Oklahoma State University’s ENDEAVOR: Transformation of Undergraduate Engineering Education through the Experience-based learning.

Dr. Hitesh D. Vora, Oklahoma State University

Dr. Hitesh D. Vora is an Assistant Professor in Mechanical Engineering Technology. He received his Ph.D. and Masters’ from the University of North Texas in Materials Science & Engineering (in 2013) and Mechanical Engineering Technology (in 2008), respectively. Dr. Vora is a Director of the Industrial Assessment Center (IAC) at Oklahoma State University, which is funded by the US Department of Energy (DOE) for the year 2016-2021 with total funding of $1.8 million. For those not familiar, the Industrial Assessment Centers help small and medium-sized U.S. manufacturers to save energy, improve productivity, and reduce waste by providing no-cost technical assessments conducted by university-based teams of engineering students and faculty. He is actively teaching several courses and pursuing research in advanced (smart/cyber) manufacturing and energy management to improve energy efficiency (reduced energy, cost, and throughput) for small to medium-sized manufacturers. In addition, he is a Matrixed Professor in the ENDEAVOR Digital Manufacturing Maker Space located in the new ENDEAVOR building, which is a 72,000-square-foot and $30 million building. This maker space provides additive manufacturing support for design courses, laboratory courses, and entrepreneur initiatives. This facility houses several different technology 3D printers that capable of printing parts from polymers, fibers, composites, and metals as well as 3D scanning and subtractive manufacturing equipment. His research focuses on machining and manufacturing with a specific concentration on the use of additive manufacturing processes for advanced materials. He emphasis on design for additive manufacturing (DFAM), topology optimization, lightweight applications, and finite element analysis in additive manufacturing processes. Dr. Vora extensively teaches the additive manufacturing technology through the dedicated undergraduate (MET 4173) class as well as through the hands-on training sessions and certification (level 1 to 4) in the Endeavor Digital Manufacturing Maker Space.

Dr. Brad Rowland, Oklahoma State University

Dr. Rowland has extensive military experience that includes military acquisition; research and development related to test and evaluation of military equipment; management of high risk technical programs and advanced application of statistical designs. He served as the Chief Scientist for the Chemical Test Division at the Dugway Proving Ground, as well as the Director of Research for NitroLift Inc. Currently, Brad is the ENDEAVOR Operations Manager who helped design the facility, developed and implemented new facility operations, coach design teams, and design and implement new applied laboratory courses with collaboration across the departments of CEAT.

Dr. Joe Conner, Oklahoma State University

JOSEPH P. CONNER JR Adjunct Assistant Professor in the School of Mechanical and Aerospace Engineering Matrixed Professor in ENDEAVOR CEAT North Campus manufacturing and design Labs Operations Manager Asset Manager for Mechanical and Aerospace Engineering

DEGREES PhD, Mechanical Engineering, Oklahoma State University, 2009 MS, Mechanical Engineering, Oklahoma State University, 2000 BS, Mechanical Engineering, Oklahoma State University, 1995


Prof. Brian K. Norton P.E., Oklahoma State University

Brian Norton received his B.S. degree from Oklahoma State University. After spending a few years in industry he matriculated to Washington State University (Richland Campus) to pursue graduate studies where he received his MSEE. At the completion of his graduate work, Brian joined Blue Mountain Community College (Pendleton, OR) as an instructor in Electrical Engineering Technology. Subsequently, he went to various engineering positions associated with the Hanford Reserve in Richland WA. Brian accepted a position with Oklahoma State University as a professor of Electrical Engineering Technology in 2007. Was promoted and tenured to Associate Professor in 2012. He was awarded the horror of "Outstanding Faculty" by the students of the College in 2015. In 2018 he accepted the additional responsibility of Electrical Lab coordinator for the colleges Endeavor lab. He has interest in student education and specifically how engineering students may gain hands on skills while in school. He has regularly taught undergraduate student level courses in Electronic Fabrication, Circuit Analysis, Communications and C Programming. In his current position as an Endeavor Lab Coordinator Brian organizes, coordinates Electrical and Electronic Lab courses for the college.

Dr. QINANG HU, Oklahoma State University

Dr. Hu is an assistant professor of practice at Oklahoma State University. He is responsible for instructing hands-on lab courses in material sciences and solid mechanics. His areas of interest include concrete durability, X-ray microanalysis, and cement hydration mechanism. He has published peer-review articles in Concrete and Cement Research, Construction and Building Material, Fuel, Acta Materia, ACI structural Journal and etc. He is a member of American Concrete Institute and American Ceramic Society. He also serves as a reviewer in Construction and Building Material.

Dr. Toni Ivey, Oklahoma State University

Dr. Toni Ivey is an Associate Professor of Science Education in the School of Teaching, Learning and Educational Sciences at Oklahoma State University. She serves as the Associate Director for the Center for Research on STEM Teaching and Learning, the graduate coordinator for the Science Education program, and the Co-executive Director for the School Science and Mathematics Association. Her research interests include science teacher professional development, science teacher preparation, engineering education, and geoscience education.
Oklahoma State University’s ENDEAVOR: Transformation of Undergraduate Engineering Education through the Experience-based learning.

Abstract

Previous studies show that ~50% of engineering students withdraw or change to other majors mainly due to the poor teaching and advising; the difficulty of the engineering curriculum; and more importantly - the lack of “belonging” within engineering. Few studies link this problem to non-engineering courses since most of their first-year courses are demanding and focusing on topics other than engineering, such as chemistry, mathematics, and physics. To tackle such issues, the College of Engineering, Architecture, and Technology (CEAT) at Oklahoma State University (OSU) is in the process of a multiyear plan to transform undergraduate education. The ENDEAVOR is the centerpiece of a paradigm shift that expands the instruction beyond the classroom and increases undergraduate laboratory and exploratory time for interdisciplinary, hands-on and industry-aligned learning. Students (even in their freshman year) can experience hands-on interdisciplinary design, applied experiments and training/use of the 5 makerspace areas. ENDEAVOR is a college asset where all eight departments in the college may use this multidisciplinary laboratory for undergraduate experiments, design, and research. The new 72,000-square-foot facility opens the door in Fall 2018 contains state-of-the-art industry-relevant technology in an immersive glass environment that promotes undergraduate interdisciplinary teaching, research, and training. ENDEAVOR facilities include a thermodynamics lab, wind tunnel, 35ft flume, advanced data acquisition lab, mechatronics lab, 3D printing makerspaces (including polymers, metals, composites, ceramics, etc.), subtractive manufacturing shop, electronic makerspace facility, material testing, and characterization labs, etc. to name a few that are under the same roof. This paper will further discuss the role of ENDEAVOR regarding engineering pedagogy and its effectiveness in transforming the undergraduate engineering education through experience-based learning.

Keywords: Experience-based learning, Undergraduate education, engineering education, lab-based learning, retention,
1. Introduction

In the past, several investigations show that around 50% of engineering students withdraw or change to other majors mainly due to poor teaching and advising; the difficulty of the engineering curriculum; and more importantly - the lack of “belonging” within engineering [1-8]. In addition, the review paper of Geisinger et al. provided a detailed investigation provides all the reasons why students leave engineering majors and identified common reasons that influence students to leave engineering programs [9]. The factors listed in this paper are: inadequate and traditional forms of teaching and advising; classroom and academic climate, difficulty in understanding course content, lack of conceptual understanding, competitive grading structure, lack of self-efficacy or self-confidence, unsuitable high school preparation, difficulty in capturing interest in engineering courses, and further obstacles due to gender, race, or ethnicity [1-9]. Furthermore, most first-year courses are demanding and focused on topics other than engineering, such as chemistry, mathematics, and physics which is a source of frustration for many students. The classic paper of Steinberg et al. also links a poor secondary mathematics preparation as a reason that many students leave engineering programs [10].

Froyd in his paper has pointed to five major shifts in engineering education have occurred during the past 100 years and one critical shift has been the moving away from a hands-on and practical emphasis of engineering learning to an engineering science and analytical emphasis for engineering learning [11]. However, to retain engineering students the study points out that student needs are not met by this shift. In fact, many researchers have investigated laboratory-based learning as a tool to mitigate retention and attrition issues [12-17]. Particularly, Lin et al. shows a link between a student’s ability to learn concepts of engineering and a student’s preference for a classroom and laboratory learning environment that is student-centered, peer-interactive, and teacher-facilitated that provides a learning environment that encourages the student to develop concepts of engineering through hands on practical application [12].

Early engagement to the engineering curriculum through experienced-based or lab-based courses have also been studied by many researchers through several different approaches [18, 19]. Hoit et al. [18] introduced a one credit hour lab-based course that introduces students to engineering by rotating groups through each engineering discipline. The results showed that this approach helped to improve retention rate by 17%. Dini et al. also demonstrated that the student who takes a design-based course in their freshman year are 19% more likely to retain engineering concepts in their subsequent years in engineering field when compared to students who did not participate in a freshmen design course [19]. In short, providing a hands-on experience-based learning opportunity to the student early in their engineering career will improve learning retention.

Along the same line, to mitigate these issues, the College of Engineering, Architecture and Technology (CEAT) at the Oklahoma State University (OSU) is in the process of a multiyear plan to transform undergraduate education. The ENDEAVOR building (Figure 1) is the centerpiece of a paradigm shift that expands the instruction beyond the classroom and increases undergraduate laboratory and exploratory time for interdisciplinary, hands-on and industry-aligned learning [20-29]. Students (even in their freshman year) can experience hands-on
interdisciplinary design, applied experiments and training in the use of the 5 makerspace areas. ENDEAVOR is a college asset where all eight engineering departments may use this multidisciplinary laboratory for undergraduate experiments, design, and research. The new 72,000-square-foot facility opens the door in Fall 2018 contains state-of-the-art industry relevant technology in an immersive glass environment that promotes undergraduate interdisciplinary teaching, research, and training [20-26]. The OSU President Burns Hargis and mentioned that the ENDEAVOR building boasts state-of-the-art technology with a design that provides an immersive learning experience, inviting collaboration and cross-pollination among disciplines [27].

The ENDEAVOR laboratories/design/makerspaces includes a thermodynamics lab, wind tunnel, 35ft flume, advanced data acquisition lab, mechatronics lab, 3D printing makerspace (including polymers, metals, composites, ceramics, etc.), subtractive manufacturing shop, electronics makerspace, material testing and characterization labs, etc. to name a few that are under the same roof. The attempts were made in this article to further discuss the role of ENDEAVOR regarding in college of engineering pedagogy and its effectiveness for transforming the undergraduate engineering education through experience-based learning. The virtual tour of ENDEAVOR, CEAT’s one-of-a-kind undergraduate hands-on laboratory can be obtain from this reference [30].

Figure 1: Picture of ENDEAVOR building [30].

2. Approach and Structure

2.1 Reimagining Hands-on Experience

Before going into the details of our approach, equipment, etc., it may help to mention the obvious – people learn better (increased retention and reduced time to learn) through active learning than passive learning. Throughout our evolution, technology has been passed down by pupils imitating their mentors. This natural preference for learning is reflected in the generic learning pyramid that was first proposed by National Teaching Laboratory Institute at their Bethel, Maine campus in the early 1960’s and the related work have been proposed by several other researchers [31-34]. Though rightly criticized, the pyramid provides a measure of content
retention from lectures (5%), laboratory experiments (70%), and design projects (90%). This disparity in content retention was recognized by the 5th century B.C Chinese proverb, “What I hear, I forget. What I see, I remember. What I do, I understand.” ENDEAVOR harnesses the advantages of active learning by immersing students in a hands-on learning environment through enhanced interdisciplinary experiments, design projects, and access to state-of-the-art makerspaces.

Even though active learning may provide better retention at a faster rate, passive (lecture) learning can’t be ignored. How else can we communicate advanced concepts and technology without traditional approaches? The answer is – we can’t, but technology has changed the way passive learning is utilized. We are seeing a strong reemergence of our natural learning through the resources provided on the internet to include instructional videos on YouTube. The best lectures in the world on almost any topic are only a few mouse-clicks away. In addition, very good “how-to” videos are available for people to learn a skill on a wide range of topics. The “student” will go back-and-forth between the mentor’s video and activity while learning. This interactive one-on-one instruction is very effective. As similar to the leveraging active learning, ENDEAVOR provides this one-on-one instruction by providing focused written instruction and videos for new experiments. For every new experiment, we provide a video for the relevant theory and working equations, safety and experiment operation, and a quiz to ensure students come into the laboratory with the appropriate background instruction.

When the active hands-on learning is merged with focused on-demand theory and operational instruction, the end experience provides an enhanced learning experience that will appeal every learning style with ample time to explore. This approach also provides the ability to perform experiments out-of-sequence from the lecture for any course, which provides interdisciplinary access for all related lecture courses across any college. Interdisciplinary laboratories also provide improved experiments because resources scattered across many departments can now be focused on one laboratory course. In addition, departments can provide experiments for courses that did not originally have a laboratory component.

2.2 Interdisciplinary Courses and Design Courses

The general criteria for ENDEAVOR interdisciplinary laboratory courses are that the experiments are self-contained (theory, operation, safety), have field application, and use industrially relevant equipment. Many of the interdisciplinary experiments are developed by professors that have decades of industrial experience. From fall 2018 to date, ENDEAVOR has developed four interdisciplinary laboratory courses and are developing two new courses.

Specifically:

(a) Engineering Toolbox (Freshman – Sophomore), new course: This course is focused on provided freshman and sophomore with skills to include mill, lathe, CNC, additive manufacturing, circuits, data acquisition, and integration. This skill building endeavor is built around the students manufacturing a working impeller pump. The students will compete to build the best pump with the winner getting an automatic A for the course. In addition to skill building, students have a section dedicated to an exploration-based design.
and build project where they are pushed and not punished for failure. The goal is for them to engage curiosity and gain experience dealing with problems that have open solutions where more than one approach is possible. The Engineering toolbox gives students the basic skill for future design, personal exploration, and the first experience on how to work with students from other disciplines.

(b) **Data Acquisition and Controls (DAC)** (Sophomore – Juniors), new course: DAC reimagines how to teach sensor, data acquisition, and controls. Instead of using a traditional approach of focusing on specific sensors, actuators, etc. This course focusing in analog in, analog out, digital in, digital out. By focusing on a few representative examples, student learn the basics of interfacing and controlling with a broad application to the real world. This course is a strong stepping-stone for advanced courses and design.

(c) **Board Manufacturing and Design** (Sophomore - Seniors), new course: This course focuses on the basic skills necessary to design and layout circuit boards and includes topics such as soldering, milling, laser milling, pick and place and etching.

(d) **Materials Science** (Juniors), revamped and new course: Materials laboratory is a core laboratory at almost any University. Our difference is that our experiments are self-contained and could be taken in any sequence. Students learn to use all the industrial test equipment in the laboratory and are expected to make some of their own test samples.

(e) **Fluids and Hydraulics Laboratory** (Sophomore – Junior), in development for Fall 20: The best way to describe this course is a smorgasbord of experiments that each department can select for their students. In general, there are 21 experiments that range from hydrostatics to open channel flow. The experiments themselves are taken directly from industry; providing the students with a hands-on experience that directly translates to the field. Basic property measurements are woven into industrial applications, such that, a deep understanding of fluids is gained.

(f) **Strengths of Materials** (Sophomore – Junior), in development for Fall 20: This series of lab modules will introduce students to basic properties of structural materials and behavior of simple structural elements and systems through a series of experiments. Students learn experimental technique, data collection, reduction and analysis, and presentation of results. Students will also utilize lessons learned through a series of design projects.

ENDEAVOR supports interdisciplinary design projects that have experienced a resurgence at the College of Engineering, Architecture and Technology (CEAT) at the Oklahoma State University. Senior design courses at CEAT have traditionally been within disciplines, which have limited the quality and complexity of the projects. Over a very short period, senior design projects progressed from departmental exercises only to multi-departmental experiences. This has increased the ability of design teams to tackle more complex projects. Oversight from professors with extensive industrial experience has helped build an expectation for industrial quality work.

**2.3 Makerspaces and Laboratories**

ENDEAVOR provides students design laboratories, laboratories stocked with industrial/industrially relevant equipment, well equipped makerspaces, and training for additive, subtractive, and electronic manufacturing. A description of the makerspaces appears below.
Traditionally, labs and makerspaces are associated with credit classes where students will not use outside of required curriculum. However, this is typically not the case at ENDEAVOR. The focus for ENDEAVOR labs and makerspaces is unique such that students do not have to enroll in any specific class to use the facilities. Instead, students are encouraged to become engaged in the ENDEAVORs laboratories and makerspaces early in their engineering career. The result is students that can utilize the makerspaces and labs as tools to convert ideas into reality or enhance their understanding of engineering topics outside of the traditional lecture format.

All undergraduate students in the college of engineering can access this facility but only after obtaining and completing makerspace training. Training includes a general online facility safety course with quiz, and equipment specific operations and safety instruction with quiz. Following completion of the online makerspace and equipment training, the students must then complete and pass hands-on training. All equipment in ENDEAVOR can be used by students after the appropriate training. We have learned that strict enforcement is key to greatly reduce damage (additive manufacturing) and reduce risk of injury (subtractive manufacturing). Below are makerspace descriptions that make this concept possible.

(a) **Subtractive Manufacturing Makerspace (SMM)**

In order to facilitate traditional manufacturing methods, the ENDEAVOR lab contains a subtractive manufacturing makerspace (SMM) that is open to students once they are properly trained. The main propose of this space is to provide the ability for rapid prototyping or proof-of-concepts using plastics and high-density foams. This makerspace houses the following units; desktop CNC, light duty bandsaw, small chop saw, manual lathes and mills, injection molding, various hand tools, heavy duty sewing machine, 75-watt CO₂ LASER, and heavy-duty work benches.

Students not only have access to the SMM space in ENDEAVOR but also have access to the WWW lab. At the WWW lab students can obtain training and clearance on larger metal cutting lathes and mills, welding, casting, sheet metal fabrication, larger CNC lathe and mills, CNC plasma cutting, CNC abrasive water jet cutting, and a 150-watt LASER.

(b) **Additive Manufacturing Makerspace (AMM)**

ENDEAVOR houses additive manufacturing makerspace (AMM) into two separate rooms called basic and advance 3D printing makerspaces, as shown in Figure 2. Basic 3D printings are mostly for the freshman and sophomore engineering students who are just learning 3D printing. While advance 3D printing makerspace are dedicated to more serious 3D printing projects of junior and senior engineering students for making functional parts and prototypes of advance materials (composites, ceramics, metals) for their industry led capstone project or upper division class projects. The AMM houses various types of AM technologies such as fused deposition modeling (FDM) aka fused filament fabrication (FFF) for polymers and composites, Continuous Filament Fabrication (CFF) for composites, Atomic Diffusion Additive Manufacturing (ADAM) for metals, Stereolithography (SLA) for polymers and ceramics, etc.
FDMs are the most common and popular 3 printers. In FDM, the filament of polymer or composite material is heated to glass transition temperature and extrude out from a nozzle that traces the design in layer-by-layer fashion until full part is printed. In the DMMS, there are total 25 Craftbots that are FDM based 3D printers that can print polymers (PLA, ABS, etc.). In addition, there are two FDM based MarkForged Onyx Pro machines that can print composite material (onyx, that is a chopped carbon fiber reinforced nylon). Whereas, CFF is a newer and derivative of FDM technology that have dual nozzles, one for composite material – Onyx and other to place continuous strands of composite fibers in previously printed composite material. The main advantage of this composite parts is their stiffness and strength due to reinforcing fibers. There are various materials such as carbon fiber, fiber glass, Kevlar, high strength high temperature fiber glass, that are available in the form of continuous strands. In the DMMS, there are two MarkForged Mark II and one Markforged Mark X.

ADAM is also known as bounded power deposition is similar to FDM except the filament comprises of metal powder and polymeric binder. The binder is washed way during the washing cycle and metal powder is fully sintered in the sintering oven/furnace. In the AMM, there one unit each of MarkForged Metal X, MarkForged Metal - Washing Station, and MarkForged Metal – Sintering Furnace. While, SLA uses the photo-polymeric process where the resin is cured by laser or light in layer-by-layer fashion. The various types of materials (polymer, ceramics, biomaterials, etc.) can be printed using SLA technology. The AMM has five Formlabs 3D printers with one washing and one curing station.

![Figure 2: Pictures of additive manufacturing makerspace](c) Electronic Makerspace (EM)

The electronic makerspace houses a LPKF-S4 Proto-Laser mill, LPKF-S63 Proto-Mat 3-axis mill, LPKF Contac S4 thru-hole plating system, two Bantam 3-axis mills, SMT max reflow oven
and a Mann Corp SMT Place 2000 pick-and-place machine. The Figure 3 shows the layout of the electronic makerspace. The vision is that undergraduate students can design and build their own single-layer and double-layer printed circuit boards (PCB) including both surface mount and thru-hole components. Undergraduate student TA’s man and train students on the use of the equipment in the electronic maker space.

Similar to the other facilities in the lab; the college assigned personnel with expertise in board layout and manufacturing to oversee the maker space facility. That individual is responsible for training of TA’s and other support personal along with insuring equipment operation and maintenance. A one-hour class has been designed that will be required for incoming electrical engineering students in the fall of 2020 and non-electrical engineering students may take the class as an elective. This class will introduce students to the design and build concepts for the development of PCBs and wiring and housing of PCBs in a chassis. The though being that lower level undergraduate students should be able to pursue their own designs from conception through to completion.

(d) Materials Laboratory (ML)

Materials Laboratory (ML) serves as an important part of the interdisciplinary program at ENDEAVOR to test and characterize the materials [35]. It is equipped with six universal testing machines (UTMs), four with a loading capacity of 100 KN and two of 300 KN, five Rockwell hardness tester, six inverted metallurgical microscopes, two sets of automated sample polishers and one X-ray energy disperse spectrometry (EDX) scanner, as shown in the Figure 4. This lab gives students the ability to perform mechanical characteristic measurements, such as tensile, compression and bending of materials, Rockwell hardness, microstructure and alloy compositions of materials. The redundant instruments give students more opportunities in hands-on learning: instead of letting the TA do the experiment and the students watch, we can afford to allow every student in the class to operate the instrument and conduct the experiment. In addition, this also increases the efficiency of the lab operations. One TA can supervise a station of many instruments in which multiple experiments can run at the same time. For a two hours lab
session, the ML can hold a maximum of 24 students. The evaluation of a student’s performance in the lab is based on his/her lab report. A template is provided for students to follow in their lab report, which includes sections on background review, experiment description, data analysis and discussion.

Figure 4: Pictures of materials laboratory

Currently, ML has accommodated lab courses from many engineering departments for about 300 students per semester. Once the students finish their lab courses and is trained on operating the instruments, they are certified to use those instruments on their own personal or course projects. For example, a student can bring an additive manufactured specimen to the ML and test for the tensile strength. A group of students working on a digital sensor project can test their strain-gauge sensors and compare measurements with lab instruments. The open environment of ML gives engineering students the accessibility to study materials they are interested in outside of the class.

The complete set of instruments in ML allow independent lab courses to be developed to teach students the related topics of material properties and behaviors by doing experiments. Two new courses have been developed. The course of Material Science Laboratory focuses on the properties of the material covering the topics of stress-strain diagram, phase diagram, heat treatment, and hardenability. The course of Solid Mechanics Laboratory that more emphasizes on the behaviors of material under loading includes experiments in tensile test, truss analysis, bending beam, column bulking, and thin-wall pressure vessel. These courses are offered at sophomore level in conjunction with traditional lectures courses in order to help students learn the same concepts from the experiment perspective.
The Fluids and Hydraulic Laboratory course is not a typical course. Due to the number of students and the extent of the desired immersion and industrially relevant experience, multiple locations throughout ENDEAVOR are required. Three to six experiments may be simultaneously running at each location for a total of 17 experiments. Students will have different experiments every week and then rotate between locations every three weeks. Locations, features, and experiments include

- **ENDEAVOR Flow Laboratory.** This laboratory (Figure 5) has a 35-foot open channel flume and an industrial sized wind tunnel that can reach windspeeds of 80 mph. The laboratory also features a constant head pressure tank that provides flow for pipe friction loss experiments. Five experiments will be simultaneously running in this laboratory, which includes Osborne Reynolds, pipe loss, pipe friction, open flow (wave speed/Froude, hydraulic jump, and weirs), and External flow (force measurements, boundary layers, and lift/drag).

- **ENDEAVOR Test Arena.** The test arena (Figure 6) is an open space with approximately 34’ high ceilings and three theater booms that can lift 1,500 lbs. At this location, elevated gravity fed hydrostatic pressure and pump head experiments are conducted. The boom system is used to provide controllable elevation. Six different experiments will be conducted simultaneously and include hydrostatic pressure, simple pump, dual pumps in series, dual pumps in parallel (or maybe positive displacement pumps), buoyancy and Torricelli.

Figure 5. Picture of the ENDEAVOR Flow Laboratory
ENDEAVOR Flow Measurement Laboratory. The flow measurement laboratory is designed for the operation of industrially relevant inferential flow measurement equipment, such as orifice meters, venturi tube (both as a meter and suction pump), and rotameter. We also have the option to run pneumatic orifice meters. This laboratory will run at least three experiments simultaneously.

ENDEAVOR Wet Design Laboratory. The Wet Design Laboratory is built to support chemical design projects and measurements. This space is used for basic fluid property measurements such as viscosity, density, surface tension, and Newtonian and non-Newtonian fluids. Again, the experiments even for basic properties are industrially aligned. Only three experiments are planned to run simultaneously in this laboratory.

3. Measuring Performance

Various measured are underway to gauge the performance of the one-year old ENDEAVOR that includes: (a) developing the grading rubrics; (b) track the student enrollment and retention. Authors would like to make the readers aware that the ENDEAVOR is started the operation in fall 2018 (one academic year) and due to the small amount of period it is difficult to get enough data that reflect the satisfactory findings. Though, the data collection methods were identified and kept in place to obtain the useful conclusion.

3.1 Development of Grading Rubrics

A common concern in open learning labs is how to fairly grade. This becomes even a larger issue when most of the topics being taught are more skilled based than tradition academically based. One of the other major issue with more traditional grading (quiz or exam based) are the number of students needing to be evaluated and the resources required to grade or other related administrative activities. By keeping the grading rubric relative straight forward, TAs and instructors are able to focus their resources on the hand-on applied learning that is one of the major focal points of ENDEAVOR lab. This problem was alleviated by the development of comprehensive rubrics that fits the nature of the open skill sets as shown in Table 1.
Table 1: Comprehensive rubrics that fits the nature of the open skill sets

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Points</th>
<th>0 – 3</th>
<th>4-7</th>
<th>8-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety (S)</td>
<td>Understanding of the safety and PPE requirements</td>
<td>0 or 1</td>
<td>This is a category that must be passed before using the equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment Description (ED)</td>
<td>Understanding of the capabilities and tolerances</td>
<td>0 – 10</td>
<td>No understanding</td>
<td>Basic understanding</td>
<td>Advanced understanding</td>
</tr>
<tr>
<td>Procedure (P)</td>
<td>Demonstration of understanding or manufacturing of training part(s)</td>
<td>0, 6, or 10</td>
<td>No understanding. Not able to build part on own. Must be show every step</td>
<td>Able to build part but had to be helped for parts/steps</td>
<td>Full understanding of all the operations involved and able to work safely with minimum oversight</td>
</tr>
</tbody>
</table>

Score Function: \( Score = S(ED + P) \)

Students need to gain an understanding that there are type types of reports; formal reporting and an informal reporting. For more traditional labs, we have broken the reports into two different categories; short informal engineering memos and more formal reports.

An engineering memorandum (memo) is defined as a document written from a member of an organization to one or more readers within the same organization. A memo in general, is written to effectively and efficiently review a task, project or experiment and act as a reminder of why a task was accomplished. Students are shown that Engineering memos are a type of informal report and that they should be succinct and concise document. The grading of memos is more in depth than skill sets and as such the grading rubric is a bit more detailed. Table 2 shows the general rubric that has been proposed for use in ENDEAVOR for memo-based reports.

Table 2: The general rubric for use in ENDEAVOR for memo-based reports

<table>
<thead>
<tr>
<th>Section</th>
<th>Objective(s)</th>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memo Header (MH)</td>
<td>Confirm all the following information is given</td>
<td>• Addresssee (ENDEAVOR Instructional Team)</td>
</tr>
<tr>
<td></td>
<td>(points either 0 or 1)</td>
<td>• Student and team members names.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Subject of the report (e.g. lab title)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Date submitted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Date Data Acquired</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• List of attachments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Introduction (I)</td>
<td>• Maximum of 3 lines of text (0 or 1)</td>
<td>not shown</td>
</tr>
<tr>
<td></td>
<td>• Summarizes memo content (0-3)</td>
<td>only partially presented</td>
</tr>
<tr>
<td></td>
<td></td>
<td>poorly presented, requires interpretation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>clearly presented</td>
</tr>
<tr>
<td>Methods (M)</td>
<td>This will be a short section (NO MORE THAN 3 SENTENCES)</td>
<td>no mention of the utilized methods</td>
</tr>
<tr>
<td></td>
<td>with an unambiguous statement of what methods techniques, and procedures were used</td>
<td>methods incomplete/wrong</td>
</tr>
<tr>
<td></td>
<td></td>
<td>it is mentioned and correct</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correct but also high detail and quality</td>
</tr>
<tr>
<td>Results and Analysis (RA)</td>
<td>The following parts should be included in the results section</td>
<td>not shown</td>
</tr>
<tr>
<td></td>
<td>(guiding questions may be in assignment):</td>
<td>only part of data presented</td>
</tr>
<tr>
<td></td>
<td>• Key result(s)</td>
<td>data poorly presented</td>
</tr>
<tr>
<td></td>
<td>• Analysis, including key formula(e)</td>
<td>clearly presented</td>
</tr>
<tr>
<td></td>
<td>• Properly formatted figure</td>
<td></td>
</tr>
</tbody>
</table>
The other type of report that students are introduced to is the more lengthen formal lab report. Engineers write longer documents such as formal engineering reports for many reasons, including the documentation of experiments as well as designs. In a formal document, the audience expects a more in depth and methodical presentation of the subject, as compared to the engineering memo, that includes summaries of important points as well as appendices on tangential and secondary points. Table 3 shows the general rubric that has been proposed for the formal lab reports for labs that are conducted in ENDEAVOR.

Table 3: The general rubric for the formal lab reports

<table>
<thead>
<tr>
<th>Section</th>
<th>Objective(s)</th>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title Page (TP)</td>
<td>Confirm all the following information is given (points either 0 or 1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Title of the report</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>• Class or Session number</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>• Student Names</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>• Department and Major</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Date submitted</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Date the data was acquired</td>
<td></td>
</tr>
<tr>
<td>Abstract (A)</td>
<td>Length (150 to 400 words) Content</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Why the experiment was performed</td>
<td>not answered</td>
</tr>
<tr>
<td></td>
<td>• How the experiment was performed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Provides the primary conclusions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Stands alone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over the word limit And/or not obvious if answered</td>
<td>1 to 2 of the contents are answered clearly Or All covered but not obvious if answered</td>
</tr>
<tr>
<td></td>
<td>All clearly answered</td>
<td></td>
</tr>
</tbody>
</table>
| Front Matter (FM) | Confirm that they have a complete:  
• Table of Content  
• Report Organization – use the table of content to assess if the paper is organized in a logical fashion  
• Nomenclature list | Missing or not able to easily locate | There but not complete/accurate | There but little to no logic in the organization layout | Complete and logical organization layout |
|---|---|---|---|---|
| Introduction (I) | Confirm that they have addressed the following:  
• Introduce your topic.  
• Create some context and background.  
• Tell your reader about the research you plan to carry out.  
• State your rationale.  
• Explain why your research is important.  
• State your hypothesis. | Missing | Contains 2 or less of the items to be addressed or provides the reader little to no understanding on the WHY paper was written. | Covers most all the topics and clearly states the rationale of the paper. | All topics are covered and states a strong argument for the paper and also includes cited work that is relevant |
| Objectives (O) |  |  |  |  |
| Experimental Methods |  |  |  |  |
| Test facility and model (TFM) | They need to provide a description of the test facility as well as description on the system/model being tested. | No discussion | Very basic discussion | Contains detailed and pertinent discussion | In depth discussion and includes key figures as appropriate |
| Instrumentation (TI) | They need to provide a description of the instrumentation used to measure each of the following items. They should provide the make, model, measurement range, accuracy, and a description of how it was used for each of the instruments mentioned in the lab module description. | No discussion | Discussion without any real details | mentioned with some information | Detailed information provides so that others could duplicate the instrumentation set up. |
| Test conditions (TC) | They need to provide the range tested for as mentioned in the lab module description. | No discussion | Little discussion on how the test matrix was formed. | Discussion on the test matrix, range of independent variable. Little to no discussion on design phase uncertainty. | Full details on the range of the independent variables, as well as fully design phase uncertainty, and design of experiment |
| Results (R) | This section is to present raw data and discuss any issues/concerns about collection of the data  
• Data collection procedure discussed  
• Data processing procedures  
• Identification and handling of outliers | Missing | Data presented but no discussion on the quality | Data presented in a logical format with some indication on the quality. Basic identification of possible outliers | Data presented in a clear and logical format. Includes confidence intervals. Along with discussion on the quality of the results. Fully justifies removal of outliers. |
3.2 Student Enrollment and Retention

Retention will be tracked by following students that have taken the hands-on courses (like the Engineering Toolbox and comparing their drop-out rate with general engineering student population. This methodology has already been established within the college of engineering and tracks student in categories – withdrew from University, completed engineering degree, and completed degree in field other than engineering [36]. Currently, we have not been operational long enough to have enough data to assess the effect on student retention, but we intend to provide follow on papers once the data becomes available.

4. Results and Discussion

ENDEAVOR facility has only been in operations for 1 academic year. Therefore, a detailed assessment of the overall impact for students, employers, and the College of Engineering, Architecture and Technology (CEAT) at the Oklahoma State University will be determined in the future. However, ENDEAVOR has had an immediate impact for the college, departments and students. These are

(a) More access to laboratories. Courses and students have access to the laboratories and makerspaces 67.5 hours a week instead of limited scheduled hours.
(b) Increased laboratories utilization. On average, every laboratory in ENDEAVOR is used by at least three departments. Number of course per laboratory range from two to five – with multiple section.

(c) Increased laboratory occupancy. When comparing to an 8-hour workday, our facility laboratory occupancy increased to 50%. Some laboratories are active more than 40 hours per week.

(d) Improved utilization of instructors and resources. Instead of instructors bouncing between several laboratories with multiple sections throughout a week because of schedule and size of laboratories, instructors can now schedule larger section and focus resources to fewer sections over one day.

(e) Common instructional platforms that can do more. Our college teamed with National Instruments to integrate the Elvis IIIs into our laboratory instrumentation [37]. Within a semester, it became the common platform for seven courses across four departments and general college courses. The Elvis III built-in capabilities replace the need for oscilloscopes, signal generators, BODE Plotters, multimeters, and power supplies. The Elvis also provides data acquisition and control capability, circuit prototyping board, and over five advanced trainer boards to including fiber optics and radio frequency trainers.

(f) More equipment is available to be used by multiple courses. Courses have added or upgraded experiments because of the availability of improved equipment or experiments that were not available previously.

(g) Industrial and Industrial relevant equipment/experiments. ENDEAVOR has moved away from benchtop experiments to build experiences around industrial questions and processes. To do this, ENDEAVOR has collaborated with companies like Shimadzu to provide students with state-of-the-art industrial test equipment [38]. In building design fixtures for experiments, fixtures will imitate processes or applied technologies as observed in the field. ENDEAVOR strives to go from abstract to applied.

(h) Accelerated Senior Design Projects. Standardization using National Instrument products and LabView has increased the complexity and quality of design projects. For very complex projects, this standardization provides easy transfer from one semester to the next.

(i) ENDEAVOR has doubled the number of students trained to use lathes and mills; provides hands-on training for CNCs; and additive manufacturing training for a quarter of our student body. Students use learned skills for courses, integrated into laboratories, design projects, and personal Entrepreneurial projects.

4.1 Performance Matrix

The set objectives for ENDEAVOR to gauge the performance are: (a) change the perception of students; (b) workforce development; and (c) boost the morale of the students.

(a) Perception of students

One of the primary goals of ENDEAVOR is to help students understand varied engineering topics and skill sets with applied learning. In order to determine student satisfaction with their perceived engagement in more applied labs as well as learned skill sets, the following questions
will be scored by the students on a 5 Likert scale shortly after finishing the topic or skill set. Example questions are:

1. This lab/module helped me learn the material
2. This lab/module was interesting and engaging
3. The amount of theory provided adequate support of the lab/module
4. This lab was frustrating and confusing
5. This lab/module has kept me interested in pursuing engineering
6. I can see where this lab/module while be relative to future course and/or real-world applications
7. I can imagine applying some of the skills learned to other problems
8. This lab/module provided me a better understanding of measuring basic physical parameters
9. This lab/module has helped me have a better understanding of uncertainties and tolerances

While obtaining feedback right after the student finishes does provide useful information, it does not provide ENDEAVOR with information on long-term retention and how the relevant skill or lab-module leads to understanding of future courses/topics. To address this issue graduating students are also asked a short series of questions that are a mix of 5 Likert scale and open-ended questions.

1. (Selection) Please check the labs and skills set modules that you engaged in at ENDEAVOR while a student.
2. (Open) From the labs and skill sets that you listed,
   a. Which did you find most useful and why?
   b. Which did you find least beneficial and why?
3. In general, I found that the labs and skills set at ENDEAVOR helped enhance retention of material.
4. In general, I found that the labs and module taken at ENDEAVOR were relative to future courses that I took.
5. (Open) What type of skill set or lab course would you like to see added to ENDEAVOR?

(b) Workforce development

ENDEAVOR workforce development has been influenced by two noted psychologist, Abraham Maslow's analysis of the learning process and Benjamin Bloom’s analysis on cognitive learning. In a 1943 paper called A Theory of Human Motivation, Maslow presented the idea that human actions are directed toward goal attainment [39]. Maslow determined that; how well students learned depended on the degree of satisfaction both teachers and students had during the learning process [39-41]. When students and teachers enjoyed the process and felt fulfilled by it, students learned faster and retained the information better.

In 1956 Bloom publication of Taxonomy of Educational Objectives followed a series of conferences from 1949 to 1953, which were designed to improve communication between
educators on the design of curricula and examinations [42]. In 2009, Krathwohl [43] published a revised edition of Bloom’s taxonomy, that slightly changed or updated the six levels of cognitive learning; Remember, Understand, Apply, Analyze, Evaluate, and Create. ABS utilize the Train-the-Trainer model as it reflects the works of both Maslow and Bloom well.

Typically, facilities like ENDEAVOR are overseen and run by full-time professional staff and in ways ENDEAVOR does as well, but where ENDEAVOR differentiates from others is that the core of the workforce is student staff. ENDEAVOR’s policy is that students can teach other students skill sets and labs for the most part better than full time professional staff. One of the main reasons the administration of ENDEAVOR thinks this is that student staff are typically able to relate and communicate better with other students. Train-the-Trainer model is where participants learn a subject and simultaneously learn how to teach others. This style of training provides feelings of satisfaction and fulfillment to the students better than other teaching models, as well as allows students to engage in the higher levels of cognitive learning. One interesting side effect of using the Train-the-Trainer format is that in many ways this method creates a force multiplier, in that a handful of professional staff can expand their time and band-width by training students, who then turn around and train/teach others. It is in this way that ENDEAVOR has over xxx student staff members assigned to the makerspace and another xxx students assigned to lab modules. These students not only help run learning sessions, but also help the profession staff shape the direction and content material that is covered. Without using the Train-the-Trainer method, there is question on if ENDEAVOR could run as it does without major cost overruns.

(c) Boost the morale

ENDEAVOR is a playground for engineers. It is a one-of-a-kind facility that excites students, faculty, donors, and the College of Engineering, Architecture and Technology (CEAT) at the Oklahoma State University [20-29]. It plays a central role in recruiting by hosting daily tours of prospective students, large events for robotic training, 4H, National Lab day, Discovery day, Summer bridge programs, Oklahoma science fair, Native American National Science fair, teacher training, and a wide range of STEM camps. This level of outreach and support is accomplished while the laboratory facility is fully functioning to support 38 courses and 2,000 students per week. We realize our mission and can effectively leverage remarkable resources to provide a superior experience in a very cost-effective manner.

5. Future Plans

It is never the end of such endeavor and therefore ENDEAVOR team will continue working on developing more systematic approach to obtain useful performance metrics. Because Endeavor is so new, you need to think about a logic model for program effectiveness. Most of the educational research is very difficult to perceive and execute by major engineering faculty team and this is the struggle for us as well. Therefore, we have partner with education department and one of our coauthors (from education department) and this faculty will help us to develop a logic model to plan and obtain more systematic data to find effective conclusions.

The proposed plan for such simple metrics will revolve around the following points:
Now that we have ENDEAVOR, what has changed?
Retention numbers since ENDEAVOR began compared to prior numbers.
What new courses are being offered that couldn’t be offered before ENDEAVOR?
What do students have access to that they did not have access to before?
How are industry partners actively playing a role in the education of students? Is this different from pre-ENDEAVOR?
Have demographics changed across your disciplines?
  i. Gender?
  ii. Minorities?
Are enrollments going up/maintained?
Develop documentation to track student learning?
Do you have clear learning goals associated with ENDEAVOR?
  i. How are you meeting those learning goals?
Student use of ENDEAVOR?
  i. Are students using the labs?
  ii. Are students getting trained to use the labs?
Get quotes from students about the impact of ENDEAVOR on their learning
Try to get quotes from students who were here prior to ENDEAVOR and are still in the system.
How are your stakeholders involved?

5. Conclusion
In this article, efforts were made to show a multiyear plan to transform undergraduate education through a state-of-the-art ENDEAVOR building at the College of Engineering, Architecture and Technology (CEAT) at the Oklahoma State University. This article shows the innovative structure and engineering pedagogy of ENDEAVOR that expands the instruction beyond the classroom and increases undergraduate laboratory and exploratory time for interdisciplinary, hands-on and industry-aligned experience-based learning. It should be noted that the ENDEAVOR lab structures are independent from the engineering curriculum that promote the early engagement of students (even in their freshman year) to access and experience hands-on interdisciplinary design, applied experiments and training/use of all the five available makerspace areas. As you can observed, ENDEAVOR is a true example of multidisciplinary laboratory for undergraduate experiments, design, and research of all eight departments in the college work together under the same roof that promotes undergraduate interdisciplinary teaching, research, and training. This article also discussed the preliminary data collection methods to gauge the performance of ENDEAVOR. ENDEAVOR is started in fall 2018 and it will take some years of time before any conclusive evidence will be drawn to link the results with the effectiveness of such facility. However, authors made attempts to show the role of ENDEAVOR regarding engineering pedagogy and its effectiveness for transforming the undergraduate engineering education through experience-based learning.
Overall, the efforts were to share the impact of our current tangible operational of becoming truly interdisciplinary and the potential impact of our interdisciplinary instruction is unique (may be tremendous). We were convinced that we should share where we are and where we want to go. In short, value of sharing this story NOW as opposed to waiting until data is available. In response, we are expecting to receive help from the members of the division of experimentation and laboratory oriented studies to explore and find the different ways to collect the right data.

References


[35] C. Rheam, "Meet ENDEAVOR," in Dr. Qinang Hu gives you a tour of just one of the many spaces inside ENDEAVOR, a 72,000-square-foot building with state-of-the-art technology., ed. [https://ostate.tv/media/Meet+ENDEAVOR/1_g9fks4kx](https://ostate.tv/media/Meet+ENDEAVOR/1_g9fks4kx), 2019, p. 6:01.


