem. In addition, an understanding of the engineering design process is beneficial for all STEM majors as they develop a better understanding of problems.

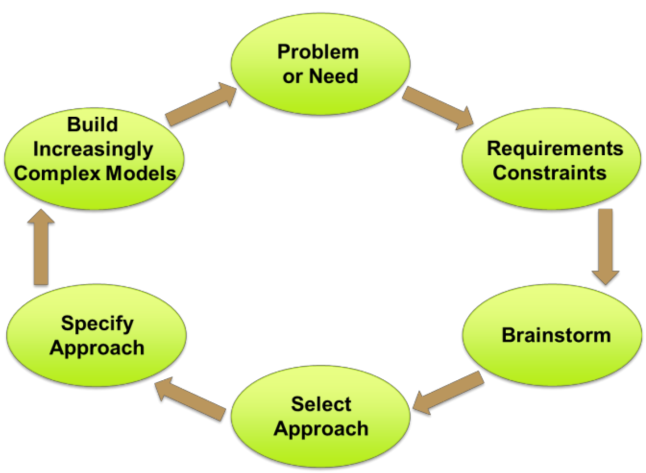

Figure 1. The Engineering Design Process Lists and Orders Steps to Successfully Solve Problems. [1]

Figure 2. Tupperware Shape-O Ball Toy Used to Introduce Students to the Engineering Design Process. [2]

The engineering design process provides a problem solving methodology that first year STEM students are likely unaware of. Without the engineering design process, problem solvers are likely to be disorganized and their ideas, approach, and work will be unfocused. Therefore, it is important to provide students with this skill early in their undergraduate studies; ingraining it into their thought process. The Tupperware Shape-O® Ball toy (see Figure 2) is a simple, yet fun and creative way for new students to apply the engineering design process [2]

Process:

This work will require the following resources:
1) *The Science of Disney Imagineering: Design & Models* DVD [1],
2) Tupperware Shape-O Ball Toy [2],
3) *The Imagineering Workout* Book [3],
4) An EngineeringUnleashed.com card for additional details and instructions [4]

Begin the lesson by introducing the students to the engineering design process (Figure 1). Give the students a brief overview of each of the steps, explaining what each step is and how they can help with all sorts of problems or needs. Make sure you emphasize the importance of asking lots of questions; this will run counter to most classroom experiences students have had previously.

Next, introduce the students to the Shape-O Ball, a toy with different holes for ten different shapes. Inserting the shapes is an easy task, yet when we include variables such as number of operators (people), hourly production rate, and reliability of assembly, we have a robust, open-ended problem for students to solve. To convey the difficulty of assembling fast, have the students assemble the ball as quickly as possible with a prize for the fastest time. To encourage the students to keep trying new solutions, tell them there is always a better way. Finally, have the students apply each of the 6 steps of the engineering design process to come up with a better way to build as many as many Shape-O Ball toys as quickly consistently as possible.

Conclusion:

The engineering design process is the fundamental method engineers should use to solve problems. By introducing the process early in the curriculum, and giving students a chance to practice the engineering process on a simple, yet open-ended problem, two benefits are realized. First, students get a thorough introduction to the process that they (and their faculty) can rely upon for the remainder of their classes. Second, students get a chance to practice working together in a fun, collaborative environment establishing a solid foundation for future projects. Through their experiences working with the Shape-O Ball, students gain confidence using the design process, will be open to new ideas, learn to question everything, and develop a sense of teamwork and cooperation.

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