A VERSATILE WEATHER STATION ENGINEERING DESIGN FROM THE VIEWPOINT OF A FIRST-YEAR TEAM

Abel Feltes (Team Weather Works)
Ryan Owen (Team Pyramid)
and Robert Knecht

Colorado School of Mines

Abstract –*The theme of the Spring 2004 EPICS Challenge was "A Versatile Weather Station." Over 60 first-year teams exhibited designs of weather stations required operating a climate network to be placed in local high schools along the front range of the Rocky Mountains. A short-term goal of this project was to have students develop and demonstrate innovative concepts for weather stations. A longer-term goal was to identify and to select the most promising stations for development both on Earth and for planetary exploration. These students will describe their processes for constructing a weather station based on a project-based curriculum in engineering design. They will discuss the design of their station to gather climate data for land use decisions as well as the potential for a weather network for planetary exploration.*

Engineering design, a complex, interactive, and creative decision-making process, evolves as the design team synthesizes information, skills, and values to solve open-ended problems. The design stem encompasses a four-year program in engineering design, summarized in Figure 1. The Design Engineering Practices Introductory Course Sequence (EPICS) Program at the Colorado School of Mines (CSM) guides teams of first and second-year engineering students through an authentic design experience that requires decision-making to address technical, client-based projects. The disciplines are responsible for years three and four. The centerpiece of each design sequence is an open-ended problem that students work in teams to solve. To help students become skilled at this process, mentors guide students through these creative, interactive, and complex processes. Project solutions are showcased in written reports, oral presentations and graphics demonstration. Past projects include designing interactive playground equipment for children with disabilities, lunar mining equipment that received NASA's attention and water treatment systems for rural communities.

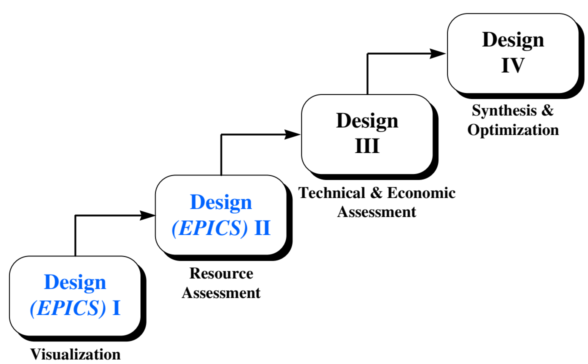

Figure 1: *Overview of Design Stem Sequence*

Through the sequence of design courses, students must develop an understanding and the confidence to address engineering design issues and projects. They must realize the importance, not only of the technical requirements but also the economic, societal, and environmental requirements of the design engineer. These skills must evolve from practice centered around a project they solve as a team and based on the following objectives.

1. Develop an ability through practice to apply creative and critical thinking skills based on a guided design methodology
2. Analyze engineering alternatives in order to select the "most desirable options"
3. Participate as a member of a team on an open-ended project to build team and interpersonal skills through practice
4. Prepare communications documents which develop evidence necessary to build an engineering case

The Spring 2004 EPICS Challenge

As part of the Spring 2004 EPICS Challenge, teams were called upon to use their ingenuity and developing engineering skills to design and possibly construct prototypes for an inexpensive and durable weather station. An integral activity for the Climate Center for Decision Making under Uncertainty, proposed by the Colorado School of Mines (CSM) to the National Science Foundation (NSF), was the collection of climate and hydrology data. Data acquisition activities relied on development and installation of instruments to acquire climate and water parameters over time. One such activity featured the hardware to collect data through a series of stations located in various middle and high schools along the front-range.

Extreme variations in climatic conditions have been recorded in Colorado in recent years including a four-year drought that contributed to the 2002 fire season, the worst in Colorado history. During the fire season of 2002 approximately 1535sq km (380,000 acres) of land was burned. The Hayman fire, which cost over 39 million dollars in property loss and fire-fighting expenses, burned 557sq km (138,000 acres). Within approximately six months, the fire season of 2002 was followed by the largest blizzard in Colorado since 1913. The blizzard of 2003 targeted the front-range to the west of Denver, the population center of the state of Colorado, and dropped as much as 221cm (87in) of snow from March 18 – March 19, 2003. This heavy snowfall caused more than 100 roofs to collapse in Denver, and snow-related accidents claimed the lives of several Colorado residents. These are just a few of the most recent examples of severe events triggered by extreme climatic variation. Many other social and economic impacts are expected to occur as a result of longer-term climate change, most notably a shortage in water resources. For example, based on projected population increases, the Denver region is forecasted to experience a shortage of about 100,000 acre-feet by 2020[1]. Because urbanized areas continue to grow and place greater demands on water resources in Colorado, it is important to better understand longer-term climate change and shorter-term climate variability when planning for this growth. It is also important to develop practical policies for managing our socioeconomic system.

The climate of Colorado provides an interesting example of highly variable conditions that are due to one of the most varied landscapes on the North American continent. Land-surface elevations range from approximately 1010m (3315ft) to 4399m (14,433ft). These differences in elevation and exposure produce large differences in precipitation and temperature patterns over short horizontal distances (Hansen, Chronic & Matelock[2]), and create vastly different microclimates. In general terms, the climate of Colorado can be described as semi-arid temperate continental, but varies from semi-arid in low-lying valleys to alpine arctic in high mountains. Average annual precipitation in high mountain regions ranges from 19cm (7.5in) to 165cm (65in) (Daly and Taylor[3]). It is not uncommon for low and high temperatures at most locations within the state to differ by more than 28^{o}C (50 ^{o}F) on a given day in both winter and summer seasons. Temperature inversions, during which air aloft is warmer than air at ground surface, are common in Colorado valleys. An urban heat island, an example of human impact on climatic conditions, is also well documented for the Denver metropolitan area (Hansen et al). Colorado's extreme climatic variation and long-term climate change need to be better understood for improving land use, urban planning and incorporation into decision making processes across the state.

The theme of the Spring 2004 EPICS Challenge was "*A Versatile Weather Station*." Over 60 first-year teams in the EPICS program researched and developed the potential to install weather stations in middle and high schools along the front-range, subject to specifications defined in Table I. The proposed breakdown structure, shown in Figure 2, organized the design process for the teams. The *instrument subsystem* afforded a means to gather atmospheric data such as temperature, pressure, wind conditions, moisture and solar radiation. The *data processing subsystem* included mechanisms to store, process, and transmit data to the Climate Center. The *structural subsystem* consisted of the housing for the weather station. Teams considered alternate or backup power subsystems as part of this subsystem. The *kit subsystem* denoted the packaging necessary to distribute the weather station to the schools.

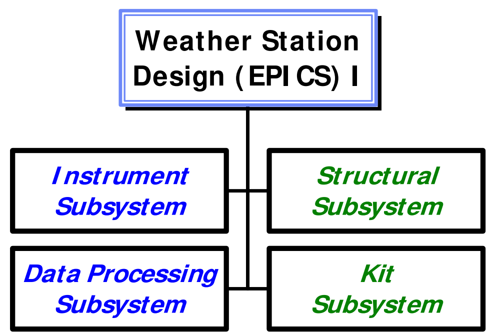

Figure 2: *Structural Breakdown for the Weather Station Project*

TABLE I Specifications for Spring 2004 EPICS Challenge Weather Station Project	
Specification	***Value***
Technical Specifications	
Instrumentation	Subject to the Globe program protocols
Durability	For use in a school environment
Storage	Defined by Dataq unit
Economic Specification	
Cost	$100 without data processing equipment
Site Specifications	
Atmospheric	Denver & Front Range Region
Safety Specification	
Structurally	No physical dangers
Electrically	No shock dangers

Teams prepared a design report and graphics portfolio documenting the design process, which included: 1) a description of background information supporting their decisions; 2) sketches of conceptual ideas; 3) a summary of the key components; 4) documentation drawings for construction; 5) a list of performance requirements; and 6) a cost estimate for the station.

Description of Two Outstanding Weather Station Designs

Team WWM (Abel Feltes)

At the Colorado School of Mines every freshman must complete an engineering design course – EPICS I. The purpose of this course is to teach students how to successfully organize a project, how to successfully utilize teamwork, and how to research for the purposes of completing a genuine engineering project. In essence, students are given an opportunity to actually do some hands-on engineering. The class was implemented in such a way as to improve the student's ability to utilize technical and business writing, use drafting software, and use the skills taught in other classes. Team WWM's mentor, Dr. Dean Dickerhoof, was stringent about making certain that there was never a loose end untied pertaining to this weather station project. He always made certain to not give his students any answers, and he encouraged the use of the elementary skills taught in all of the classes that any student had taken. He was never an easy grader. He would leave your paper strewn with red ink. This was sometimes irritating, since some of the errors appeared to be nitpicking, but it really showed how much he cared. He was willing to spend the extra hours to ask of his students more than just to output a good product. He asked his students to design a product that could surprise even them.

Students were asked to design a weather station to be used at Front Range schools in Colorado. The specifications for designing our weather station were:

- Since these weather stations will be implemented at schools, special attention must be given to the safety of the weather station.
- Since the Front Range tends to have some extreme weather conditions (in particular, it can be quite windy), the weather station must be design so that it could withstand such conditions.
- The weather station must measure temperature, barometric pressure, rate of precipitation, solar index, and speed of the wind.
- This weather station must store data that it receives in the Dataq DI-194RS Starter Kit. This unit was a voltmeter that operated in the range of 10V. The data were interpreted by a program that used Active X controls.
- The measurements must follow the Globe Protocols, which are government protocols used to standardize experiments and equipment.
- It was to cost under $100.

These specifications would put some significant constraints on the design from Team WWM, shown in Figure 3. The most important would be that care needed to be taken when placing the weather station within the school setting. For example, to accurately measure the solar index the weather station must not have been place in the shade. To measure the temperature the weather station would need to be positioned to measure the ground temperature. To measure the rate of precipitation the collection funnel must remain unobstructed. To measure the wind speed the weather station must be placed in the open. Another consideration that needed to be taken into account was that our weather station needed a supply of power, and would need access to a computer, so it was reasonable to make certain that it was near the school. Taking all of these considerations into account the roof seemed like the best locale for the weather station. This would alleviate the potential obstructions that could hinder the wind speed gauge, precipitation gauge, and solar index gauge, while it would only slightly hinder the temperature-measuring device. This would assure that the weather station would be out of reach of students at the school, which would alleviate some of the safety issues associated with student tampering (particularly, electrical shock).

Figure 3: *Team WWM Finished the Competition with the "Best Overall Design of a Weather Station"*

Figure 4: *WWM's Weather Station*

The structure of the weather station was designed to facilitate easy access to the internal components (the barometer, and the circuitry) while supporting the external components, illustrated in Figure 3.

To measure the atmospheric temperature at the ground level a thermistor (a resistor whose resistance changes according to its temperature) was used. Ten volts of direct current were supplied to a bridge circuit. The bridge circuit was chosen for a couple of reasons. The first was that current passed through the thermistor would cause it to heat up. If there were a significant amount of current passing through the thermistor, the data would be skewed by this heat build-up. The second was that the Dataq unit measured in the range of ±10V, and a bridge circuit was a convenient circuit to supply either a negative or positive output of voltage. The only problem with a bridge circuit was that it outputs on a much smaller scale compared to the input. To combat this problem an amplifier that consisted of a 3-operational-amplifier circuit was employed. This circuit was adequate to measure the atmospheric temperature, but, if you recall, the weather station was to be placed on the roof, so an extension wire was supplied to allow the thermistor to measure at ground level.

To measure the barometric pressure reliance was placed on the same method that classically allows a j-tube barometer to measure the barometric pressure. The construct was a barometer with a tube in which one half was a vacuum, and the other half was pushed by atmospheric pressure. The amount of pressure would lift the liquid in the side with a vacuum, and the amount of pressure would be measure. To measure the difference, the barometer lifted a buoyant "floater" in the side of the tube open to the atmosphere, and the floater would connect to a circuit that would go through a different number of resistors according to the height. The most difficult part of this design was choosing a liquid that would not evaporate or freeze, and that was of a reasonable density. The barometer would need to be housed inside of a box to protect it from the elements. The resistors were placed in a bridge circuit, and an amplifier was used in a similar configuration as the temperature-measuring device.

To measure the rate of precipitation we designed a funnel that would gather water. As the amount of water increased to a certain point it tripped a switch that would trigger the collection bucket to drain. The precipitation rate would be determined by how often the device drained. Care was taken to allow rainwater to be collected and still protect other instruments.

To measure the solar index some solar cells were placed on top of the weather station. The cells would be hooked up in series, so that they gained voltage across each one. We would use an operational amplifier to increase the voltage to meet the 10V range.

To measure the wind speed, a motor was connected to a turbine that would spin at a rate determined by the speed of the wind. As the motor spun it would output a voltage. As with other subsystems, an operational amplifier was used to increase voltage to meet the 10V range.

To power the weather station an AC adapter was purchased that would convert the school's power supply from approximately 120V alternating current to approximately 10V direct current. Each of the separate subsystem's circuits was supplied 10V via parallel circuits.

The program, that would output the refined data, would be programmed in C++ and would be Microsoft's Active X controls to gather the raw data. Once raw data were obtained, functions would be formed through interpolation of data points obtained through calibration. These functions would output the refined data in SI units.

Team Pyramid (Ryan Owen)

Team Pyramid, shown in Figure 5, worked on was a weather station that would allow researchers to collect data on the affects climate has on the weather. Since the researchers would like a complete study along the Front Range, it was decided that placing the weather stations in high schools along the Front Range would be the best course of action. Because the weather stations were going to be placed into high schools, the weather station had to be inexpensive ($100 or less) and had to be durable. The weather station also had to meet the Globe Protocols for gathering weather data.

Figure 5: *Team Pyramid Finished with the "Best Structural Design of as Weather Station"*

An important aspect of the project was the specifications of the client. The station was to be durable, cost less than a $100, meet the Globe Protocols, and it had to transmit the data back to researchers at CSM. Two options existed for a weather station prototype: 1) it would go to the high schools pre-assembled and they would install it or 2) it would go to the high schools as a kit and the high school students would assemble it themselves and then install it. Team Pyramid choose to go with a pre-assembled weather station because we felt that we would not have enough time to design a weather station as a kit.

Figure 6: *Team Pyramid's Weather Station*

The first aspect of the design was the overall look and feel of the weather station. Since it was going into a high school, the weather station, shown in Figure 6, must attract students to it. If they could look inside of the weather station and see how it worked, they might become interested in meteorology. To do this, the weather station was designed with a clear shell and where possible out of clear materials. We tried not to hide any part if possible. To allow high school students to use information coming from the weather station, a program was developed that would display the data coming from the weather station before it was sent out to CSM. The information would be displayed as a graph and would be display in spreadsheets, one for each day.

High school students and the environment can be destructive to equipment. Because of this, the weather station was going to have to be very durable. Since the strongest structure is a pyramid, the overall shape of the weather station became a pyramid. The side brackets of the structure were made out of aluminum angles. An aluminum rod went up the middle of the pyramid, acting as support for some of the parts and to give the structure more durability. Horizontal cross-supports of aluminum held the side brackets to the metal rod. The sides were made out of Plexiglas, with one side being hinged at the bottom. To facilitate ventilation, the bottom was made from a wire mesh and holes were drilled into the PVC tube on top.

Attention was then given to what pieces of data the weather station was going to need to take. It needed to measure the precipitation, the wind speed and direction, the aerosols in the atmosphere, the barometric pressure, and the temperature of the atmosphere and ground. To help with the costs, a decision was made not to buy individual instruments, but instead to build them using the chips that make the instruments work. Because individual chips take measurements, a motherboard was developed to bring all of the information to one chip.

Since the barometer and atmosphere thermometer were simple chips, they were place directly onto the motherboard instead of giving them their own boxes. To measure the ground temperature, a thermometer in a closed metal tube was buried several inches into the ground.

Since Colorado receives varying amounts of precipitation, the rain gauge must handle large and small amounts of precipitation. A tipping bucket rain gauge with a heated funnel was selected to measure precipitation. The heated funnel would melt any snow on contact, allowing the tipping bucket to measure it. A photometer box was used to measure various aerosols in the atmosphere. The box was a light-sealed box with a hole in the top. Light came through the hole and struck a photometer chip.

The anemometer (wind speed) had four cups located evenly around an aluminum shafts. Inside of the tube was a disk with teeth cut out of it. As the teeth rotated around, they broke the beam of light from a light sensor. A wind vein attached to plastic tube measured the wind direction. Two sets of ball bearings, one at its base and another several inches above, supported the tube. At the very bottom of the tube was a gear, which was attached to another gear with a 360°-potentiometer on it. As the wind vein spun around, it spun the potentiometer, allowing it to measure the direction of the wind.

This information from all the instruments was sent to the motherboard, which was calibrated for the various instruments.

Next, it became necessary to power the weather station and get the information from it to a computer inside the school so it could be analyzed. To give the high schools a lot of flexibility on where they could put the weather station, the weather station needed to be self-sustained. Two solar panels on the side of the weather station and a battery inside were used to power the station. The solar panels provided enough electricity to allow everything to work and the battery acted as backup during the nights or days when there was too much cloud cover. A transmitter transmitted the information to a computer. There was a receiver hooked into the computer and the program collected the information, displayed, and saved it.

The last design issue was how the computer was going to send the information back to CSM. The program was expanded to send the information by an Internet connection. This provided high schools the ability to install the weather station without having to get addition equipment.

Student Perspective of the Engineering Design Course

Having gone through the process of designing this weather station, and enjoying the EPICS class, it has become quite apparent that students come away from the class with more than knowledge of how to build a weather station. Knowledge of how to use engineering software and a feel for how to successfully orchestrate and organize an engineering project also help to learn how to delineate tasks in such a way to provide maximum efficiency. It goes beyond that. This class teaches students how to learn for themselves, as is often required in engineering industries. When choosing engineering as a discipline, a student must realize that often tasks are prone to being left completely open, and undefined. For many graduates entering an industry there is a learning curve coming out of a university as to how to deal with the different organizations of different companies. The course helps to deal with the dilemma of what one is to do when they come across a problem that they do not know how to solve, or even that may have never been solved. In other words, the EPICS classes get the students at the Colorado School of Mines to use ingenuity. This aspect of the curriculum is invaluable, and improves everything that the school does.

The things that we, Team Pyramid, learned as a group from this project was vast. We were given a project that we knew very little about and were in a group of people whose skills varied immensely. We as a group had to learn to work together or we would have never have finished the project. We had to learn how to access each person's skills and divide work accordingly. We as a group also learned about deadlines and how these deadlines can creep up on you. We also learned how to have fun even during the stressful times and how to stay focused when we were having too much fun.

Students learned a great deal from this project, such as learning many different things about drafting and computer-aided drafting. Learning that dimensioning objects was far more than just defining lengths was one of the main lessons learned in the drafting workshops. Students learned that many parts of drawings must be dimensioned with respect to other parts or the part will not come out right. Students also learned about a CAD program, Solid Works, and how to use it. This was quite a challenge because I, Ryan Owen, had previously used AutoCAD, and Solid Works and AutoCAD are very different when it comes to drawing parts. It took me some time and work to be able to use Solid Works.

The importance of the project in students' learning is that it taught them how the real engineering world is going to work. It teaches them how to work in a group of people with many different skills and how to come together to finish the problem at hand.

1) Civil engineers for the structures,
2) Mechanical engineers for the heat and cooling systems,
3) Electrical engineers for the various electrical systems,
4) Architects for designing the structure,
5) Accountants to make sure that it's on budget,
6) Lawyers to make sure the laws are upheld, and
7) Draftsmen to make sure the structure is actually feasible.

All of these people will have to come together to finish the project because no individual can finish it by himself or herself. This project also gives them their first taste of what it's going to be like having to deal with a customer and their agendas. The groups have to design things to what the customer wants, not to what they want to do. In this particular project, the requirement that the weather station be less than $100 was one of the hardest requirements to fill. When first looking at buying the various parts, students noticed that they would go over the budget quickly. They were required to think of creative ways to make the various instruments while still staying under budget.

Summarizing a Successful Experience

The short-term goal of this project was to have students develop and demonstrate innovative concepts for weather stations. A longer-term goal of the Division will be to identify and select the most promising stations for further development and distribution to local schools

By involving students in research and team-oriented design and construction projects, the Design (EPICS) Division prepares them for careers in the engineering disciplines. This project satisfies the following objectives of the Design (EPICS) Division mission:

- ♦ ***To develop and demonstrate creative engineering technologies***
- ♦ ***To build effective teams of engineering students***
- ♦ ***To communicate design products to a societal market***

These skills must evolve from practice centered on a project they solve as a team.

The Versatile Weather Station Challenge provided an exciting environment for students to develop not only their engineering skills but also their creative and critical thinking skills. Using a guided decision-making methodology, they focused on the visualization of a weather station through sketching and CAD graphics. Working in teams of 4 to 6 students, they identified the needs of the client and turned those needs into a practical device useful for gathering weather data along the Front Range in Colorado. It was not sufficient to build the weather station, they also had to document their findings and market their products as part of the process. The Challenge ended with efficient products and satisfied students. The Design (EPICS) program closes the Spring 2004 Challenge with a sense of pride and a warm thank you to all who participated, supported, and contributed to the students' learning.

Bibliography:

1. Colorado Department of Local Affairs, (2003), *Colorado population estimates and projections in five-year increments (1990-2030)*
2. Hansen, W.R., Chronic, J. and Matelock, J., (1978), *Climatography of the Front Range urban corridor and vicinity, Colorado*, U.S. Geological Survey Professional Paper 1019, Washington D.C., pp. 59
3. Daly, C., and Taylor, G.H., (2000), *United States average annual precipitation, 1961-1990*, USDA-NRCS National Cartography and Geospatial Center, Fort Worth, TX

Biographical Information

ABEL FELTES & RYAN OWEN
Abel and Ryan are second-year students at the Colorado School of Mines. Their teams participated in the Spring 2004 EPICS Challenge – a Versatile Weather Station. As an award for their outstanding work on the project, they were selected to submit this paper to the ASEE.

ROBERT KNECHT
Robert Knecht's 23 years of experience in the engineering industry focuses on technical and management support for minerals, energy and waste projects. He currently directs an engineering design program based on a curriculum that focuses on projects from industry. His projects require students to implement a design methodology in teams to solve open-ended problems and to communicate these solutions both in written and verbal forms.