Addressing the Disconnect between Engineering Students and the Physical World

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Abstract

There is ample evidence of a growing disconnect between engineering students and the physical world. This chasm is being created by social and technological changes; in particular, the proliferation of microprocessor-based "virtual experiences" for children and adolescents has had an inhibiting effect upon their opportunities to explore forces, causal factors, and effects in the real world. Diminished opportunity to *physically experience* produces diminished ability to *perceive.* The predictable result is that students in engineering and the applied sciences struggle to critically evaluate their work in problem-solving exercises.

In the fall of 2006 efforts were undertaken to reconnect undergraduate chemical engineering students with the physical world. Four groups of volunteers (27 students) from ChE 530, Transport Phenomena 1, were provided with a large-scale field experience in which water was: **1)** pumped through a series of nozzles (trading pressure for kinetic energy), **2)** pumped into a 325 gallon tank to test the delivery rate achieved by the pump (and the horsepower requirement), and **3)** allowed to drain from the tank through a valve and a short length of 2-inch diameter hose (evaluation of Torricelli's theorem). The intent of this exercise was to provide students with the opportunity to *experience* fluid forces, velocities, and frictional losses in a physically meaningful context. Experience has shown conclusively that *these objectives are not being met* by the small-scale activities carried out with our present laboratory experiments.

Results from the activities described above have been evaluated through quizzes, examinations, and direct student responses (questionnaires completed by the participants). The physically-relevant field experiences appear to have had a positive impact upon test subjects and the findings of this study are described in detail here.

Introduction

Social and technological changes have affected the abilities of students in the sciences and engineering to critically evaluate results obtained in problem solving exercises. Many students' physical experiences are no longer adequate to produce in them a sense of reality or a mechanism by which they might estimate probable outcome. Jeffrey Zaslow[1] *(Wall Street Journal, October 6, 2005)* notes that the technology-focused lifestyle of today's children can "leave them disconnected from the wider world," and "oblivious to adult culture." Furthermore, electronic technology has led to pervasive multi-tasking among adolescents, making conventional classroom instruction—the "transmissionist" model described by Finkelstein[2]—less effective than it was decades ago. Under these conditions, education in the sciences can result in a veneer of technical sophistication coupled with a complete lack of physical understanding, as noted by Wankat and Oreovicz[3]. We have developed several large-scale field exercises designed to combat this problem and complement our transport phenomena sequence (ChE 530-531) by providing experiential learning with a rich, somatic component. Some preliminary results from this effort were described by Glasgow[4].

It is crucial that we note how the childhood environment for the previous generation of engineers was different. Grose[5] recently reviewed the formative influences upon six accomplished engineering educators; he found active childhood pursuits in airplanes, chemistry sets, dissection equipment, farm equipment, and electronics. These activities are lost to today's children; the proliferation of microprocessor-based "virtual experiences" for children and adolescents has had an inhibiting effect upon their opportunities to explore forces, causal factors, and effects in the real world. Indeed, many of the play activities of children of the 21st century are incomprehensible to previous generations. Dwindling opportunities for children to *physically experience* diminishes their ability to *perceive,* and in engineering and the applied sciences the consequences can be catastrophic. Zaslow[1] further observes that "…technology has exacerbated the gulf between today's parents and kids in ways we need to notice." It has become much easier for kids to be completely isolated from the physical world around them.

Examples of the Failure of Current Classroom Practices

Several educators have employed the battery, lightbulb, and wire scenario (students are asked to complete a simple circuit given a bare bulb, a battery, and a single piece of wire) to explore the apparent fracture between instructional objectives and learner outcomes. In a well-known study, McDermott and Shaffer[6] found that "…students often manipulate formulas without relating the algebraic symbols to concepts." They observed that the "…typical introductory physics course is a passive learning experience for many students" and they also noted that mental and *physical engagement* can improve learning outcomes for students. In a large study, Slater, Adams, and Brown[7] found that just half of science and engineering students in college could complete a circuit with the single wire, battery, and bulb (58.5% of males and 25% of females).

Similar examples of disconnect have pervaded every engineering discipline. In chemical engineering we have begun to see students with absolutely no physical frame of reference—students for whom an order-of-magnitude estimate is an unthinkably abstract analysis. To better understand how the disconnect problem impacts chemical engineering education, consider the following question and actual student response from a recent ChE 530 (Transport Phenomena 1) Final Exam:

Gasoline is being pumped 17 miles through nominal 3-inch, schedule-40 steel pipe at a rate of 9500 gal/hr. What horsepower will be required if the pump's efficiency is about 75%?

The average velocity in the pipe: $$<V>=\frac{\dot{M}/\rho}{\pi R^2}$$

therefore, $<V>=\dfrac{4571856}{\pi(0.1278)^2}=8.9x10^7$ ft/s. So,

$$\text{Re}=\frac{d<V>\rho}{\mu}=\frac{(.1278)(8.9x10^7)(55)}{(0.56)(6.72x10^{-4})}=1.66x10^{12}$$

This Reynolds number verifies turbulent flow.

$w=g\Delta z+\tfrac{1}{2}V^2\dfrac{L}{R_h}f$ so, power=$1.66x10^{16}$ hp.

The student knew what was needed and followed the necessary steps. However, he made a conversion (dimensional) error in the very first step and failed to recognize that his computed average velocity was ridiculously large (the correct value is 6.87 ft/s). Nor was he perturbed by the resulting Reynolds number. The student determined the required power from the macroscopic mechanical energy balance; his result was nine orders of magnitude larger than the combined power of the five F-1 engines of a Saturn V launch vehicle. We acknowledge that such errors can be made by anyone, from a novice to an experienced engineering professional. What we cannot accept—and what the engineering profession cannot tolerate—is the complete absence of the physical insight that engineers have always relied upon to detect such errors.

We believe that a significant part of the problem evident in these examples stems from isolation of today's students from the physical world. This perception has been reinforced by several members of our External Advisory Board who tell us that the effects of disconnect are becoming increasingly apparent with new engineering hires in the workplace. It is also clear from the scope of the problem that we are witnessing something more than mere failure of the "transmissionist" method of instruction; many other engineering educators have recognized similar changes in student performance and have tried to develop more effective teaching/learning strategies. For example, Laura P. Ford[8] in her article "Water Day" describes an experiential opportunity for engineering students that emphasizes somatic understanding of simple fluid flow phenomena using nothing more complicated than a garden hose and Nalgene® carboys. She noted that the activity was well-suited to visual and active learning styles.

Developing an Appropriate Field Experience

Our objective is to provide experiential opportunities of somatically relevant scale that employ *contextual learning* to accomplish the reconnection of chemical engineering students to the physical world. The significance of this approach was noted in 1995 in the NSF Report 95-65[9], "Restructuring Engineering Education: A Focus on Change." The panel members observed that "*…the learning experience must move from the lecture*.." and that "*…contextual experiential learning must be integrated within the classroom*." The advantages offered by contextual instruction (CI) have been recognized by education professionals everywhere; for example, see the Mississippi Department of Education website[10]. Some of the desirable features of CI are provided in the following list:

- ♦ *new concepts are presented in familiar, real-life situations*
- ♦ *there is reliance upon spatial memory*
- ♦ *there are opportunities to employ higher-order thinking skills*

- ♦ *multiple subjects are often integrated in the learning process*
- ♦ *new information is related with prior knowledge*
- ♦ *authentic assessment is obtained through practical application*
- ♦ *the activities often stimulate student receptiveness—the attitude that "I need to learn this…" is cultivated.*

In addition to these benefits, we expected the field activities to create somatic learning situations of the type that are often missing completely from the life experiences of today's engineering students.

Feisel and Rosa[11] have recently observed that the design of a new "laboratory" experience must be preceded by formulation of clear instructional objectives. The ABET-sponsored colloquy of 2002 (funded by the Sloan Foundation) produced a list of thirteen objectives for engineering instructional laboratories. Of that list, four are especially important to the large-scale field exercises undertaken in this study:

Experiment. <u>Devise an experimental approach, specify appropriate equipment and procedures, implement those procedures, and interpret the resulting data.</u>

Data Analysis. <u>Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments.</u>

Creativity. <u>Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.</u>

Sensory Awareness. <u>Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.</u>

We believe that scale-appropriate experiences for our students—ones that effectively reconnect students with the physical world—must certainly have these four fundamental objectives. In addition, it is essential that such activities integrate multiple subjects, relate new information with prior experience and knowledge, emphasize spatial memory, and have a strong somatic component.

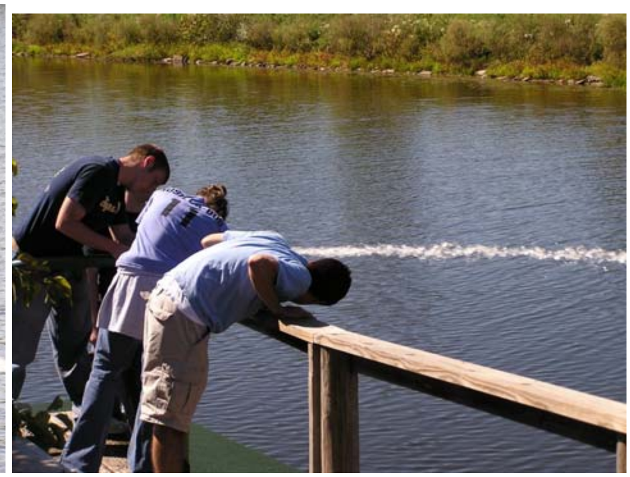
Initial Experience with the Field Activities

In the fall of 2006 we initiated a series of field exercises designed to address the disconnect between chemical engineering students and the physical world. Four groups of volunteers from Transport Phenomena 1 (ChE 530) totaling 27 students were provided with a large-scale field experience in which water was: 1) pumped through a series of nozzles (trading pressure for kinetic energy), 2) pumped into a 325 gallon tank to test the delivery rate achieved by the pump (and the apparent horsepower requirement), and 3) allowed to drain from the tank through a valve and a short length of 2-inch diameter hose (evaluation of Torricelli's theorem). The intent of this exercise was to provide students with the opportunity to *experience* fluid forces, velocities, and frictional losses in a physically meaningful context and to determine whether such experiences could translate to enhanced success in the classroom.

Trading pressure for kinetic energy

Figure 1a. Discharge fittings, left-to-right: 1 inch pipe nipple, 1 inch tubing barb, ¾ inch tubing barb, and ½ inch tubing barb.

Figure 1b. Discharge apparatus (2 inch PVC tee) with pressure gauge. The pump discharge is connected to the 2 inch male NPT on the right.



Figures 2a and 2b. Students shown evaluating the discharge of the 5.5 hp pump (200 gpm against a 10 ft head) through different nozzles. Each student had the opportunity to hold the discharge apparatus in order to experience the thrust (reaction) force.

Figure 3. The discharge velocity can be estimated from the horizontal distance traveled by the jet (from an initial height, h, of 5.83 ft) and also from the macroscopic mechanical energy balance (using kinetic energy, pressure, and loss terms). The two relations for discharge velocity, V_2, are shown below along with a table of student-generated results.

$$V_2 = L\sqrt{\frac{g}{2h}} \qquad\qquad V_2 = \sqrt{\frac{2g_c(P_1 - P_2)}{\rho(1+e_v)}}$$

The last column in the table is the ratio of discharge velocities: experimental to calculated (with the mechanical energy balance).

Discharge Nozzle	Inside Diameter, in	Distance and Pressure	Discharge Velocity, ft/s	Velocity from MEB	Exp Velocity / MEB Calc
1 inch pipe nipple	1.055	18 ft @ 11 psig	29	35	0.83
		27 ft @ 18 psig	44	44	1.00
1 inch barb	0.768	26 ft @ 18 psig	43	44	0.98
		37 ft @ 30 psig	61	57	1.07
¾ inch barb	0.602	30 ft @ 20 psig	50	46	1.09
		41 ft @ 36 psig	68	62	1.10
½ inch barb	0.453	36 ft @ 32 psig	59	58	1.02
		43 ft @ 40 psig	71	64	1.11

Testing pump delivery by discharge into a tank

Figures 4a and 4b. Two of the volunteer groups are shown filling a 325 gallon tank, through 27 ft of 1 ½ inch hose (left) where the measured flow rate was 96 gpm, and through 51 ft of 2 inch hose (right) where the delivery rate was found to be 164 gpm. The pump was rated at 200 gpm against a 10 ft head and it was powered by a 5.5 hp Briggs & Stratton engine.

Draining the tank by gravity through a 2-inch valve

Figure 5. Water flowing out of the tank.

The students found experimentally that the initial rate of discharge was about 130 gpm; about 7 minutes were required to "empty" the tank by gravity. Torricelli's theorem, $V_2=\sqrt{(2gh)}$, indicated that the initial flow rate should be about 150 gpm. This scenario was used as a quiz problem in the lecture course and the student success rate was very high among the 27 participants in the field exercises.

Student evaluation of the field activities

Each student was asked to complete a questionnaire following the field activity; the responses were compiled and evaluated and some salient findings are highlighted below.

♦ *80% of the students had not previously operated a pump to transfer water.*

♦ *75% of the participants had seen the Bernoulli equation in engineering physics, but most noted that they had not used it for any "real" purpose. Consequently they saw little or no connection between the equation and pump operation and discharge.*

♦ *70% of the participants noted that they enjoyed the opportunity to learn outside of the classroom; many observed that the experiential nature of the exercise was useful to them.*

♦ *65% of the students reported that the measured water velocities corresponded to their expectations. But 35% admitted that they had no idea what water velocities would be either in the 2 inch hose or through the nozzle (constriction).*

The participating students were favorably impressed with the overall experience. They seemed to enjoy the opportunity to gain a somatic appreciation for the forces and velocities associated with water transfer by pumping. Many cited the value of the exercise as a complement to the lecture course. Students were also asked to provide comments regarding the field activities and samples are included below.

"Wow, that was fun. Low stress, and we just got to learn."

"I really enjoyed the experiment because seeing a topic in the real world augments my enthusiasm."

"I think you should really encourage students to do this. It's really easy to get caught up in the book and calculator part of fluid flow and forget about the actual physical, wet part of it."

"This was a great experiment because it allowed everyone to get hands-on experience."

"Just a small pump can move a lot of water fast! Lawn mowers are almost that size and what they do is not as impressive."

"I enjoyed an afternoon with practical application and not just book work."

"The most interesting thing I learned was the actual complexity of the emptying-tank problem. I had never really considered a horizontal cylindrical tank as it empties and the changing surface area at the top of the water."

"It was a very useful exercise to gain real-world experience and perspective."

"I liked actually seeing the nozzle size and the relation to the velocity escaping the hose."

"I was shocked to learn how much the surface roughness affects the jet distance. The steel pipe felt pretty smooth but its distance was greatly shorter than the PVC."

"I enjoyed getting the practical experience and being able to actually see the types of things that we've been discussing in class. It was interesting to compare the pump's rating against its actual performance."

Assessing the effectiveness of the trial program by examination: ChE 530 final exam question, December 2006

A centrifugal pump with a motor rated at 5.5 hp is used to fill a 325 gallon polyethylene tank. The tank is filled in 3.43 minutes, meaning that the average delivery rate is about 95 gpm. The water temperature was only 39°F, so the viscosity of the water was 1.58 cp. The water was pumped from a pond, through a 1 ½ inch PVC manifold (with valve), and then through about 27 ft of 1 ½ inch hose. There is a change in elevation (+) of about 11 ft. If the pump efficiency is 75%, what power (hp) is actually required?

Four classifications were used to characterize the 37 student responses:

1. *Problem was accurately worked* *49%*
2. *Problem worked with minor numerical error(s)* *27%*
3. *Fundamental conceptual error occurred* *11%*
4. *Major numerical error was undetected* *19%*

The evidence obtained through student success rates (on particular exam and quiz questions) in ChE 530 during the fall of 2006 suggests that progress was achieved through the trial program. We are particularly anxious to reduce the percentage shown immediately above in category 4, and it should be noted that only one of the volunteer participants in the trial program fell into the 19% of students who were unable to recognize a major numerical error. Certainly we feel we have obtained strong anecdotal evidence that the initial field activities were successful in achieving some of the desired results.

Conclusion

The disconnect between contemporary engineering students and the physical world is an increasingly serious problem—and it is not being addressed by the current laboratory experiences provided in our undergraduate curriculum. One of the principal difficulties with the existing fluid-flow experiment is that it is not physically relevant; there is no interface that permits the student to actually experience fluid velocities, pressure, or momentum transport. Furthermore, the results are of indifferent quality and apparatus itself offers little flexibility as to procedure. We have found in recent years that students tend to conduct the experiment mechanically, deriving little benefit from its execution. Their conclusions tend toward the banal, partly because the scale of the experiment is so small that it completely fails to provide a somatic experience that could connect students with forces associated with fluid motion. *Most importantly, this type of experiment involves a 40-year old approach that does not take into account the life experiences of today's students.*

The new field activities described here promote the development of physical reasoning through implementation of large-scale, practical, somatic learning experiences. The importance of this approach cannot be over-emphasized. Many students who select engineering as a course of study do so because they are visual and tactile learners. Yet their opportunity to use these learning styles has been compromised. Weith[12] recently noted that tinkering—seeing with your hands—is crucial to the development of engineering creativity. We would add that "tinkering" on a physically-relevant scale can help reconnect engineering students with the larger world and promote the development of engineering judgment.

In the context of the trial program initiated last fall, there are numerous questions that can be posed for student exploration or "tinkering." These cover a breadth of sophistication so as to be suitable for students throughout the program of study. They include:

- What are achievable discharge rates for this pump?
- What are the discharge velocities?
- Can one person hold the discharge hose?
- Is the pump meeting its rated capacity?
- Can we estimate the pump efficiency? How?

•How many horsepower are actually being used to move the water?
•Is the suction strainer design adversely affecting pump delivery rate? How might the suction strainer design be improved?
•Would it matter if the intake were on the bottom of the pond, or barely below the surface?
•Would it matter if the pump were raised above the dock (say 6 ft)?
•Do calculations from the MEB (mechanical energy balance) correlate with the experimental results?

The results that we obtained from the trial program in 2006 are encouraging. We certainly acquired anecdotal evidence that efforts like the one described here can help with the reconnection of engineering students to the physical world around them. At the same time, we recognize that a single experience—though of value—cannot possibly achieve the stated goal of the exercise. We are working to develop an expanded program of field activities that will reach our underclassmen as well; we envision a sequence of activities for freshmen, sophomores, and juniors to achieve reconnection and exploit (longitudinally) the advantages of contextual learning at physically relevant scales.

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