THE MULTIDISCIPLINARY UNDERGRADUATE RESEARCH IN TURBULENCE (MURT) PROGRAM AT VALPARAISO UNIVERSITY

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Abstract *? A new interdisciplinary research program at Valparaiso University, the Multidisciplinary Undergraduate Research in Turbulence (MURT) program, was introduced. The program engaged undergraduate engineering and meteorology students in experiential learning activities through laboratory studies and fieldwork. Programmatic information including the mission statement, educational directional themes, desired outcomes and a list of assessment tools was presented. Three key elements of the program were addressed: the field studies, the appropriateness of undergraduate multidisciplinary work among engineers and meteorologists, and budgetary considerations. Commonality in research problem content and formulation, undergraduate curriculum, and student learning styles suggested that undergraduate meteorology and mechanical engineering students were well suited for collaborative multidisciplinary research. Program initiation costs were below $50,000; field study execution costs were less than $3,000. Based on the data presented, engineering educators can evaluate the suitability of similar research activities at their own institutions.*

Index Terms ? Undergraduate Research; Multidisciplinary; Turbulence; Atmospheric Boundary Layer; Field Studies.

INTRODUCTION

Both meteorologists and engineers seek to understand turbulence. Engineers are interested for many reasons; for example, turbulence affects airplanes in flight, governs heat transfer in many industrial situations and plays a significant role in automobile aerodynamics. Meteorologists are interested because turbulence contributes to the birth and death of weather systems, the transport of contaminants through the atmosphere and the overall dynamics of the planet's oceans. The Valparaiso University (VU) Multidisciplinary Undergraduate Research in Turbulence (MURT) program brings students of meteorology and engineering together to examine atmospheric boundary layer turbulence and the related transport of mass, momentum and energy.

Officially funded by the National Science Foundation on August 1, 1999, the MURT Program recently completed its sixth full semester of active research. The program's mission statement is as follows:

> Through faculty-guided experimental research, the MURT Program prepares undergraduate students in the VU College of Engineering and the VU Department of Geography and Meteorology for graduate study in turbulence and related transport phenomenon.

From this mission statement flow two educational directional themes. The MURT Program fosters 1) interdisciplinary undergraduate education for students of engineering and meteorology and 2) development of research skills using state-of-the-art experimental measurement techniques to study turbulent flows. With these overarching goals in place, five desired outcomes are identified for the research students. Upon successful completion of at least two semesters in the MURT program, the student will be able to

1. describe the importance of turbulence in engineering and meteorological flows and give relevant examples,
2. describe the concept of turbulent length scales,
3. give examples of methods used to estimate/correlate turbulent surface fluxes,
4. demonstrate proficiency in using state-of-the-art laboratory equipment to experimentally investigate turbulent flows, and
5. list problems commonly encountered in team-based research and corresponding management techniques to counter the problems.

Student achievement of desired outcomes is assessed using various items such as a research student exit survey, instructor laboratory observation form, student research reports, student presentations, and team activity sheets.

The research team is conducting laboratory and field experiments that are designed to measure various length scales in turbulent boundary layers. The length-scale data is used to evaluate the effectiveness of different turbulent transport models. To date, six meteorology, one electrical

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engineering and thirteen mechanical engineering students have participated in the program.

This paper addresses three elements of the MURT program: the field studies, the appropriateness of undergraduate multidisciplinary work among engineers and meteorologists, and budgetary considerations. The hope is that by presenting programmatic information, other engineering or science educators will be assisted in evaluating the suitability of similar research activities at their own institutions.

SELECTED PROGRAM ELEMENT INFORMATION

Numerous elements contribute to the overall success of the MURT program. Institutional ethos, interdepartmental collegiality, student interest in learning, and facility adequacy name a few. However, the field studies, interplay between engineering and meteorology students, and the overall budget are key pieces to understanding whether or not a similar program is a good fit at a different institution. Information regarding these three items is presented below.

Field Studies

Students examine many interesting flows in the laboratory. However, the ultimate experimental experiences in the MURT program are the field studies. In the program's three-year existence, a variety of instrumentation and apparatus validation tests were performed during local field studies on the VU campus. However, during each of two consecutive spring recesses, a major field study was performed away from campus. In March 2000 the MURT team conducted its first major field study in Galveston, Texas; in March 2001 the team gathered near-surface atmospheric boundary layer data at the Argonne National Laboratory Atmospheric Boundary Layer Experiment (ABLE) in Whitewater, Kansas (near Wichita). For both studies, the students transported all data acquisition and support hardware to the field-study site, conducted experiments and analyzed the resulting data.

The field study hardware includes a 35-foot instrumentation boom assembled from 5-foot segments of 2-inch diameter galvanized pipe, a 6-foot instrumentation boom made from a single segment of 1.5-inch PVC pipe, two portable hot-wire anemometers (DC powered), a collection of hot-wire probes and a laptop computer equipped with a 16-bit A/D data acquisition board. The instrumentation booms support delicate hot-wires that measure wind speed at different heights. The segments for the 35-foot boom were designed to fit in the cargo area of a standard minivan for ease of transport. The boom is raised from horizontal to vertical using a custom-designed steel base with a permanently mounted boat winch for assistance. The 35-foot boom is shown being raised and in its vertical position in Fig. 1. All components of the 6-foot and 35-foot booms were designed and fabricated by the student researchers.

Galveston, Texas – March 12-18, 2000 The purpose of the Galveston field study was primarily to gather turbulent velocity data that would allow the calculation of characteristic turbulent length scales near the surface of a sea-breeze-dominated boundary layer flow. The method of Barrett and Hollingsworth [1] was used to calculate turbulent length scales in the shear flow. Galveston was selected because of its rich weather history, the tropical nature of its weather systems, and its proximity to colleagues at the University of Houston and the NASA Johnson Space Center. The fairly repeatable (and predictable) nature of the Gulf-of-Mexico sea breeze increased the probability that quality data could be acquired. Also, to promote student interest and provide a societal reference for the relevance of the MURT research, the 100-year anniversary of the 1900 Galveston hurricane was integrated as a cultural backdrop for the trip. In preparation for the trip, an historical review of weatherman Isaac Cline's life revealed that Galveston's September 1900 hurricane was the United States' most deadly natural disaster; as many as 12,000 people were killed by the storm. In the days before weather radar, forecast models or satellites, the lack of warning drew a large toll. Having studied detailed accounts of the disaster in Erik Larson's book, *Isaac's Storm* [2], the trip to Galveston also gave the students a personal feel for the scale of the 1900 tragedy and a respect for modern forecast model capabilities.

Despite some anemometer difficulties (finally eliminated through recalibration at the University of Houston Turbulent Shear Flow Laboratory), velocity data was successfully gathered during the Galveston trip. Near-surface length scales were calculated from the data [3]. The Galveston trip verified that the field apparatus could be shipped significant distances, deployed, and used to gather meaningful velocity data.

Although the field apparatus worked properly, later data analysis identified that the weather information from the Galveston airport was insufficient for a thorough evaluation of the local atmospheric boundary layer characteristics. The need for more elaborate local atmospheric data to supplement our calculations caused us to select the ABLE site for the next major field study in March 2001.

Whitewater, Kansas – March 18-22, 2001 The primary objective for the ABLE 2001 field study was to evaluate the surface-flux correlations of Barrett and Hollingsworth [4] in an atmospheric flow. Velocity data was acquired using both the 35-foot and 6-foot instrumentation booms. Additional ABLE instrumentation

[5] provided ground heat flux and local temperatures and velocities up to an altitude of 1 km. Data collected from the combination of MURT and ABLE instrumentation allowed the student researchers to evaluate length scales and flux correlations never before tested in the atmospheric boundary layer. Analysis of the ABLE data is ongoing but is already leading to presentation and publication opportunities for the student researchers [6, 7].

(A)

(B)

FIGURE 1
DEPLOYMENT OF 35-FOOT INSTRUMENTATION BOOM: (A) RAISING, (B) VERTICAL POSITION.

Why Meteorologists and Mechanical Engineers?

There are several reasons why undergraduate meteorology and mechanical engineering students are well suited for this type of multidisciplinary research. A brief examination of four reasons follows.

First, whether examining near-ground moisture transport in the atmosphere or turbine-blade heat transfer in an aircraft engine, the governing physical laws and the resulting mathematical formulation of the problem are essentially identical. However, since discipline-specific nomenclature varies, instructional time must be allocated to deliberately address terminology and orient the students to their differing "languages." Something as simple as identifying different labels for standard reference frame axes in mathematical formulations will greatly promote a unified understanding by tying the research framework to previous material encountered in discipline-specific coursework. For example, most engineering fluid mechanics textbooks label a Cartesian reference frame's vertical axis as y; meteorologists use z – an insignificant difference, but still a potential source of misunderstanding if not recognized.

Second, at Valparaiso University, many of the fundamental math and science curricular requirements are shared by the undergraduate meteorology and mechanical engineering programs. As shown in Table 1, students in both programs are required to take basic and advanced calculus, physics, dynamics and thermodynamics. Since many of the fundamental courses are completed in the Freshman and Sophomore years, students in both programs can meaningfully contribute to the research very early in their academic careers. This affords the students the opportunity to participate over a number of semesters promoting learning at advanced levels and enhancing semester-to-semester continuity in the research team.

TABLE I
SIMILARITIES IN CURRICULAR REQUIREMENTS

	Meteorology	Mechanical Engineering
Mathematics	? Anal Geom/Calc I & II, or alternate Calc I & II sequence	? Anal Geom/Calc I & II
	? Calculus III	? Calculus III
		? Differential Eqns and Linear Algebra
Physics	? Mechanics and Heat	? Mechanics and Heat
	? Elect., Mag. & Waves	? Elect., Mag. & Waves
Dynamics	? Atmospheric Dynamics I & II	? Mechanics-Dynamics
		? Fluid Mechanics
Thermo	? Atmospheric Thermodynamics	? Thermo I & II

Next, through limited testing of Valparaiso University students, no significant differences in learning style preferences appear between the engineering and meteorology students. To date, the Index of Learning Styles (ILS) survey of Felder and Soloman [8] has been administered to approximately 400 engineering students and 30 meteorology students at Valparaiso. The ILS tests for learning preferences in four categories: active vs. reflective, sensing vs. intuitive, visual vs. verbal and sequential vs. global. Adjusting for differences in sample sizes, no statistically significant ($p < 0.05$) differences exist between student groups in any of the four categories. Of course, individual participants will always have different preferred learning styles that can be accommodated by employing a variety of instructional and experimental approaches in the research setting. (This is, perhaps, an even more compelling reason to administer the survey.) However, the lack of correlation between learning style preference and program enrollment does suggest that no "self-selection" mechanism exists at Valparaiso to raise additional instructional or team-behavioral challenges.

Finally, by bringing meteorology and mechanical engineering students together, the research program greatly benefits from their complementary areas of expertise. Students in both majors are expected to participate in activities traditionally viewed as the "other" discipline's specialty area – this enhances the overall undergraduate learning experience and is one reason that Valparaiso is fundamentally committed to undergraduate research activities. Nonetheless, both groups uniquely augment research team capabilities. The meteorology students explain atmospheric models, forecasting techniques, previous atmospheric studies, and current issues related to the research topic. The mechanical engineering students share fundamental fluid transport models (particularly involving turbulence), instrumentation and measurement theory, computational programming and analysis techniques, laboratory experimental methods, and hardware manufacturing skills. Fortunately, in the team-based research environment, aptitudes from both disciplines are shared *with* students *by* students and peer-learning is facilitated.

When one examines graduate-level atmospheric research, one discovers some of the most successful programs inherently integrate engineering and the atmospheric sciences. It seems instinctive, then, that mechanical engineering and meteorology students work together at the undergraduate level as well.

Advantages of meteorology-engineering collaboration extend to other fields in engineering. In fact, one electrical engineering student participated in the MURT program; she examined different signal processing techniques used to analyze turbulent dissipation spectra. Again in this instance, both the student and the overall program profited from the multidisciplinary experience.

Budgetary Considerations

An estimate of "start-up" and operating expenses is required for the reader to realistically evaluate the potential of initiating a team-based research activity similar to the MURT program. Table 2 shows the initial instrumentation expenditures for lab and field studies. The expense estimates assume all of the required instrumentation hardware must be purchased; any hardware already owned would, of course, reduce start-up costs. However, it is assumed that a laptop computer with a PCMCIA slot is already available. It is also assumed that either the engineering or meteorology program already owns a wind tunnel that can be used for laboratory studies and field hot-wire calibrations. The MURT students program their own data acquisition software applications in Microsoft® VisualBasic®, so data acquisition software expenses are omitted. Approximately $18K of the initial laboratory hardware costs for the MURT program were funded through National Science Foundation grant number CTS-9977424. Remaining expenditures were drawn from VU funds.

TABLE II

ESTIMATES OF INITIAL INSTRUMENTATION COSTS

IEEE 488 Data Acquisition System (Lab)	
GPIB interface card	$ 500
High-speed, simultaneous s&h, 16-bit A/D converter	4,000
Control, storage, and analysis computer w/software	2,500
Hot-wire Anemometer System (Lab)	
Two-channel (velocity) integrated anemometer with one-channel (temperature) for cold-wire thermometry	15,000
Assorted hot-wires	1,600
Digital oscilloscope	2,500
Cabling and support hardware	100
Multi-axis automated traverse and probe mounts*	2,000
Heated flat plate for wind tunnel studies*	600
Heated flat plate for water tunnel studies* *[optional]*	5,000
Assorted hot-film probes for water studies *[optional]*	1,500
Hot-wire Anemometer System (Field)	
Two single-channel, portable hot-wire anemometers	6,000
Assorted hot-wires	1,200
Instrumentation booms*	1,000
Cabling and support hardware	300
Multichannel PCMCIA 16-bit data acquisition card	600
TOTAL (without water studies):	**$ 37,900**
TOTAL (including water studies):	**$ 44,400**

* Designed and built in-house by student researchers

The actual expenditures for each of the aforementioned field studies are shown in Tables 3 and 4. The field studies were completely funded through various VU initiatives and campus entities.

TABLE III

ACTUAL COSTS FOR GALVESTON, TX FIELD STUDY

Rental Cars/Vans (2)	$ 800
Gasoline	330
Housing (6 nights; 8 students, 1 professor)	1,340
Misc. Repairs and New Equip.	100
Galveston TOTAL:	**$ 2,570**

TABLE IV

ACTUAL COSTS FOR WHITEWATER, KS FIELD STUDY

Rental Car/Van (1)	$ 280
Gasoline	140
Housing (4 nights; 6 students, 1 professor)	930
Misc. Repairs and New Equip.	200
Whitewater TOTAL:	**$ 1,550**

CONCLUSIONS

Undergraduate meteorology and mechanical engineering students are well suited for collaborative multidisciplinary research. Characteristic similarities in relevant physical problem formulations and curricular requirements facilitate the integration of the two student groups. Also, no significant differences in preferred learning styles have been identified between the groups among Valparaiso University students. Finally, unique strengths of both student groups combine to greatly enhance a research program that requires the integration of theory, modeling, test apparatus manufacture, and fieldwork.

A program similar to MURT can be initiated for less than $50,000; a major field study involving six to eight students can be executed for less than $3,000. Costs will vary depending on currently owned equipment, field study destinations, and the number of students involved in the program.

Additional information regarding the MURT program is found on the main web page at http://www.valpo.edu/home/faculty/mbarrett/MURT.htm.

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