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Experiential Learning of Data Acquisition and Instrumentation Using a Met Tower in a Laboratory Setup for Wind Power Technology Education

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Abstract
We share an experiential learning experience from the design and development of an integrated learning environment (iLED) implemented at Appalachian State University as a part of a wind power technology course. The five-week integrated course plan includes a set of experiments for each of the four phases of David Kolb's experiential learning for wind resource measurement, focused especially on data acquisition (DAQ) and instrumentation of met towers. Our experience could be a meaningful pedagogical resource to instructors who offer hands-on engineering and renewable energy technology education. This paper presents a case study of implementing educational research, including theory, design, implementation, analysis of learning objectives, and outcomes of the experiential learning project in a laboratory-scale setup. We anticipate the iLED contributing to improving teaching and learning outcomes of wind energy education that align with current workforce demands of the global renewable energy industry.

Keywords: Data Acquisition, Met Tower, wind rose, experiential learning, integrated learning environment, wind power

I. Introduction

Experiential learning is a teaching and learning method that connects theories and knowledge learned in the classroom to real-world applications. In this method of learning, students participate in the course content and learn ideas or knowledge by applying them to real world applications. In this active learning method, students learn subjectively and synthesize knowledge by reflection and apply the concepts to develop technological solutions through active experimentation. Human beings process experiences differently into knowledge and technological solution.

Wind power technology converts the kinetic energy of moving air into electrical energy. Wind resource assessment is an important phase of a wind power project's development and operation. Project financials and the viability of a wind power project rely on wind resource class, availability of land, and accessibility of transmission infrastructure, among many other factors. Post construction, wind resource measurements inform power performance evaluation of the wind turbines and optimization of operational performance of the wind farm. It is important that wind resource data are collected following applicable standards (such as IEC 61400-12) and best practices of the wind energy industry [1, 2]. If a student can learn such transferable technical skills in a university laboratory setting, it could be beneficial for the wind industry [3] as well as for students who are aspiring to high paying jobs in the renewable energy industry.

Wind resource measurement is an important phase of wind energy project development and operational performance analysis. Wind resource measurements are carried out mainly to estimate the free stream hub height and in turn to estimate turbine annual energy production (AEP) and uncertainties. To accomplish this, a met tower is installed to measure the wind resource at various heights, and a data acquisition system (DAQ) logs data. However, technical (fluid dynamics effects, wake) and economic (number and density of turbines) criteria influence met tower selection, specifications, area density, and instrumentation of the met tower.

A wind turbine converts the kinetic energy (KE) of moving air into electrical energy. Accordingly, the master equation of the wind power is written as a change in KE per unit time:

Wind power $P = \Delta KE/t = ½\, mu^2/t = \frac{1}{2}\eta\, \rho\, A\, u^3$; .... [1]

where m = mass of air, u = wind speed, η = efficiency, ρ = density of air, and A = swept area of the wind turbine rotor.

A typical 60 m met tower consists of sensors to measure wind speed, wind direction, and site-specific air density. The tools used to measure each of these variables are shown in Table 1.

Table 1: Sensors for wind resource measurement in a typical tower.

SN	Variable	Sensor	Nos
1	Wind speed	Anemometer	6
2	Wind direction	Wind vane	2
3	Ambient Temperature	Thermistors	2
4	Pressure	Barometer	1
5	Water vapor in air	Relative Humidity	1
6	Solar radiation	Pyranometer	1
		Total	13

Appalachian State University hosted a Class 5 small wind research and demonstration site at Beech Mountain in North Carolina from 2005 to 2020. Activity at the site included various industry collaborations related to turbine prototyping and performance testing utilizing full-scale models. Students got hands-on experience with various aspects of wind energy system design, development, testing, and commissioning, including micrositing and instrumentation of met towers. Subsequently, a wind energy education lab was commissioned on Appalachian State's campus, where students installed full-scale 10 m met towers and conducted power performance testing of a Primus 400-watt wind turbine. Unfortunately, this site was repurposed by the University after a year, highlighting the challenges of maintaining experiential learning sites. Now, the met tower work is undertaken in a classroom using tripod towers.

II. Background

Appalachian State University is a teaching institution at its core which has recently earned a Carnegie Research 2 classification. The University has a legacy in teaching sustainable technologies and renewable energy since Professor Dennis Scanlin envisioned this program over 40 years ago. The Department of Sustainable Technology and the Built Environment (STBE) in the College of Fine and Applied Arts (CFAA) offers both undergraduate and graduate degree programs in Renewable Energy Technology and Building Sciences. The Department has a focus on exemplary teaching through experiential learning, synergistic curricula, and community engagement. This department has developed a unique reputation for applied research and sustainable development in the areas of construction and building science, renewable energy, and other sustainable technologies. The Renewable Energy Technology program is currently served by a dual undergraduate/graduate course, *TEC 4607/5607: Wind and Hydro Power Technology*, which introduces students to the basic concepts, tools, techniques, and materials needed to design and construct systems that convert wind and hydro resources into electricity. Our M.S. Technology is one of the growth programs identified by the School of Graduate Studies for strengthening and invigorating graduate-level courses and research outcomes of students and faculty as a strategic effort across the university. There are graduate and undergraduate university programs in wind energy [4, 5] to support workforce development [6] in the United States who are then employed worldwide by the global wind energy industry.

2.1 Appalachian State Wind Farm

Appalachian State is one of a very few universities in the United States that owns its own electric utility company, New River Light and Power (NRLP). The campus also hosts a wind farm, which is part of the Innovation District's zero-carbon energy system. The district energy system is an integral part of wind power technology education within the STBE department.

The Appalachian State Wind Farm portrayed in Figure 1 consists of three wind turbines with different owners. The NPS 100 kW wind turbine is jointly owned by the University, the student-led Renewable Energy Initiative (now called RENEW), and New River Light & Power. Harrison Street Real Estate LLC owns two Vestas V47 – 660 kW wind turbines, and was responsible for the development, construction, and operation of the district's zero-carbon energy system. This I district energy system, known as Innovation District, is supported through a public-private partnership (P3). The project displays a balance of ownership, business case, and local community engagement.

Photo by Wes Craig and Troy Tuttle (February 11, 2026)

Figure 1: Appalachian State Wind Farm, an academic building under construction, and the District Energy System Building.

The Appalachian State Research Institute for Environment, Energy, and Economics (RIEEE) is leading efforts to provide student and faculty access to Innovation District energy data, including turbine data, through an AVEVA PI data server. This on-campus asset is available for interdisciplinary research, hands-on experiential learning, training, and community engagement.

2.2 New River Light and Power | On Campus Utility

Appalachian State's New River Light and Power (NRLP) is a nonprofit electric utility operated by the Division of Business Affairs, serving nearly 9000 residential and commercial customers who reside in and near the town of Boone. This campus-owned utility has been providing electric power to campus and the Boone community since 1915.

III. Student Backgrounds

Students studying Renewable Energy Technology (RET) at Appalachian State have diverse backgrounds, experience, and aptitudes toward engineering and mathematics, and typically possess a strong inclination toward clean energy and other sustainable technologies. The RET program is particularly attractive to potential engineering students who prefer a more experiential education less focused on advanced mathematics. Accordingly, the Wind & Hydro Power Technology course is designed for students without engineering backgrounds and is updated each year with hands-on exercises that emphasize experiential learning. The course description is documented in Appendix A1. The dual-listed section of the course consists of a mix of graduate students and undergraduate students.

3.1 Learning Style Preference: Survey

Each student has a unique way of learning. Instructors may have to adapt and update teaching methods to better accommodate the aptitudes and backgrounds of the students. To learn more about the distribution of students in the Wind & Hydro Power Technology class, we administered a Learning Styles questionnaire developed by Richard M. Felder, and Barbara A. Soloman at NC State University [7] over eight semesters. The survey helped us understand our students' learning styles, preferences, and aptitudes. The web-based survey summarizes learning preferences of students in terms of an index of learning in the following categories: (i) Active | Reflective, (ii) Sensing | Intuitive, (iii) Visual | Verbal, and (iv) Sequential | Global. Figure 2 presents typical results of a learning survey by one of the students in the class.

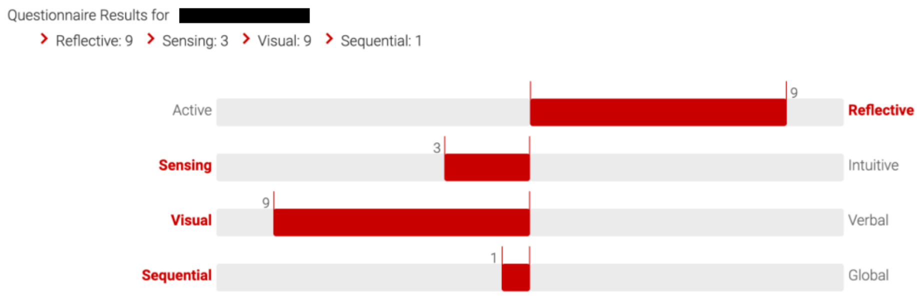


Figure 2: Learning Survey Sample Output

3.2 Distribution of Students: Aptitude of Students Toward Learning

There have been various categories of learners in each section of the Wind & Hydro course, and these change each semester. We aggregated the results of the survey binarily. Binary aggregation splits the result into two categories irrespective of degree of learning preference (for example, as indicated by the number '9' of Reflective category in Figure 2 of dualism: Active or Reflective). Figure 3 presents a binary distribution of interdisciplinary cohorts based on a survey of 96 senior undergraduate technology majors. These reveal that the majority prefer active over reflective, sensing over intuitive, visual over verbal, and global over sequential learning styles. The preference varied slightly but remained consistent over the semesters.

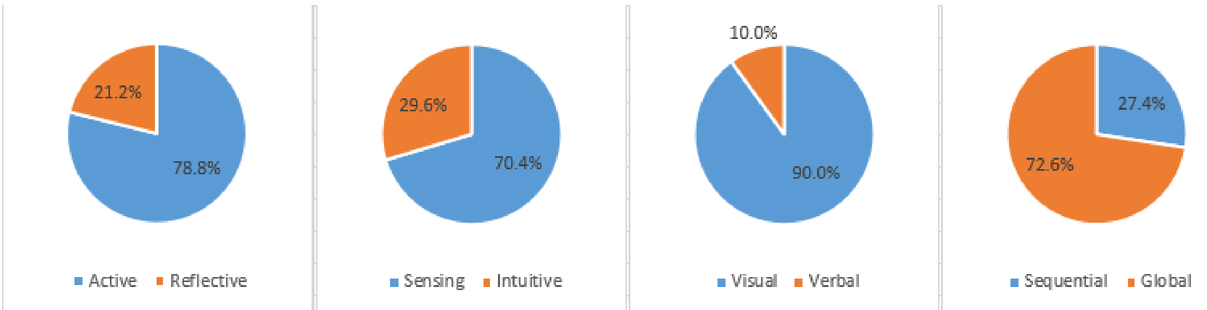


Figure 3: Learning Styles Preferences of RET Students at Appalachian State

We are interested in providing learning opportunity for those interested in technical jobs in the renewable energy industry. We emphasize hands-on teaching and learning experiences that engage, inspire, and motivate interdisciplinary learners of all types. Experiential learning is a learner-centered pedagogy that can benefit all types of learners. Following the Center for the Integration of Research, Teaching and Learning (CIRTL) goals [8], we aspire to develop evidence-based teaching knowledge and cultivate teaching skills through reflective improvement.

IV. Theory of Experiential Learning

Experience has been a source of learning and development for mankind for a long time. The theory of experiential learning put forward by David Kolb in 1984 is based on an assumption of how a person understands and processes information. In this framework of learning, knowledge is created through the transformation of experiences and application of knowledge in subsequent problem solving. Teaching and learning encompass a continuous cycle that includes hands-on experiences, reflective observation, abstract conceptualization, and active experimentation. This theory of learning suggests that students learn best when they can actively engage in experimentation, reflect on that experience, and then apply new concepts and ideas to real-life problem solving [9].

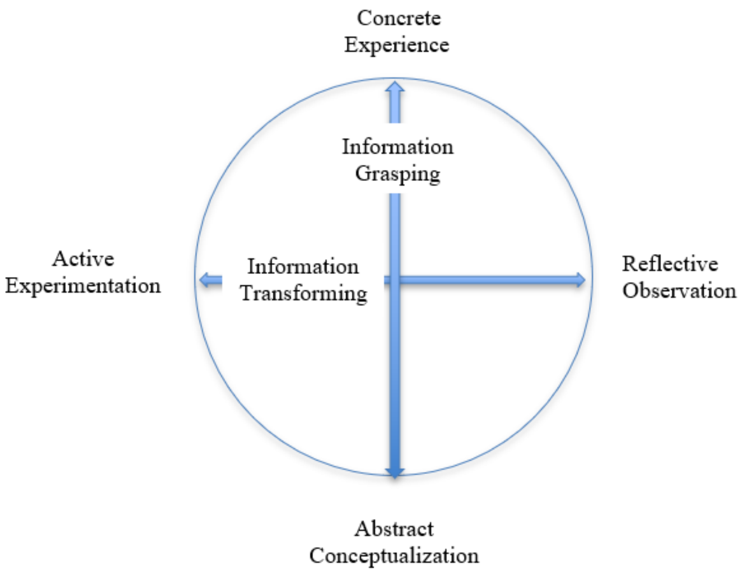


Figure 4: Cycle of Experiential Learning

As depicted in Figure 4, Kolb's experiential learning cycle is composed of four stages: (1) Concrete Experience (CE), where students participate in an actual experience; (2) Reflective Observation (RO), where students reflect on the experience and try to make sense of it; (3) Abstract Conceptualization (AC), where students develop theories or concepts based on their reflections; and (4) Active Experimentation (AE), where students apply these concepts to new situations. This cyclical process can be repeated continuously, allowing learners to refine their understanding and improve their problem-solving skills. By understanding these four cycles of experiential learning, educators can tailor teaching and learning activities to engage students in ways that align with their strengths, fostering a more personalized learning experience.

Individuals may extract knowledge from experience based on their background: culture, education specialization, life experiences, career choice, personality type, etc. According to David Kolb, experiential learning is a process where knowledge results from making meaning as a result of direct experience [9]. An ontology of learning is a combination of experience, perception, cognition, and behavior. No two individuals may go through the same phase of the learning cycle. However, the more deliberate one is about engaging in opposing phases of the learning cycle, the more effective a learner one can become. Thinking and Experiencing can be considered as two opposite phases of the learning cycle. Similarly, Acting versus Reflecting are two opposite ways of dealing with ideas and experiences. Reflecting looks inward for meaning, while Acting internalizes meaning directly through external sense experience of the physical world.

Learning is a process grounded in experience. In the following section, we try to combine experiential learning with the best practices of the wind energy industry through an integrated learning environment development (iLED). This design aims to align experiential learning with the job functions of the wind industry in a way that teaches students to collect bankable wind resource data to support wind power project development.

V. Design: Experiential Learning in Wind Energy Education

We designed a 5-week-long course on data acquisition (DAQ) and met tower instrumentation. An outline of the weekly work plan is as follows:

- Wk 01: Introduction to GIS and Database
- Wk 02: DAQ and Statistics
- Wk 03: Wind Resource Measurement: Met Tower
- Wk 04: Prototyping and Measurement: Met Tower in a Laboratory Setup
- Wk 05: Installation and Commissioning

During these five weeks of interaction, the students go through the four phases of David Kolb's learning cycle summarized in Section 4. Students also learn the best practices of wind resource measurement focused on bankable data collection and project documentation traceable back to the met tower installation and commissioning. This integrated session was designed and developed with the following learning objectives in mind:

1) Introduction to fundamental theory, concept, tools (sensors, logger, GIS), and technique of wind resource measurement.
2) Micrositing of a met tower for a given wind energy project.

3) Design of sensor configuration for anemometers, wind vane, and temperature sensors.
4) Functional testing of data loggers, including transfer function, sampling, and aggregation time.
5) Collecting and validating data (quality control) using the industry standard four statistics [10] of wind resource data.

These objectives address the broader goals and student learning outcomes (SLOs) of the RET program at Appalachian State. These five week-long course modules are contained within the TEC 4607/5607 Wind and Hydro Power Technology course.

5.1 Equipment and Tools: Integrated Learning Environment Development (iLED)

An Integrated Learning Environment Development (iLED) emphasizes multi-disciplinary perspectives and problem solving. This learning environment includes a feedback loop of student evaluation to inform curriculum development and the teaching and learning process and is designed to benefit both students and instructors. In this section, we summarize the experience of training students on DAQ and instrumentation of wind met towers at Appalachian State.

Many of our students are visual learners. The iLED developed for TEC 4607/5607 helps students gain hands-on experience working with sensors and data loggers and, at the same time, helps them learn best industry practices to estimate the hub-height wind speed and parameters that influence uncertainty in wind speed.

Equipment List: iLED Testbed

An iLED testbed is a teaching learning platform designed to teach a set of ideas connected to an integrated objective. These ideas together make sense for a deliverable in an industry setting. The iLED consists of laboratories, datasets, and software to train students on the best practices of wind resource measurement.

Each lab-scale setup consists of the following equipment:

- Mounting Tripod (7-ft) for Weather Stations from Davis Instruments
- Anemometers (2): NRG 40H
- Wind Vane: NRG 200 M/P
- Temperature Sensor (1): NRG 110S
- APRS Wind Data Logger (1) from APRS World, LLC
- Table Fan – artificial wind (1)
- Handheld anemometer (1): Kestrel 5500

Optional field-scale equipment includes a 10-m NRG tower. The field scale met tower is instrumented with all sensors listed in Table 1. It consists of about 12 sensors (6 anemometers, 2 wind vanes, 2 temperature sensors, 1 pressure sensor, 1 relative humidity sensor, and 1 pyranometer) connected to a Symphonie(R) data logger.

Other digital datasets/software include:

- Software: Symphonie Data Retriever (SDR)
- MS Excel spreadsheet
- NRG SDR Dataset daily file for a year (365 RWD files)
- 1 Hz resolution performance data for a day from the NPS-100-21C wind turbine.

The iLED Testbed for wind resource measurement demands a multi-dimensional approach designed to minimize cost, ensure effective delivery, and minimize the multiplicity of tools for various teaching and learning outcomes. The test bed consists of capabilities to conduct the following five labs related to wind resource measurement:

- Lab 01 GIS and Wind Resource Data
- Lab 02A NRG Reports - Export Windrose and Data
- Lab 02B Data Aggregation and Statistics: NPS
- Lab 02C Data Acquisition and Statistics: APRS
- Lab 03 Met Tower Siting and Instrumentation

5.3 Implementation: Experiential Learning in Wind Energy Education

When learners and the learning environment interact, both are susceptible to change as a result of the constructive feedback loop. Experiential learning evolves through the collective experience of instructors and learners who apply theory and practices in teaching and learning. The following section presents a short description of each phase of the learning cycles as implemented in the Spring 2026 semester. These phases align with the 5-week plan with first week (Wk 01, see Section 5.0) being introduction to iLED and review of pre-requisite for a successful implementation of an integrated learning experience.

5.3.1 Introduction: iLED

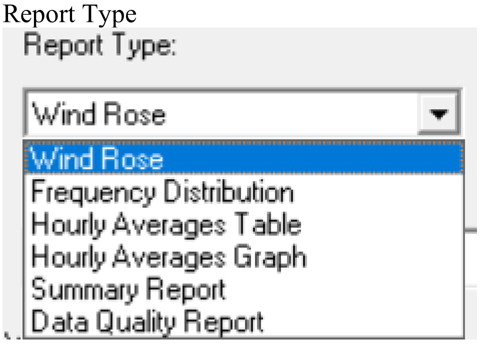
In this introductory iLED, we introduce students to GIS using Google Earth Pro, a free desktop version tool available to download from Google. Students learn to navigate the U.S. Wind Turbine Database and identify wind farms in their neighborhood or state. Students learn to use basic spatial measurement tools that come with Google Earth Pro. This week has a lab (Lab 01 GIS and Wind resource data) that helps students download data from the Wind Toolkit database using the System Advisor Model (SAM). They use metadata to perform cursory measurements such as distance between turbines, perimeter, area density, and elevation profile of the wind farm.

5.3.2 Concrete Experience

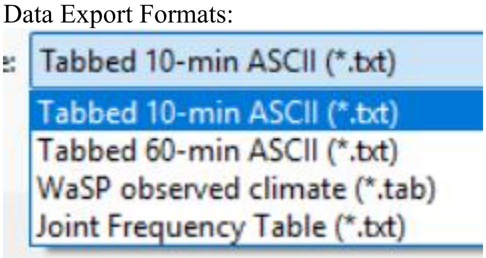
A concrete experience with DAQ and Instrumentation is provided to students after an introductory lecture on DAQ. The lecture covers the theory of DAQ, especially sampling time and aggregation time. The lecture introduces students to various sensors relevant for met tower instrumentation in relation to the master equation Eq 1 of wind power. Here, students also learn how electrical signals from sensors are converted into useful measurements using transfer functions such as y = mx + c; where *m* is slope and *c* is offset associated with the measurement unit.

We use NRG daily raw data files (RWD) for a year. Utilizing default/consensus transfer functions that come with RWD files, students learn to create a wind rose and export data in 10-minute, hourly (60-minute), and TAB (WAsP observed climate file) formats utilizing the Symphonie Data Retriever (SDR) software. These are some data formats relevant to the wind energy industry. The IEC 61400-12 standard stipulates a 2 Hz sampling (30 data points per minute) and 10-minute aggregation. This week's lab (Lab 02A NRG Reports - Export Windrose and Data) consists of creating and interpreting a wind rose and exporting data from SDR in 10-minute resolution CSV format (Figure 5).

Report Type



Data Export Formats:



Wind Rose:

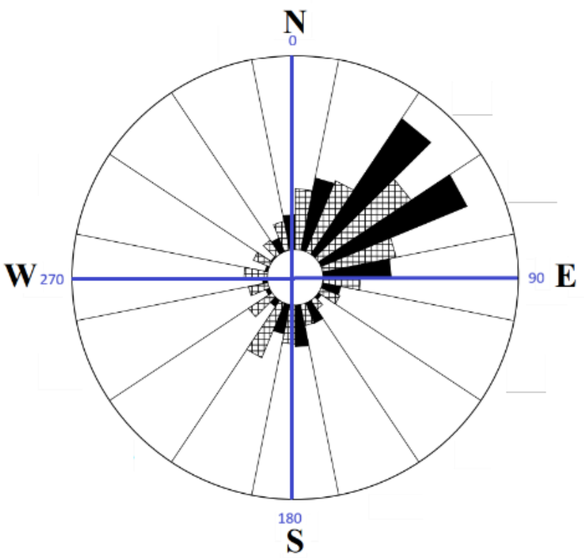


Figure 5: Report types and data export options in SDR by NRG Systems

We use 1 Hz resolution performance data from the NPS-100-21C wind turbine at the Appalachian State Wind Farm to reinforce the theory of DAQ (e.g. sampling and aggregation time) and to introduce students to the concept of turbulence. Following Reynold's decomposition, we decompose instantaneous wind speed u(t) into average (U) and fluctuating components (u′); i.e., u = U + u′. Figure 6 illustrates these components using data sampled every one second and aggregated at a 10-minute resolution. The turbulence, defined as fluctuating components, always has a zero mean.

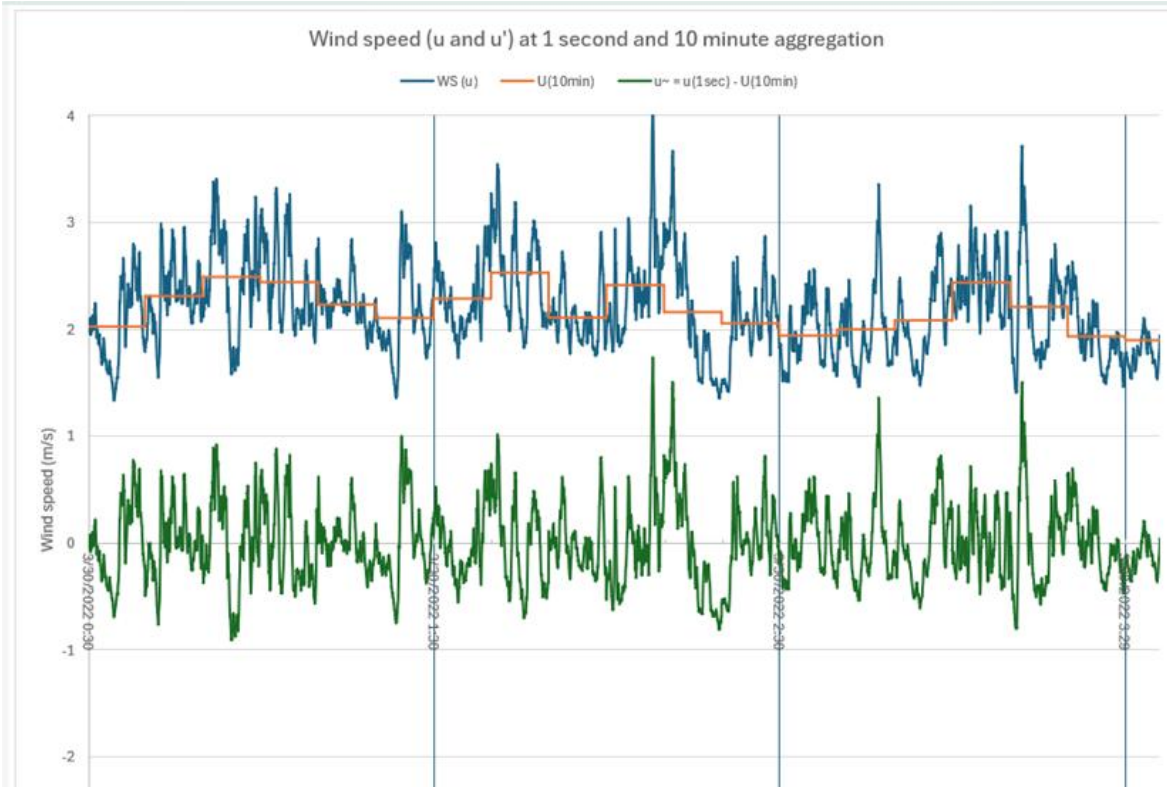


Figure 6: Reynold's decomposition of wind speed into average (U) and fluctuating (u′) components

Lab 02B, Data Aggregation and Statistics: NPS, introduces students to 10-minute, hourly (60-minute) data aggregation using pivotTable features of MS Excel. Students learn about date and time functions, date vectors, and how to create unique Group IDs for data aggregation by combining date vectors.

These two labs (Lab 02A and Lab 02B) provide a concrete experience examining the nuances of wind speed and wind direction measurements. The wind rose is a visual tool that helps students interpret predominant wind direction. The windrose experience prepares students for the next phase of experiential learning: reflective observation about the configuration of sensors on a met tower.

5.3.3 Reflective Observation

In this week's lab, students are introduced to met tower types (tubular and lattice) and tower shadow effect on sensors attached to the tower, as relevant to wind resource measurement. The students get to learn about multi-level instrumentation of sensors (anemometer, wind vane, temperature, etc.), with each level consisting of two anemometers (primary and redundant). A typical met tower has six anemometers A1 through A6, see Figure 7 at three levels, with the first level being 10 m to facilitate extrapolation of wind speed to the hub height of the wind turbine.

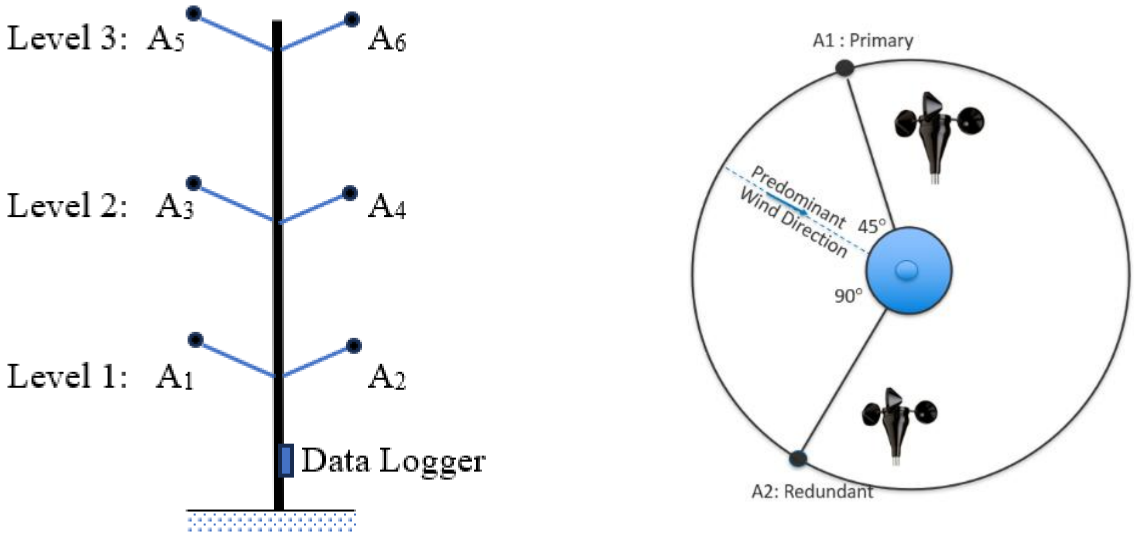


Figure 7: A typical met tower with primary and redundant anemometers at three levels

Students learn about standard met tower heights (80 m, 60 m, 50, 30 m, and 10 m) available in the US markets and associated tools for installation and commissioning. We use the following two video resources that introduce students to site layout and installation of a tilt-up met tower using gin poles and a griphoist.

1) Instructions for the Site Layout of a Tilting Tower
   https://www.youtube.com/watch?v=U8Qyle_1HUA
2) Lowering and Raising a Tilt-Up Wind Turbine Tower using a Griphoist
   https://www.youtube.com/watch?v=Ac9SK3ph3os

5.3.4 Abstract Conceptualization

This phase is implemented via teamwork with at least two students in each team. Using the experience and reflective observation accumulated thus far, students are asked to microsite a met tower for performance evaluation of a representative wind turbine on a wind farm. Each team conducts their own desktop study to arrive at the location (latitude, longitude, elevation) of the met tower. Each student team presents their concept and action plan and receives feedback from other students and the instructors supporting this experiential learning. Students are given an industry standard site commissioning form (SCF) of a met tower. The SCF helps students organize their reflection in a systematic way and contains all metadata necessary for a work order associated with the installation of a met tower.

5.3.5 Active Experimentation

Prototyping is the process of creating an early model of a product or a system. In engineering education and practice, prototyping is an iterative process of quickly building a simplified version of a system to test ideas, gather feedback, and refine the final solution. Prototyping of a met tower helps visualize and test ideas about sensor configuration before students build lab-scale or field-scale systems. Students work in teams to build a high-fidelity functional model to refine system design and performance.

In this active experimentation phase, the students are given all the equipment and tools listed in Section 5.1. They are asked to come up with a prototype of the system with some predetermined parameters such as sampling rate and aggregation rate of DAQ. The main objective of this phase is to develop problem-solving skills by combining subsystems, skills, and reflective knowledge introduced in the previous labs. Students should be able to demonstrate how different skills and information connect to deliver data acquisition (DAQ) systems that can help estimate wind resource measurement at the hub-height.

We do have an option of conducting the active experimentation phase of learning cycle either in laboratory or in field environment. The following sections present a short description of these setups and snapshots of the iLED in action.

A. Laboratory-scale Prototype Tower

A typical lab class spans one hour and fifty minutes. Students learn about programming the APRS data logger for various parameters, such as sampling and aggregation times. Students then collect data from sensors (anemometer, wind vane, thermistor) using an APRS Logger for at least 10 minutes to generate four statistics: average, standard deviation, maximum, and minimum. Figures 8 and 9 present laboratory-scale met tower and a team of students working on assembly and testing DAQ in a laboratory environment.

Figure 8: Lab-scale Met tower and sensor assembly

Figure 9: Testing of DAQ in laboratory environment

B. Field Scale Prototype: 10-meter tilt-up Met Tower

For the field scale set up of a 10-meter tower with three levels of anemometer, students use the DAQ parameters stipulated by IEC 61400-12. Accordingly, students are asked to sample data at 1/2 Hz using a Symphonie® data logger and aggregate the data at 10-minute intervals, with a recorded time stamp at the beginning of the aggregation time.

Figure 10: Field-scale met tower

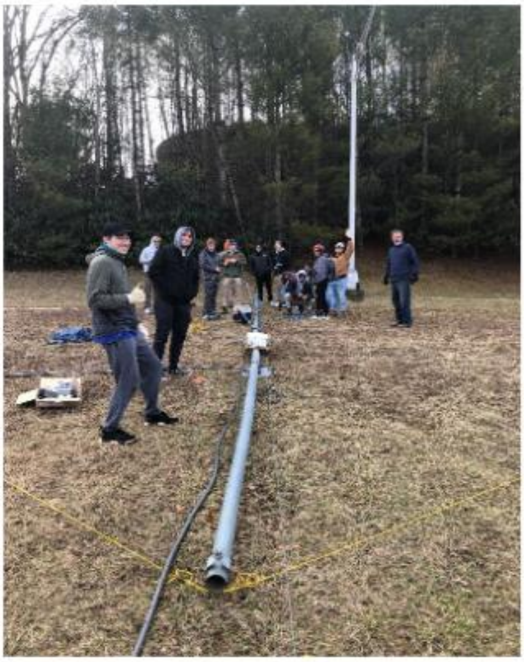


Figure 11: Students working on met tower

It is very important to conduct field-scale activities following the installation manual [11]. The supervisor must be extra vigilant for the safety of students, especially during the raising and lowering of the tower. Students tend to rush and overlook safety protocols during the raising of a tower due to excitement, which sometimes may result in over tension on stay wires and/or guiding wires. The wires can snap and risk the safety of the students and equipment if not done properly. It is recommended to raise the tower in stages and make sure it is stable, and safe to hoist it to the next stage without much tension or slack on the supporting and guiding wires.

In both lab-scale and field-scale setups, students first determine a preliminary wind rose to inform the boom orientation of the anemometer and other sensors. There are two anemometers, primary and secondary, at each level (Figures 10 and 11). There are three such levels in the field scale set-up, reflecting a typical industry standard 60 m met tower. We keep the boom orientation the same across the levels to facilitate wind shear calculation and extrapolation of wind resource to the hub height. The main idea is to isolate tower shadow effects using selective averaging techniques to minimize the risk associated with extrapolating wind speed to the hub height. One must be cognizant of data validation, analytics and algorithms used to extrapolate wind speed so that uncertainty associated with extrapolation can be minimized during design and instrumentation of the met tower.

VI. Analysis of Learning Objectives: Survey

We designed and developed a survey to assess the learning objective outlined in Section 5, and to document the experience of students. The survey has both structured and unstructured free form responses. The structured survey has multiple-choice responses in Likert 1 - 5 scales (Strongly disagree | Disagree | Unsure | Agree | Strongly agree). These responses help quantify the effectiveness of the iLED to deliver learning in an objective manner, as reflected in the average of the responses coded in Likert scales. A survey was designed in Google Forms to evaluate the hypothesis that the iLED has positive outcomes on improving undergraduate STEM education. The free form responses help us to make necessary changes and adapt iLED for better learning outcomes for students in the next round of implementation.

The structured questionnaire and responses were organized into three categories of learning objectives: (i) Pedagogical and General, (ii) Technical Competency, and (iii) iLED Course Development. These survey questions are coded in Table 2, and an average value of the responses from the survey is presented in Figure 12 for these three categories.

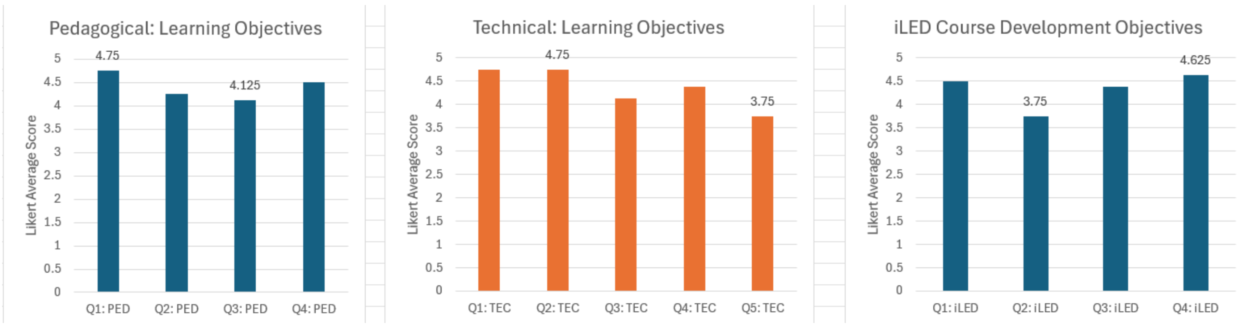


Figure 12: Analysis of Learning Objectives in Likert 1 - 5 scales

Table 2: Survey questions grouped in three different categories

A) Pedagogical and General Survey Questions

Q1: PED	These labs increased my understanding of data acquisition (DAQ) systems.
Q2: PED	I learned about best practices of met tower Instrumentation.
Q3: PED	This laboratory increased my confidence working on a team toward a common goal.
Q4: PED	This laboratory exercise increased my understanding of data analysis, visualization, and interpretation.

B) Technical Competency Questions

Q1: TEC	I learned to plot a wind rose and interpret it for the predominant wind direction.
Q2: TEC	I learned that sensor configuration and orientation depend on the site location.
Q3: TEC	Now, I know how to connect sensors, and program the logger for wind energy applications
Q4: TEC	I learned how to calculate statistics and aggregate data at different time intervals.
Q5: TEC	I learned how to extrapolate/interpolate hub height wind speed from met tower anemometer data.

C) iLED Course Development and Improvement

Q1: iLED	Learning objectives were clear.
Q2: iLED	Course content was organized and well planned.
Q3: iLED	Course workload was appropriate.
Q4: iLED	Course organized to allow all students to participate fully.

Analysis of the learning objectives, in both pedagogical and technical categories, suggests the average score for each survey question is above the average of the Likert 1 - 5 scales. Students seem to benefit more from the technical content, such as data analysis, visualization, and interpretation. We need to work further to build the confidence of students to work toward a common goal in a team setting as suggested by responses to the question [Q3: PED]. Technical surveys suggest that about 12.5% of students are not confident enough to connect sensors [Q3: TEC], and similarly 12.5% students are not sure about extrapolating/interpolating hub height wind speed [Q5: TEC] from the time-series data. Regarding the iLED improvement, the course needs to be adjusted in organization, planning and delivery of content to improve student experience Q2: iLED. The responses to the free-form questions, which are not reported here, are also being used to improve the design and delivery of the iLED going forward.

The outcome of the multi-module/week iLED is to help students turn classroom experience into problem-solving by combining ideas and knowledge gained through active conceptualization and reflection. The analysis of learning objectives reported using the average scores and their distributions suggests students have learned a good range of specific and transferable technical skills relevant to the renewable energy industry. In a laboratory setup, the iLED introduced students to design, implement, and manage wind resource measurement campaigns following the industry standard practices.

VII. Conclusions and Recommendations

An integrated learning environment (iLED) has been developed and implemented to support teaching and learning of data acquisition and instrumentation of a met tower as part of wind power technology education. This multi-week course consists of weekly lesson plans for each of four cycles of experiential learning. Together, the iLED modules aim to enhance the quality of STEM education in terms of content, pedagogy (method and approach), and its relevance to the renewable energy industry. The technical content focused on educating students on marketable and transferable skills relevant for the wind energy market. This project focuses not only on improving the technical competency of interdisciplinary STEM students but also on improving the resources and teaching experience of wind power technology instructors. The iLED might enhance the job prospects of students in the growing renewable energy market.

Data acquisition is an important technical skill widely used across the energy industry. We summarize our experiences and laboratory setup to train students on data acquisition, micrositing, and instrumentation of a met tower. Students learn fundamental aspects of instruments as well as engage in a problem-solving experience working in a team setting. The laboratory setup and equipment list we describe here can help students understand science, models, and assumptions underlying wind resource measurement. The active experimentation phase reinforces the learning in the laboratory setup such that experiential learning is scalable to the field scale and elsewhere that bankable wind resource measurement is necessary. This iLED could serve as a reference and help students and other institutions expand the breadth and depth of workforce development and wind energy education by improving the competencies of STEM students.

In this educational research, we focused more on the design of an integrated learning environment and students' perception of learning through iLED through a structured survey. We did not link survey response to the students' aptitude and learning preferences, nor did we try to link it to background student data such as lab or final grade, or cumulative GPA. A longitudinal study may be designed as a further study to slice and dice how the distribution of students with a preferential combination of learning styles (see Section 3.2) benefit from this experiential learning, and if these students learned the skillsets they reported in the survey.

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Appendix A

A.1 Course Description: Wind and Hydro Power Technology

TEC 4607 - Wind and Hydro Power Technology (3)

[Dual-listed with TEC 5607.] Dual-listed courses require senior standing.

This course will introduce students to the basic concepts, tools, techniques and materials needed to design and construct systems that convert wind and hydro resources into electricity. Students will study how to measure these renewable resources and to estimate the power that could be produced from them. They will also have the opportunity to learn how to design and construct complete renewable electricity systems and become familiar with many contemporary products used in renewable electricity systems. The course will include classroom and “hands-on” design, construction and possibly some field trip experiences outside of class. Lecture two hours, laboratory two hours. [When Offered: Fall; Spring]

A.2 Program Goals and Student Learning Outcomes (SLO)

1. Goal: Students will develop technical proficiency in areas of Renewable Energy & Sustainable Technology
   - SLO 1.1: Students will analyze trends and developments in the field of sustainable technology.
   - SLO 1.2: Students will apply essential math and science skills to solve engineering problems in energy and resource systems.
   - SLO 1.3: Students will conduct physical experiments, including analysis and interpretation of data.
2. Goal: Students will create integrated solutions for problems in project-based applications.
   - SLO 2.1: Students will design a renewable energy system to meet desired needs.
   - SLO 2.2: Students will collaborate on a sustainable energy related project in teams.
   - SLO 2.3: Students will develop skills related to commissioning renewable energy systems including system monitoring and problem-solving through troubleshooting.
3. Goal: Students will develop multi-modal communication skills relating technical competency in the discipline of Sustainable Technology.
   - SLO 3.1: Students will communicate effectively in professional presentations using graphic and verbal means.
   - SLO 3.2. Students will communicate effectively in professional settings using written means.
   - SLO 3.3: Students will use the techniques, skills, and technical tools necessary for professional practice in the field of Sustainable Technology.