2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37664

# The Foggy Mirror Experiment: Pedagogical Approach and Outcome for ABET's Design and Conducting Experiments for Architectural Engineering

**Dr. Ryan L. Solnosky, P.E., Pennsylvania State University**
**Prof. Moses Ling, P.E., Pennsylvania State University**

## The Foggy Mirror Experiment: An Active Pedagogical Approach for ABET's design and conducting experiments within Architectural Engineering


## Abstract

ABET Criterion 3, Student Outcome (6) requires engineering programs to showcase student ability to develop and conduct appropriate experiment, analyze and interpret data, and use engineering judgment to draw conclusions. The breadth of this requirement may be achieved by wide varieties of pedagogical approaches. Regardless, the core challenges facing students are: recognizing the actual problem, developing potential solutions, applying experimental methods, understanding the significance of appropriate data collection, and ability to execute engineering judgement. These outcomes is often realized in labs and upper level courses once technical knowledge is solidly mastered. Mapping learning outcomes in the architectural engineering program, we recognized the need to institute a disciplined inquisitive mindset early on, therefore, establishing the foundation for future advanced coursework. The resulting project known as the "Foggy Mirror" exercise, deployed in the first AE in-major course, provided opportunities to realize multiple pedagogical outcome. Foggy Mirror challenges students to develop a method to clear a bathroom mirror without physical contact with the mirror. The exercise is carried out over a period of several weeks in successive exercises, allowing for feedback at each step. Having repeatedly assigned the Foggy Mirror exercise to new to the major 2nd year Architectural Engineering students over several years, we uncovered other invaluable pedagogical opportunities embedded in this simple exercise.

- Better understanding - Appreciate the learning phenomenon of "illusion of explanatory depth". Can students explain the subject matter?
- Better storytelling - Learning to write clearly and concisely.
- Better methodology - Appreciate the importance of developing a detailed proposal. Look for opportunities to discover the total process, not simply confirm the phenomenon.
- Better data collection - Deciphering the critical data points for collection and presentation.

This paper will attempt to detail the Foggy Mirror exercise so that the ideas can be adopted in other curriculum, provide insights into successes and challenges, and how to meaningfully encourage students to become disciplined inquisitive engineers.



**Keywords:** Experimentation, ABET, Problem Solving, Teamwork, Active Learning


## Introduction

Broadly, engineering is perceived as a practical profession with hands-on design. To the extent that undergraduate engineering experiments are essential to prepare these future engineers to excel in their profession [1-2]. Whetton [3] states that instructional design requires the thoughtful choice of reading materials, assignments, activities and most of all learning objectives. In the context of experimentation, Sivaloganathan et al. [4] adds that the choice between experiments is critical for an often tightly packed curricula. For more than two decades, the engineering community has struggled with finding an appropriate balance between classical pedagogy and practical experiences for developing engineers [5]. Kolb's work [6] is often cited regarding experiential learning as the start of discussions regarding active experimentation [7]. Open-ended laboratory courses or even traditional classes with experimentation exposure have shown to provide greater learning value as compared to the traditional lecture only focus [2,8]. Such courses employ an approach to learning science that are backed by a significant body of work on research-based and active pedagogies in various engineering disciplines as well as have demonstrated superior levels of student engagement and learning. Introduction of real-world problems not only allows students to master appropriate techniques and technologies, but also allows the students to design strategies for solving problems and practice an overall process of inquiry [9-10].

Since experimentation is so critical to the profession [11], ABET has included mandatory evaluation through Criterion 3's Outcome 6 [12]: ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. Outcome 6 consists of four elements [13]: designing an experiment, conducting an experiment, analyzing data, and interpreting data. According to Abdel-Magid [14], the last three elements can easily be addressed in a typical engineering laboratory course; however, the first element of "designing an experiment" is rather difficult to address in an undergraduate course. Some educators argue that it is better to have students run fewer but more open-ended experiments than many well-prescribed and guided experiments [13-15]. Adding to this, Feisel and Rosa [16] had identified three basic types of engineering laboratories: development, research, and educational. For practicing engineers, the development laboratory is preferred for two reasons: (i) to obtain needed experimental data to guide them in designing and developing a product (ii) to determine if a design performs as intended. For engineering, these development experiments can be structured in three ways [7]. They are [17-18]: 1) Observational Experiment: students perform to investigate a new phenomenon; 2) Testing Experiment: students use an explanation or relationship to make a prediction of the outcome; and lastly, 3) Application Experiment: student typically solves a practical problem or determining an unknown quantity.

Literature is sparse on assessing Outcome 6 directly in both architectural and more holistically civil engineering [19] where as many papers and best practices for Industrial, Electrical, Mechanical and Biomedical Engineering experiments have been regularly documented [20-21]. The organizing principle of many traditional engineering laboratory courses are their pre-planned experiences wherein students duplicate technique(s) to learn it [6-7]. Such approaches lack the element of solving authentic engineering problems [19].

Knowing the formal definition from ABET on Outcome 6, the AE program at The Pennsylvania State University breaks down Outcome 6 into two sections: 1) 6.1. Select and apply appropriate methods to collect, analyze, and interpret data and draw conclusions and 2) 6.2. Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to validate (computer) model results. Beyond AE 202, in the upper levels of the Penn State AE curriculum, discipline specific 400 level classes incorporated their interpretation of design and experimentation for Outcome 6. Some are physical, others are simulations, but they all related to discipline contexts. To more broadly capture Outcome 6 our self-study report indicates that AE students take several courses outside of AE as part of the program of study that require experimentation, analysis, data interpretation, and use of engineering judgement, notably in the lab components of physics (Phys 211, Phys 212, Phys 213) and chemistry (Chem 110 and Chem 111).

This paper will show that while students have had exposure to Outcome 6 in physics and chemistry, they are not necessarily prepared for more open-ended and AE centered projects that require experimentation. Detailed in this body of work is an attempt to deliver an activity meeting ABET Student Outcome 6 in an AE-specific setting. The "Foggy Mirror" project was developed to introduce Outcome 6 in a collaborative fun environment, where students hypothesize, plan, and then execute an experiment on a proposed method to clear a bathroom mirror after condensation forms. This project can also be a barometer for gaging attitudinal shifts in incoming cohorts of students, as well as their commitment and readiness for learning. How "Foggy Mirror" is structured, deployed, assessed and tie to learning objectives are detailed in this paper.

## The Foggy Mirror Experiment

Within Architectural Engineering (AE) at Penn State, the "Foggy Mirror" project is placed within the first introductory AE course. This project introduces the concepts of developing and conducting an experiment with appropriate scope, followed by analyzing and interpreting the data, and lastly using engineering judgment to draw conclusions on how the problem is solved. The "Foggy Mirror" project is an integral part of the first course as it sets up experimentation foundation that will be called upon in other courses throughout the later years in the AE program at Penn State. As it is defined, the project seeks to elevate learning beyond understanding and comprehension towards the application level of the Bloom's Taxonomy framework. Given students' typical course offerings up to when this is deployed, this project is likely their initial experience with a rather open "application level" learning experience.

The current experimentation assignment lists the following learning objectives that students can achieve after the exercise:

- Be able to solve psychrometric problems.
- Be able to design and execute an experiment to determine if a hypothesis is substantiated.
- Able to present data in an effective and informative manner.
- Be able to problem solve in a group setting.

An additional intended outcome that is not as easily measurable is that "Foggy Mirror" presents an opportunity for intense engagement between the students and faculty through multiple iteration of grading/feedback.

### *Class Containing the Experiment*

Foggy Mirror is the first AE student exposure to experimentation within the program. It is also viewed as a rite of passage. Here, "Foggy Mirror" is deployed in AE 202 within Penn State's AE program. AE 202 is titled "Introduction of Architectural Engineering Concepts" and centers on introductory AE concepts such as psychrometry. The typical student cohort for AE 202 consists of 110 to 120 students which are roughly 60% second year students and 40% new-to-the-major third year students. Approximately 5% of the students in a given year repeat the class. All students are architectural engineering majors due to course controls limitations. Each week AE 202 has two lectures and two work session practicums. Lectures are 75 minutes and are taught in a hybrid active and traditional format. Each practicum lasts 75 minutes and are geared towards just-in-time learning with heavy application of lecture materials. The following mission statement is captured from the course syllabus.

> *"AE 202 is intended to familiarize architectural engineering students to certain principles relevant to the profession, particularly building environmental control systems. This course is not intended to be mathematically intensive. More in-depth curriculum is offered in upper-level courses."*

Key topics in AE 202 are: Psychrometry, thermal comfort, solar environment, heat transfer, heating load, fire protection, and plumbing. Given the key topics, some of the following learning objectives are available to frame individual topics as appropriate:

- Demonstrate an understanding of the key topical principles and appropriate applications.
- Describe a building system, component or construction process design and how it satisfies the specified needs and constraints.

- An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments.
- An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
- An ability to acquire and apply new knowledge towards the course topics for the projects.
- An ability to apply engineering "design" to produce solutions that meet specified needs with consideration of public health, safety and welfare, as well as environmental, and economic factors.

The Foggy Mirror project was created to specifically address the learning objective regarding developing and conducting experimentation. The project compliments the learning objectives listed for understanding the topical principles of psychrometry.

### *Project Description and Delivery*

The project brief asks students to demonstrate the principles of psychrometry by devising a method for hotel guests to clear a "foggy" bathroom mirror without physical contact. The goal is to simplify housekeeping efforts (avoiding streaks on the mirrors) and reduce laundry costs (avoid the use of a clean towel to wipe the mirror). A proposal to hotel management is the expected end product. Students undertake six key steps to achieve the project goals as described in Table 1. These steps will span over several weeks, allowing for faculty feedback along the way.

Table 1: Six Critical Steps in Foggy Mirror Project

| Steps | Key attributes to each step |
|---|---|
| **Step 1**: Establishing Phase | • Discover the reason mirrors fog and explain the phenomenon supported by psychrometric principles.<br>• Develop a hypothesis to avoid or remove condensation, supported by psychrometric justifications. |
| **Step 2**: Developing Phase | • Design step-by-step instructions for the experiment.<br>• Design data collection and presentation templates to best explain the phenomenon. |
| **Step 3**: Executing Phase | • Conduct the experiment in a typical student apartment.<br>• Collect appropriate data. |
| **Step 4**: Analyzing and Interpreting Phase | • Review the data for consistency.<br>• Review data for unexpected outcome. |
| **Step 5**: Judging and Concluding Phase | • Apply engineering judgement to determine whether the outcomes support the hypothesis. |
| **Step 6:** Presenting Phase | • Present the finding in a concise written technical report.<br>• Determine whether graphical representation can tell the story better. |

To provide a balance of student technical learning, teamwork skill building, and the grading, this experiment is conducted in self-selected groups of four students. Depending on the class size, sometimes a group of 3 or 5 is permitted. Students have a week to establish their own team. After that timeframe, the faculty places the remaining students randomly in a few groups to conclude the teaming process. While there are exceptions, the teams that were assembled by the instructor generally exhibited problems collaborating and succeeding in meeting project goals. The self-selected teams collaborated more organically. The majority of the experiment work is conducted as an out-of-class activity. Yet, there are two opportunities designated for in-class work with the faculty member and teaching assistants present.

The six steps presented in Table 1 are spread across six weeks of the semester. To allow time for students to establish a proposal, execute the proposal, gather faculty feedback then submit the final report, the six-week project is carefully laid out. Table 2 provides a timeline of the six-week project along with key focus points, deliverables and feedback gathered. Given the typical group size of 4, approximately 30 teams reports are submitted at each step. The instructors are significant team players since grading and commenting in a timely manner contributes greatly to the success of students' work. The time commitment can be a significant burden on the instruction team.

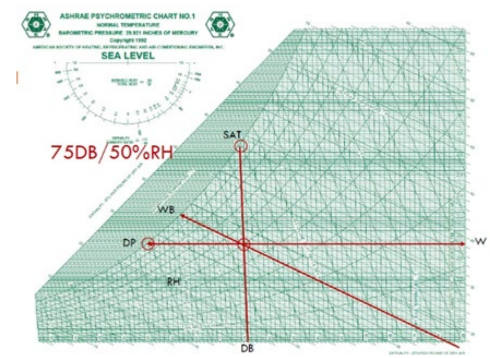
Table 2: Location, Structure, and Deliverables of the Foggy Mirror Project

| Week | Focus | Deliverable | / Feedback |
|---|---|---|---|
| Lecture 1.2 | • Start with a lecture on psychrometry | • Learn psychometric principles. | • N/A |
| Practicum 1.2 | • Brainstorming practicum examines the students' comprehension of psychrometry by individually using psychrometric principles to answer the question why condensation forms on bathroom mirrors.<br>• Each team is encouraged to perform a mind-mapping exercise using a digital white board to brainstorm. | • Form Teams of 4 for the assignment.<br>• A single page proposal is submitted at the end of the first week explaining why condensation forms on bathroom mirrors after hot showers and how the proposed method will clear the mirror.<br>• This is an in-class assignment with a deadline in 2 days. Ideally feedback is provide by the next class, week 2. | • The proposal is turned back within a week.<br>• Teams with unacceptable work must resubmit. |
| Out-of-class Week 2-3 | • Teams design a procedure to document the process by which the intervention works. | • The proposal must include step-by-step instructions of the experiment and a data collection/presentation plan. This is the most critical phase of the project. Successful proposals lead to smooth execution. Poor proposals will result in problematic execution and wasted effort.<br>• This is 2 week assignment. Again, ideally feedback is provide by the next class, week 3. | • Instructor assessment and input at this stage is critical.<br>• Poorly conceived proposals were rejected. Resubmissions were required. |
| Practicum 3.2 | • This practicum was designed as another opportunity for individual students to document their understanding of the concepts behind the exercise. | • Completion of a practicum problem<br>• Resubmit proposal as appropriate<br>• This is an in-class assignment with a deadline in 2 days. Feedback is provided by a team of undergraduate learning assistants. | • A answer key is provided to students for self-assessment. |
| Out-of-class Weeks 4-6 | • Each team signed up for a 2 day time slot to perform the experiment. A set of tools were loaned out. The tools include a sling-psychrometer, an infrared temperature sensor, and a digital temperature logger. Teams may repeat the experiment at the end of the 3 week period if necessary. | • No formal submission at this stage. | • Students interact with instructors and learning assistants during practicum as necessary. |
| Practicum 6.2 | • In this final phase, collected data is analyzed and interpreted. Based on engineering judgement. Teams either declare the experiment a success or identify the missteps that led to a failed experiment. | • At the end of week 6's practicum, teams upload their report of final submission.<br>• Grading and feedback can take up to two weeks for these reports. | • The final reports are meticulously reviewed and comments provided in 2-3 weeks.<br>• The critiques are posted to the teams as the instructor completed each report. |

Lectures are refereed to X.Y where X is the week and Y is the lecture number and similar with the practicums.

## *Equipment to Conduct the Experiment*

To truly understand psychrometry, which is the study of air and moisture in a mixture, two rudimentary tools are used by students to complete the experiment, a sling-psychrometer and psychrometric chart. A sling-psychrometer (Figure 1a), explicitly demonstrates how dry-bulb and wet-bulb temperatures were physically measured before the introduction of digital devices which reduced the science of measurement to black-boxes with readout windows. A psychrometric chart (Figure 1b) aids in mapping the other psychrometric properties of air, humidity ratio (W), specific volume (v), enthalpy (h), relative humidity (%RH), saturation temperature, and, most importantly, dewpoint ($T_{DP}$). The handheld tool and the graphical tool working together reinforces the understanding of psychrometry.




a) Sling-psychrometer b) Psychrometric chart with properties shown

Figure 1: Needed Tools that are provided to students.

To perform the experiment, students need access to a small shower room. Most students have access to campus dormitories or off-campus housing with appropriate facilities. Occasionally, a team of commuter students may need help locating a convenient facility. It is important to note that since students are given creative freedom, their use of other implements may stretch the limits of good ideas. For this reason, providing thoughtful safety guidelines is necessary.

## *Psychrometric Principles built into the Experiment*

To better understand the psychrometric process in the event readers wishes to adopt this project, a short overview of the AE principles is discussed here. At its core, psychrometry is the study of air and moisture in a mixture. The key focus of this project is the dewpoint temperature ($T_{DP}$). Dewpoint is marked by reading the dry-bulb temperature of the condition at which condensation forms, as the air-moisture mixture cools. Simply put, as air is cooled (lowering the dry-bulb temperature) while the moisture content is not changed (constant humidity ratio), the air will reach a point where it is saturated (100% relative humidity). This temperature read on the dry-bulb scale is identified as the dewpoint ($T_{DP}$). This process is shown by drawing a horizontal line from any point on the psych chart to the left until the horizontal line crosses the saturation curve (Figure 2). In a typical room, surface temperatures are typically higher than the dew point temperature, hence these surfaces are dry. If a cool object in brought into the room, such as a cold drink, the surface of the container may become wet, or condensation can form on its cooler surface. Condensation on the cool surface is the result of the surface temperature of the container being lower than the room air dewpoint. Another way to state the psychrometric principle involved is:

- If the surface temperature is higher than the room air dew-point, condensation will not form on that surface.
- If the surface temperature is lower than the room air dew-point, condensation will form on that surface.

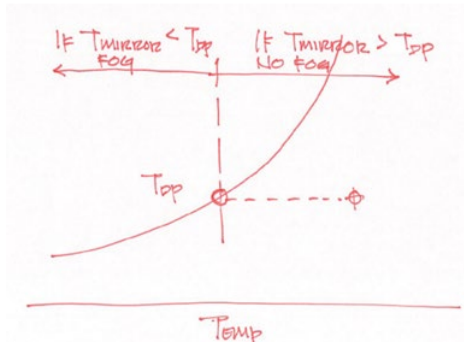



Figure 2: Condensation Explained on a Simplified Psych Chart

## Potential "Foggy Mirror" Solutions

Since psychrometric principles point to the relationship between the surface temperature of the mirror and the dew point temperature of the air, the solutions can be organized into two categories, adjusting the temperature of the mirror and/or adjusting the moisture content of room air. Students often propose enthusiastic solutions with multiple heavy handed action items, the sledge-hammer effect. Students must be encouraged to execute one intervention at a time to clearly determine the impact of each intervention.

To adjust the surface temperature of the mirror means heating the mirror. This can be accomplished by students in a variety of ways; yet, using a hair dryer to apply hot air over the mirror is the easiest given their resources. If students propose attaching electric heating cables to the back of the mirror, a safer solution is to simply place some hot water in a sealed plastic freezer bag against the back of the mirror if the back of the mirror is accessible. Most students recognize that using a hair dryer is the most efficient method as most hotels already furnish this device. This also supports the broader project description of a hotel setting. If conditions are right student should be able to clear a fogged mirror in about 10 to 15 seconds.

Exhausting bathroom air fits into the second category of student proposals. The clearing of the fogged mirror is not so much caused by removing moist air as it is caused by mixing in replacement cooler/dryer air from the space outside the bathroom. This dilution of the bathroom air drops its humidity level resulting in a lowering of the humidity ratio (W) of the room air. When the room humidity ratio ($W_{Room}$) drops below the humidity ratio of the critical dew point, condensation will dissipate. However, the time needed to clear the mirror is significantly longer. Tying this back to the prompt, students should correlate this to the possibility that hotel guests may be annoyed by the delayed use of the mirror. This experiment makes the point that that captured evidence supported by science can be graphically displayed on psychrometric charts (Figure 3 provides examples).

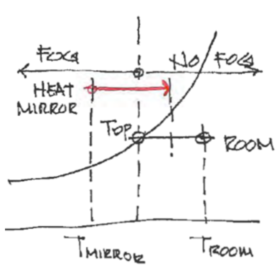



Fig. 3.A – Heating Mirror
$T_{Mirror} > T_{DP}$
(Move horizontally to the right)

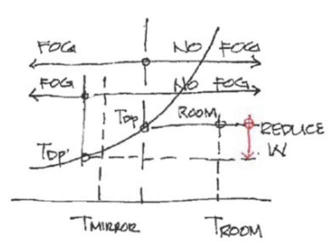



Fig. 3.B – Ventilate to Dilute Room Air
$W_{Room}$ < W of $T_{DP}$ of Room Air
(Move vertically down)

Figure 3: Key Captured Behaviors within the Foggy Mirror that Students Should Find.

After the experiment has been completed, the instructors can increase students' appreciation for the phenomenon by pointing out that the physics of this exercise applies to subsequent coursework (AE 310: Fundamental of HVAC) that is taken by every 3rd year student. Key talking points for inclusion with this discussion are:

- ASHRAE weather data published for dehumidification uses dew point as its marker.
- ASHRAE Standard 62.1-2019 Paragraph 5.10 sets a limit to the maximum indoor air dew point of a mechanically cooled building to 60°F.
- Building enclosures as a barrier to vapor flow is critically related to the dew point of the indoor condition.
- Cooling coil's ability to dehumidify depends on it apparatus dew point.

## Project Assessment Structure

While this assignment is an engagement opportunity to provide regular feedback, the assessment effort can be overwhelming depending on how much detail one wishes to provide the students. Recognizing that continuous assessment and meaningful comments are necessary to ensure successful outcome, subdividing the project into multiple submissions facilitates intermediate assessment and spread work of the instructional team over the six week period. For the latest offering of "Foggy Mirror", this project spanned the first 6 weeks of the Fall 2022 semester. With a large cohort of 112 students, two assigned instructors shared the teaching responsibilities. The second-half instructor was able to administer this project during the first half while the other instructor took responsibility for lectures and exams. While not done, it is possible to involve trained and experienced teaching assistants in the "Foggy Mirror" assessments.

### *Assessment Structure*

While every word in the student reports were scrutinized, the grading was made easy by publishing a set of rubrics in advance. Two graded assignments made up the project grade - proposal 40% and final report 60%. The same set of rubrics (Table 3) was used for both assignments. The first submission are typically below expectation. Not surprising since this most likely is the students first attempt to formulate hypothesis and present proposal. Encouragement at this stage is important to coach the students to resubmit and address the shortcomings in their work. Most students are receptive. Unfortunately, some groups are unfazed by the feedback and plow ahead as they saw fit, probably due to self-inflicted time pressure.

Table 3: Simplified Grading Rubric for Foggy Mirror

| Metrics | Points | Description |
|---|---|---|
| Understanding psychrometry | 20 | Evaluate whether students have a clear understanding of the principles of psychrometric. |
| Design of the experimental method | 40 | Evaluated whether the step-by-step instructions can be executed, perhaps without prior knowledge. |
| Data collection and presentation | 20 | Evaluate whether student teams have clear understanding of the principles. Attention to details is a key metric for this assignment. |
| Writing | 10 | The quality of the writing is graded based on grammar, flow, clarity, conciseness, professionalism, ability to summarize results and draw conclusions. The use of graphics is also considered. |
| Professionalism | 10 | Review the level of care, commitment to excellence, and thoroughness of execution. |
| Total | 100 | |

### *Representative Assessment Outcomes*

In looking back over the many years that Foggy Mirror has been deployed in AE202, student performance has largely been consistent. Using the multiple feedback loops along with the rubric (Table XX), we can observe students' performance. Here, data from the Fall 2022 semester is provided. In Fall 2022 a total of 31 teams were form, 21 had 4 members, 9 had 3 members and 1 had 5 members. At the end of the self-selection processes ~85% of the teams were filled while the faculty member form the remaining 15% of the teams. At the proposal state first submission of the proposal resulted in the following descriptive statistics: M= 57.8%, Max = 100%, Min = 0%, Median = 79% with a SD = 38%. After proposal feedback was given students could resubmit for a better score, of those who resubmitted (n= 32), the descriptive statistics are: M= 74.2%, Max = 90%, Min = 29%, Median = 75% with a SD = 11%. Since resubmission was optional, the combine final scores for the proposals were M= 78.7%, Max = 100%, Min = 0%, Median = 81% with a SD = 15%. These descriptive statistics show that the overall final performance given feedback did improve through the cyclic reviews for students who took up that opportunity.

Moving to the final submission of the results, there were overall performance improvements. Here the M= 81.3%, Max = 100%, Min = 0%, Median = 85% with a SD = 17%. In the end, only two students out of 111 did not do the assignment, apparently hoping to rely on the solo teammate's work. It should be noted that the scores presented are for individuals after they were adjusted for peer reviews and actual work by the individuals. Being ABET centered, the Fall 2019 cohort was surveyed (for that cycle's self-study report), their perceptions on if this course has improved their ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. 90% of the student responses agreed positively that AE 202 did deliver on that.

## Faculty Observations and Outcomes on Designing and Conducting an Experiment

In support of the literature on creating engineers who can create then execute experiments while applying engineering judgement, several unique observations have been documented that are worthy of being shared. This section will offer observations captured during the execution and assessment process from the last several years of "Foggy Mirror" delivery that go beyond the numerical summary provided previously. While some of the observations were expected, there were a number of concerning surprises. Many of these observations can be considered for future experiments in other classes and with other types of projects.

### *Student Attitudes and Approaches*

One of the first observations the instructors typically witness is the approach and attitude that student teams take when assigned the project. For the most recent year, students generally appeared to be less prepared and energized after the remote learning period caused by the pandemic. The drive for excellence appeared to have waned. Carlton Fong quoted a study by the Journal of Adolescent Health in his MIT TLL talk that academics and motivation are the top concerns of college students [22]. While perhaps more prevalent for post-Covid, aspects of this was always present as earlier natural science labs seemed to do little for more open ended experiments. From their attitudes and approach 10 trends were summarized to provide a broader picture.

**Work Mediocrity** – The lack of high self-expectation by each student was surprising. It appeared that students attempted to minimize work to meet the project expectations was high on the list of team values. Some teams did not differentiate the expectations and approaches of a 6-week long project from that of an overnight homework assignment. Some turned in hand-written homework-quality work without regards to appropriate formality or technical rigor as stated in the briefs.

**Lacking Proactive Initiatives** – Few teams went beyond the minimal expectations of the project scope. Achieving a cleared mirror by any means seamed good enough even if the process was not sound or the approach was flawed that would introduce errors or partially invalid results (a less than clear mirror). There was a general lack of concern for other issues. For example, leaving the hair dryer running during the entire duration of a shower was a strategy promoted by many teams. Looking for the most efficient (least work) option was rarely presented as a concern. Sledge-hammer approaches were common. Experiment procedures that might discover the threshold for success were rarely promoted.

**Preconceived Notions** – Some reports clearly reflected the team's preconceived notions of the project goals or requirements. Project narrative was ignored by some teams. Many groups ignore privacy and thermal comfort issues mentioned as critical concerns in the project brief and proposal opening the door right after a shower similar to their practice at home. Some team even suggests bringing in box fans blowing air into the bathroom.

**Ineffective Internal Team Collaboration** – In student teams, collaboration rarely resulted in even distribution of work and, by inference, learning outcomes varied significantly member by member. As an extreme example, there was a project that was completed by one single member. To sound the alarm, that student wrote the entire report in a first person singular voice. Where the inequities were significant enough, students did not hesitate to provide evaluation appropriately. A surprising observation was that the low performing students did not push back. Some honestly graded themselves lower.

**Simple Discoveries** – This project demonstrates that engineering issues are embodied in mundane everyday problems. Instructors should remind students that for every problem there is a solution waiting to be discovered. For the instructor, problem-solving inspirations come from an accumulation of past experiences and observations. Educators must embrace the challenge to help students raise their curiosity quotient (CQ) and passion quotient (PQ) through these types of experiments.

**Observation Roadblocks** – Students face an over-abundance of distractions in this age of acceleration. New electronics, games, entertainment, social media platforms, etc. are competing for their constant attention. Current Gen Z students are digital natives who often lack the "stop and smell the roses" philosophy that can build robust observation skills. They are more likely to snap a picture with their smart-phones than to understand the lecture slides. They appear to be less informed about how things work. Introducing more exercises similar Foggy Mirror may encourage these students to observe simple phenomenon and take an interest in how things work. To make a point, students are forbidden to search the internet. Evidence of such activities are considered violations of academic integrity. Students must provide original work. This proof to be stressful for some students.

**Missing Interconnected Experiences** –While this issue is not an integral part of this project, the most concerning observation is that almost no student recognized that the front and rear defrosters in an automobile are two proven solutions to this problem. Almost habitually, all drivers apply hot air onto the front windshield and activate heating cables embedded in the rear windshield. The lack of connection between this everyday habitual experience to the problem at hand is concerning. This is a teaching moment to mentor students. At the minimum, students should be alerted to the need to develop cognitive connectiveness.

**Limited Proactive Testing** – Another disappointing observation was that very few students recognized that they shower daily and can easily test ideas and confirm assumptions in advance of the experiment. Most students have access to a hair dryer. No one mentioned that they tried their idea in advance to determine the most efficient method. Rather they made wild statements in the proposals that they could have easily confirmed or dispelled the next time they showered. With proper feedback, most students recognized and took advantage of the opportunity to pretest.

**Learning from Failure** – With open-ended projects, the degree of detail in the instructions may be a point of consideration. Is it better to help students get it right the first time? Or is it better to let students discover their shortcomings and help them learn from their mistakes? Studies have shown that the latter is preferential. In place of explicit instructions and rubrics, in the Foggy Mirror project, the instructor turned to providing timely feedback as an alternative means to achieve similar outcomes. Admittedly, having two instructors assigned to this course greatly helped tackle the workload.

**Social Awareness** – Perhaps the most delightful moment from the foggy mirror experiment came from a student's proposal to take shorter showers. The suggestion came from the perspective of water and energy conservation, and perhaps awareness of the societal problem of self-indulgence. While adoption of this suggestion by hotel management is unlikely, the student discovered a third category of solution, time.

These 10 substantive observations aligned with the already recognized need to help students better their critical thinking skills. Experimentation or looking at the data from a test is often the focused activities for many lab-based classes. Exercises such as Foggy Mirror can be devised or restructured for other courses in architectural engineering that promote broader critical thinking and engineering judgement skill building. This is particularly important because critical thinking and reflective thinking skills are the foundational cognitive abilities for engineering problem solving. Possible strategies for overcoming these concerning areas that others could try moving forward are presented in Table 4. Please note that not every problem has an identified solution.

Table 4: Methods to overcome Student Attitudes and Approaches

| Observation Areas | Approaches to Mitigate |
|---|---|
| Mediocrity | • This is a sensitive issue. The authors prefer to first allow the students to exhibit their current approach to their education and follow up with encouragement as appropriate. |
| Lacking Proactive Initiatives | • An additional rubric can be added to promote extra effort. |
| Preconceived Notions | • This falls in the category of learning by failing. It is not easy to detect this shortcoming in advance. |
| Ineffective Internal Team Collaboration | • In this latest semester, we have added team contracts and peer evaluations to encourage equitable participation. |
| Simple Discoveries | • Small activities in advance of assigning the project may improve student inquisitiveness. |
| Observation Roadblocks | • Perhaps out-of-class activities can be assigned in the first-year experience courses to promote curiosity. |
| Missing Interconnected Experiences | • Making students aware of this needed attribute can motivate students to improve in this area. It takes repeated deliberate attempts for improvement. |
| Limited Proactive Testing | • Making students aware of this needed attribute can motivate students to improve in this area. It takes repeated deliberate attempts for improvement. |
| Learning from Failure | • Making students aware of this needed attribute can motivate students to improve in this area. It takes repeated deliberate attempts for improvement. |
| Social Awareness | • Making students aware of this needed attribute can motivate students to improve in this area. It takes repeated deliberate attempts for improvement. |

### *Developing a Better Experimental Process*

The previously identified and discussed student attitude and approaches have greater reach into other learning settings. Having reviewed students' submissions, five categories of improvements are identified. Central to all five categories is that students need significant help to recognize the value of each steps undertaken. Knowing the "why's" helps with working with the "what's".

**Reading and Following Instructions** – The fact that instructions are provided to help steer the project in the right direction seemed to have escape some students. Observed challenges included:

- Lacking Instruction Reading - A small cohort failed to even read the project brief. These students developed the projects based on their self-understanding of the assignment but missed all of the key details provided. These teams also tended to severely underestimate the work and/or involved. To correct this, clear and strong emphasizing that reading the instructions is the fundamental first step of the process will set the teams on the right path.
- Lacking Instruction Compliance – The ability to track multiple requirements of this project seemed challenging to many teams, particularly those that were randomly connected. A common shortcoming is the failure to remember that the final recommendations should be addressed to a hotel management group. Some teams approached the entire project from their personal experience showering in their apartment bathroom. Perhaps the more impactful pedagogical path is to allow students to first exhibit this shortcoming before being corrected. Resubmitting work has proven to improve outcome.
- Confusing Presentation of Work –Having no previous experience with responding to request for proposals (RFP's), students often did not frame their work in a meaningful manner. Instead, they provided response in seemingly random manners. To correct this, instruction on good report writing must be introduced to the students. A good idea for novice engineers is to present the results in a format following the key points of an RFP. This is a good career advice. Making it easy for reviewers to identify responsive points certainly will encourage positive responses.

**Developing a Hypothesis** – Novice engineers will need guidance to develop meaningful hypothesis. By definition, hypothesis is a proposed explanation for a phenomenon based on previous observations. To be valid, the hypothesis must be accurately and concisely stated. It should not be an unsubstantiated wild guess. It should be possible to validate or discredit the hypothesis. This is not a simple task for students for whom psychrometric principles are newly learned concepts. A practicum exercise was devoted to the development of the hypothesis. Poorly developed or worded submission were rejected, requiring resubmission. Iterative writing is a good learning experience. While it is time consuming, it also provides invaluable insight to the mentor.

**Designing the Experiment** – Given the problem statement posted by the project brief, the student suggested experimentation process typically involved only the verification of the proposed intervention worked and not the broader process with reasoning. Adding to this, many of the proposed interventions were excessive measures, such as, heating the mirror for the duration of the shower or to a very high temperature. Discovering the threshold when condensation forms or disappears was generally not discussed in the proposal missing the critical point of the entire project. Perhaps this is to be expected given its open-ended format. Instructors may help students design the experiment beyond validation, to discovering as much about the phenomenon as feasible. If students increase the frequency of observations, that will change results of the experiment from binary answers towards understanding incremental changes. A well designed experiment offers opportunities for additional discoveries, such as the point when water changes phase from vapor to liquid.

**Data Gathering** – Identifying the critical data to collect was another skill novice engineering students need guidance to master. To be safe, students will list all the psychrometric properties for each state point, rather than just those necessary. In the process, they confuse themselves as to which properties matter to the problem at hand. They would rather "dump all values" hoping the right ones will surface and the meaningless ones will not matter. Synergizing the last two steps, developing the hypothesis and designing the experiment, the critical psychrometric properties can be isolated for collection. In the foggy mirror project, it is the mirror surface temperature and room air dry bulb and wet bulb temperatures. Using the dry bulb and wet-bulb temperatures, the room air dew point can be identified. To maximize the learning outcomes, all these fine points must be discussed in the debriefing sessions at the conclusion of the project.

**Data Presentation**: A common misconception is that data can simply be listed show the work is adequate. Little attention is typically given to how data presentation can be designed to tell a better story. Having established that condensation is dependent on the precise relationship between the mirror surface temperature and the dew point of the room air, a clearer picture would immerge if these data points are in adjacent columns. Graphically presenting the data would tell a better story. The cross-over point of the mirror surface temperature line and the room air dew point line pinpoints when condensation occurred or dissipated.

*Developing Stronger Writers*

College students have an amazingly wide range of writing skills, not surprisingly. Many students lack the ability to communicate clearly and concisely early in their careers. Their poor writing brings to question whether the writing is confusing or the thought process is confusing them. Addressing these two deficiencies deserves a review of the university writing curriculum. Three questions should be examined by programs: 1) *Should all freshman students receive instruction in creative writing?* 2) *Should engineering students be taught differently than the general college population? a*nd 3) *Should technical writing be introduced earlier in the curriculum?* Three areas to improve engineering writing were identified in Foggy Mirror:

- Sentence structure to express a complex idea is difficult to master. Students often resorted to complex and compound sentence structure. Conveying ideas in simple sentences is an art form that student should be encouraged to learn.
- Student report usually rely on text only. This habit may have been created by the tools given to them, the smart phones and handheld devices. Given these text-only tools, students are less likely to choose a table or a graph, which can tell a better story. When graphics are done, they tend not to be professional in nature; rather they are the simple images with limited quality (e.g. like poorly take pictures that are fuzzy or shadows and backgrounds showed on non-scanned images).
- Student reports need detailed peer review for grammar and structure. Team writing often contain changes in tense, inconsistent 1st vs 3rd person voice and other variations from section to section.

In comparison with architecture studios, students are taught to seek out precedence studies. Students "borrow" design ideas from exemplary projects. Learning from this pedagogical style, appropriate reading assignments were introduced in a 3rd year course. In retrospect, reading assignments should begin with introductory courses to build better foundations for technical communication at the onset of engineering education. The lack of reference to reading material, even textbooks, can contribute to the lack of appreciation for good technical writing. Technical magazines articles can be a source of exemplary writing.

## Broader Pedagogical Opportunities

For a project that started as a fun exercise to promote the development of a disciplined inquisitive mindset, the project eventually exposed a myriad of other pedagogical opportunities beyond the initially identified challenges. Some of the challenges/opportunities have not received adequate attention in the traditional classroom within current education systems. Incorporating the Foggy Mirror project in this course made it possible to begin to address multiple pedagogical goals in one exercise. Five more robust takeaways were concluded from carefully working with Foggy Mirror.

**Deepen Understanding** – Embedded in ABET Criterion 3, Student Outcome 6, the design and execute of an experiment, is the fundamental question of whether students have an adequate knowledge base to develop the experiment. Without a sound knowledge base, attempts at experimentation cannot possibly reap positive results. That said, learning from failure is a great way to actively kick start learning but can have impacts on time as well as perception of "busy work". If it is project-based learning, students can associate their issues with Dunning Krueger Effect [23] and Illusion of Explanatory Depth [24]. It is incumbent on the instructional team to discover the shortfalls and respond proactively to support successful outcomes in the learning process. One way to do this is to tie the importance of the project's process to future work to show students it's actual value. More importantly, helping students recognize these elements in the learning process will set the students on a better life-long learning trajectory.

**Creating Logical Methodology** – Developing a detailed proposal makes the execution more efficient and on target. Students need help recognizing the significance of this stage of the project to the total success. An analogy can be made to a cookbook recipe. When the instructions are well-developed, the execution is simply a process. Another aspect to developing better methodology is the possibility of reaching multiple outcomes. Encouraging students to design the experiment to not only validate the hypothesis, but include other possible discoveries is an extension to the disciplined inquisitive mindset.

**Relevant Data Collection -** Deciphering the critical data points for collection requires successful mastery of the topic, the fundamentals, and methodology in use. Developing enough confidence to overcome the insecurity of not listing everything takes time. Providing smaller exercises before assigning the larger project can pave the way. Students need to learn to eliminate noise so they can see a better picture in their minds.

**Establishing Storytelling -** Learning to express ideas clear and concise for others requires mastery of the previous pedagogical goals. Without in depth understanding of the project goals and outcomes, the stories can only be described as "half-baked". Beyond the basics, clarity, flow, precision, and brevity are good storytelling traits to instill in students. Designing the written and presentation material using bullet points, tables, and graphics helps makes the information more organized and easier to digest for the reader.

**Promoting Teamwork Reputation** – As students self-select into their first team experience working with other AE students, evaluating how to set up this opportunity is important. Since Foggy Mirror is assigned to the entire cohort of incoming Architectural Engineering students, working together in small group promotes bonding [25]. It is also the defining event for future teaming preferences. Students need to consider of the consequences of a self-made reputation as either an outstanding or an undesirable team member. The performance in the first team exercise exposes work ethics, social skill, commitment, and compatibility issues that can take time and efforts to mitigate.

Unique to our challenging Covid-19 era of online learning regarding hybrid teaming, three tips may be adopted moving forward to set up student teams for success. All three of the listed items below are in response to limited time that students spend time together beyond class hours.

- **Create Bursty Team Time** – Even during together time, teams are not collaborating 100% of the time. Team collaboration involves periods of high functioning and collaborative activities followed by slow periods. Research suggests that these bursity team time followed by longer periods of silent focus work periods breeds successful teams. Bursity team times are created when all team members are gathered and available [27].
- **Brain-write instead of Brainstorm** – Using digital white-boards or shared real-time writing platforms (i.e. Google Doc.), team members can work independently in a shared space while easily seeing what others are doing and provide more instant-in-time input [28]. Their ideas can be tackled collectively, not necessarily synchronously.

- **Avoid Multi-tasking -** Make time for deep work means minimizing distractions. Each time a team member switch tasks, they lose productivity, studies showed.

## Conclusions

Over time, assigning this project to suggestive cohorts of architectural engineering students, many of these described observations were made and opportunities uncovered. In addition to sharing how this project can help meet an ABET student outcome, the authors attempted to present the opportunities offered by team project assignments in hopes that similar projects can enrich course work in other settings. A quote from an educator in the XX Architectural Engineering program in the early 1900's, shows that the basic learning objectives have remain true over the last 100 years. ABET criteria help organize the constituent parts in explicitly details. The execute is reliant on to the current educators' creativity and dedication to excellence.

> *"This course is designed to furnish the student with a broad and liberal training in both the aesthetic and constructive sides of Architectural Engineering. It recognizes that, for the successful practice of the profession, the student must be trained along the lines of logical reasoning and clear thinking, their imagination stimulated, their sense of form and proportion developed and directed, and the faculty of expressing themselves concisely and clearly upon all occasions cultivated."*

## References:


[1] Abdel-Magid, B. (2021, June), Empowering Undergraduates to Design and Conduct Experiments and Attain Outcome 3b of the ABET Engineering Criteria Paper presented at 2010 North Midwest Section, Minnesota State University, Mankato, Minnesota. 10.18260/1-2-1128-36450

[2] J. Palmer and H. Hegab, "Developing an open ended junior level laboratory experience to prepare students for capstone design," in 2010 ASEE Annual Conference and Exposition, June 20, 2010 - June 23, 2010, Louisville, KY.

[3] Whetten D.A. Principles of Effective Course Design: What I wish I had Known About Learning-Centred Teaching 30 Years Ago, Journal of Management Education Vol 31 No 3, June 2007 pp339-357.

[4] Sivaloganathan, S., & Ayad, O. G., & Hittini, W. Y. (2015, June), Design and Conduct Experiments, Analyze and Interpret Data: Learning Experience in the Design and Manufacture Lab Course Paper presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. 10.18260/p.25119

[5] Benson, M. J., & Thomas, H. J., & Reed, S. A., & Floersheim, B., & Condly, S. J. (2013, June), Leveraging Summer Immersive Experiences into ABET Curricula Paper presented at 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia. 10.18260/1-2—19881

[6] Kolb, A. Y., & Kolb, D. A. (2005). Learning styles and learning spaces: Enhancing experiential learning in higher education. Academy of management learning & education, 4(2), 193-212.

[7] Jones, A. L. (2021, June), A Metric for Assessment of ABET Accreditation Outcome 3B - Designing Experiments and Analyzing the Results Paper presented at 2010 North Midwest Section, Minnesota State University, Mankato, Minnesota. 10.18260/1-2-1114-36442

[8] A. Hossain and M. A. Zahraee, "Experiential learning of students through prescriptive laboratory experiments versus open-ended laboratory assignments," in 126th ASEE Annual Conference and Exposition: Charged Up for the Next 125 Years, ASEE 2019, June 15, 2019 - June 19, 2019, Tampa, FL

[9] S. Gulce-Iz and J. de Boer, "Challenge based learning in an applied cell biology course for biomedical engineering students," in 48th Annual Conference on Engaging Engineering Education, SEFI 2020, September 20, 2020 - September 24, 2020, Enschede, Online, Netherlands, 2020, pp. 1280-1285:

10 [11] Y. Li, "Enhancing undergraduate education through research-based learning: A longitudinal case study," in 2015 122nd ASEE Annual Conference and Exposition, June 14, 2015 - June 17, 2015, Seattle, WA

[11] Milligan, M. K. J., & Sussman, J. L., & Brackin, P., & Rajala, S. A. (2016, March), ABET Update Proposed Revisions to EAC General Criteria 3 and 5 Paper presented at 2016 EDI, San Francisco, CA. https://peer.asee.org/27370

[12] ABET (2022). CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS: 2021-2022 Accreditation Cycle. Engineering Accreditation Commission, 11/17/22

[13] Felder, R.M., and Brent, R., (2003) "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria," Journal of Engineering Education, Vol. 92, No. 1, p. 7-25.

[14] Al-Bahi, A. (2008, June), Designing Undergraduate Engineering Lab Experience To Satisfy Abet Ec2000 Requirements Paper presented at 2008 Annual Conference & Exposition, Pittsburgh, Pennsylvania. 10.18260/1-2--3416

[15] Felder, R.M., and Brent, R. (2003). "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria", Journal of Engineering Education, 92:1, 7-25.

[16] Feisel L.D. and Rosa A.J. The Role of the Laboratory in Undergraduate Engineering Education, Journal of Engineering Education, January 2005. PP121-130

[17] Etkina, E., Murthy, S., and Zou, X., "Using introductory labs to engage students in experimental design," Am. J. Phys. 74 (11), American Association of Physics Teachers, November 2006.

[18] Feisel L.D. and Peterson, G.D., "A Colloquy on Learning Objectives for Engineering Education Laboratories," Proceedings of the 2002 ASEE Annual Conference & Exhibition, Montreal, Quebec, Canada, 2002.

[19] Pai, B., & Patil, K., & Fernandez, T., & Benkeser, P., & LeDoux, J. (2022, August), *WIP: A novel problem-driven learning laboratory course in which biomedical engineering students conduct experiments of their own design to answer an authentic research question* Paper presented at 2022 ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/41519

[20] McCreanor, P.T. (2001). "Quantitatively Assessing an Outcome on Designing and Conducting Experiments and Analyzing Data for ABET 2000", Proceedings, Frontiers in Education Conference, October 10 – 13, 2001, Las Vegas, Nevada.
South Dakota State University, Civil Engineering Program. (2009) "ABET Self Study Report", Confidential Document.

[21] Winncy Y. Du, Burford J. Furman, Nikos J. Mourtos. (2005) "On the ability to design engineering experiments" 8th UICEE Annual Conference on Engineering Education Kingston, Jamaica, 7-11 February 2005.

[22] Fong, C. (2021) "Creating Learning Environments to Support Student Motivation Post-Pandemic." Talk at MIT Teaching and Learning Lab Speaker Series

[23] Schlösser, T., Dunning, D., Johnson, K. L., & Kruger, J. (2013). How unaware are the unskilled? Empirical tests of the "signal extraction" counterexplanation for the Dunning–Kruger effect in self-evaluation of performance. Journal of Economic Psychology, 39, 85-100.

[24] Mills, C. M., & Keil, F. C. (2004). Knowing the limits of one's understanding: The development of an awareness of an illusion of explanatory depth. Journal of experimental child psychology, 87(1), 1-32.

[25] Han, J. (2018). Team-bonding and team-bridging social capital: conceptualization and implications. Team Performance Management: An International Journal, 24(1/2), 17-42.

[26] Freidman, T. (2016). "Thank You for Being Late: An Optimist's Guide to Thriving in the Age of Accelerations"

[27] Riedl, C., & Wooley, A. (2020). Successful remote teams communicate in bursts. Harvard Business Review.
[28] Neupane, U., Miura, M., & Kunifuji, S. (2006, January). Inheriting Traditional Concept of" Turn" in Electronic Brain Writing for Group Idea Generation. In Fourth International Conference on Creating, Connecting and Collaborating through Computing (C5'06) (pp. 200-209). IEEE.