INTERACTIVE FRESHMAN ELECTROMAGNETISM

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Abstract — *Electromagnetism is the most complete and tested branch of physics. Lacking knowledge of vector calculus and field theory, freshmen are introduced only to snippets of the full picture, and finish the course generally unenthusiastic about the role of electromagnetism in their lives. In response to a need for more interactive learning, we designed an electromagnetism course that incorporated writing-to-learn principles that allowed students to meld in-class theory with real-world practice. Course exercises included writing biographies or describing an electro-magnetic phenomenon or device. Students "published" their drafts and final papers on the open-access web. This exercise necessitated that students understand principles sufficiently to break them down for a general audience and also gave them a sense of ownership and pride knowing that others may read their work. We will discuss how we conducted this course and provide examples of student work resulting from the course.*

Index — *physics, world wide web, writing.*

INTRODUCTION

What motivates aspiring young scientists and engineers is seldom a burning desire to conquer the intricacies of Newton's or Maxwell's equations. In many cases, scientific motivation begins with an adolescent thirst for answers to philosophical questions, long nights under the stars, or a biographical book or movie about a successful role model. A good high school instructor will respond to this thirst and help "turn on" students to science, motivating some to pursue careers in science or engineering (S/E). Lacking sufficient calculus and trigonometry skills, many high school physics students are prepared for only qualitative discussions of the topics that will later be explored in depth during the freshman year of college. Owing to this limited training, the rigorous freshman year experience in physics regrettably comes as a shock to many students majoring in S/E. These intensive college courses seldom nurture these budding inventors and pioneers with qualitative information, biographical antidotes, or philosophical quandaries. There is simply too little class time available, and the fundamentals justifiably take precedence over material that can be obtained from outside reading. But engineering, as Hazelrigg has argued, "is not problem solving. It is decision making" [1]. Engineering students, in other words, need experience with situations that do not offer a clear-cut solution; they need practice communicating and developing judgment skills. Additionally, because they have little exposure to writing in technical fields, students may see themselves as strangers "in strange lands" [2], i.e., outcasts when asked to do writing outside of the English classroom. They may approach college writing assignments with a mistaken monolithic impression of writing, thinking that all writing is essentially the same and that the rhetorical context is of little import. They may also feel that engineers and scientists need only technical proficiency in order to excel in their chosen profession. But students who are technically proficient may nevertheless lack the ability to discuss technical material with a range of audiences [3], and, upon graduation they may discover that communication skills play a larger role in their profession than they had anticipated.

We surmised that teaching freshman with writing in the physics classroom would provide an early beginning that would address many of these pedagogical concerns. It is our opinion that college S/E instructors serve neither their students nor their profession by altogether ignoring non-analytical aspects of the course material. We believe that both students and educators can derive lasting gratification from out-of-class assignments that allow the students to benefit from a qualitative research project. For example, students return home able to describe what they learned to a parent or friend. And just possibly, students begin to dread college physics a little less. Previous research finding that diversified writing assignments improves student learning in physics by allowing students to engage scientific concepts [4] confirms our beliefs. And our own earlier attempts to have students describe "why a magnet sticks to a refrigerator" demonstrated the power of coupling analytical subject matter with writing assignments. Here we describe two assignments given to freshman physics students when both authors were at Worcester Polytechnic Institute (WPI). The assignments coupled the in-class analytical course work (on Electromagnetism) with out-of-class investigations. Most correspondences and instructions were conveyed over the internet, and only one lecture of technical material was sacrificed. This model was also repeated by the authors in courses in Astronomy and Advanced Electromagnetism.

ASSIGNMENT AND DETAILS

Each student was required to select a unique topic to investigate. During one seven-week term the theme was biographical. The students reported on the life and scientific contribution of a pioneer in the field of electromagnetism. The following year another class was asked to explore either an invention or naturally occurring phenomenon related to electricity or magnetism. For a class size of roughly forty-

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five students, it was not difficult avoiding overlapping topics.

The students were encouraged to consult with peer tutors from the Center for Communication Across the Curriculum (CCAC) at WPI. These consultations, a kind of collaborative learning, simulated the kind of writing that 90% of all professionals experience [5]. The collaborative nature of the tutorial conversation encourages non-directive learning, engages the student, and teaches writing strategies that the student may transfer to other learning contexts [6]. The non-threatening nature of the peer consultation may also help to build students' confidence in their ability to write, as opposed to the anxieties that conferences with instructors sometimes produce [6].

To promote a sense of common purpose and to establish a bona fide audience, the work had to be published on the World Wide Web. Effective web writing, as has been argued, requires all of the traditional rhetorical elements, such as "purpose, coherence, supporting details, appeals to logos, ethos, and pathos," but it also necessitates that students consider the additional demands of an electronic environment [7]. In addition to the usual audience concerns, web writers must also be cognizant of their readers' technological capacity, such as browser capabilities [7]. Paragraph length and organization also differ in web documents [7]. Quite possibly, publishing on the web might also serve to make students more critical consumers of web knowledge.

The use of the web helped to develop student awareness of visual rhetoric as well. As they developed their pages, students had to recognize the graphic component of their argument. Rather than conceiving of the pages as written reports with some pictures added in at the last minute, the students began to conceive of their pages as rhetorical wholes. The printed word and the graphical element had to work to complement one another; neither one could be privileged or ignored if the students were going to communicate effectively. To that extent, this exercise helped to amplify students' understanding that visual communication requires the same rhetorical considerations that good writing does, and that it, like writing, contributes to the ethos that a writer creates [8].

Roughly half of the class had prior experience designing a web page. Simple HTML templates were provided for those lacking experience. To be fair to those with less design experience, and to emphasize the importance of compositional elements, the published work was not graded on the use of savvy graphics. The equivalent target length of text was two pages, double-spaced. The project grade constituted ten percent toward the final grade. The remaining ninety percent was earned from exams, home work, and lab reports.

The biographical assignment was motivated by several goals, which were reflected in the assignment. To show that these S/E pioneers had, in many cases, fairly ordinary upbringings and to give them an appreciation for the human element in scientific discovery, the students were asked to write several paragraphs about the personal history of their subject. This portion of the assignment allowed them to practice decision-making about relevance, audience, and context. When faced with a wealth of biographical information, the students had to sift through and make judgments about which biographical elements were relevant to a lay audience with scientific interests. The students were also required to write additional material about a qualitative understanding of the subject's contribution. This portion of the assignment also reinforced the students' understanding of context. While every undergraduate might be able to state that Albert Einstein was a major scientific figure, few of them can explain why he was important in terms that a lay reader can comprehend.

Finally, to promote good scholarship, we discussed the evaluation, selection, and documentation of secondary sources with the students. As many researchers have noted [9], the proliferation of and accessibility of knowledge through the web has made the reproduction and circulation of knowledge an increasingly complex task for students and faculty alike. To a certain extent, the web seems to have a leveling effect; that is, because of the ease of access, all web pages seem to carry the same authority. Teaching students to discriminate among sources is therefore more important than ever.

Teaching students to acknowledge sources, likewise, is equally complex task in the cyber realm. To help develop their skills selecting and documenting borrowed knowledge, we explained to the students that we would be expecting them to use secondary sources and to provide the proper documentation for any material that they used. We also pointed out that over citing was always preferable to under-citing, and we encouraged them to use the CCAC resources in any instances where they were unsure. The actual list of subjects that were self-selected by the students is given in Table I. The list includes scientists and engineers from the 18^{th} century to the present. Most are not well known outside their area of scientific expertise, so this breadth of selection introduced students to new major figures while also developing an increased historical appreciation for the work of the past.

While the pedagogical goals were similar for the assignment on an invention or naturally occurring phenomenon, the reporting requirements differed slightly. Both qualitative and quantitative sections were required, and a graph, simple equations, and a sample calculation were expected. Again a list of references was also required. Table II shows the actual list of writing subjects selected for one term.

Given the constraints of a seven-week term, it was particularly important to encourage the students to get an

TABLE I

ACTUAL LIST OF WRITING SUBJECTS CATEGORIZED AS "BIOGRAPHICAL" FOR PH1121 (B TERM, 1996).

Alvén	Ampere	Aston	Bardeen	Basov	Bell	Biot
Bohr	Brattain	Braun	Carlson	Coulomb	DeForest	Edison
Einstein	Esaki	Faraday	Franklin	Galvani	Gauss	Gilbert
Heaviside	Henry	Hertz	Josephson	Karl Muller	Kirchhoff	Kusch
Lorentz	Marconi	Maxwell	Michelson	Ohm	Onnes	Penzias
Prokhorov	Savart	Shockley	Stark	Tesla	Townes	Volta
von Helmholtz	Weber	Zeeman				

early start on their projects. The CCAC assisted in developing the following schedule of milestones:

- Week 1: Presentation by the Director of the CCAC. Class discusses writing and revision processes and the use of secondary sources.
- Week 2: Students create a minimal web page and select a subject; Professor links the student web sites to the class home page.
- Week 3: Students place draft introductory paragraphs on web pages and begin discussing their work in small groups.
- Week 4: Students encouraged to meet with CCAC peer tutors, who visited class to review drafts. These meetings covered audience, purpose, development and global organization. They also discussed the relationship between the document's textual and visual components. At the end of the tutorials, the tutors and writers devised plans for the next stage in the composing process.
- Week 5: Students place first drafts on web pages; Professor flags students making insufficient progress. Students again encouraged to work with peer tutors who discuss local concerns such as sentence construction and variety, and grammar and usage. The students review the document for its overall design, such as layout and page formatting.
- Week 6: Students prepare final draft, including references, graphics, and web links. The students continue accessing and discussing one another's pages, making suggestions as needed.
- Week 7: Class discusses what they learned from the experience and what they feel they will be able to apply in other contexts. Final drafts due the last day of the term; Professor assigned grades.

CONCLUSIONS

The very good compliance with this schedule might be attributed to the population of advanced and "gifted" students in the course. The extra time required by the professor to attend to administrative details became significant only at the end of the term. In addition to grading final exams and tallying scores from home work, labs, and exams, the professor had to read and evaluate the reports. A five-point grading system based on composition elements (concise introduction, adequate references, logical flow, and human and/or technical story line) was used. Science faculty are at times reluctant to teach with writing for several reasons. Some fears that they need specialized knowledge in grammar or the teaching of composition; others fears that bringing writing into the science classroom will detract from the time devoted to content. At the same time faculty can derive little gratification from teaching only material that is soon forgotten (e.g., the meaning and use of equations, technical definitions, or proper approaches to particular problems). We were determined to provide an assignment with a lasting impact, and something that the students could share with their parents or friends. We believe that through writing, each student was able to develop an integrated

TABLE II

ACTUAL LIST OF WRITING SUBJECTS CATEGORIZED AS "INVENTIONS OR NATURAL PHENOMENA" SELECTED FOR PH1121 (B TERM, 1997).

AC/DC Generators	Amplifier Power Tube	Aurora Borealis
Ball Lightning	Bug Zapper	Conducting Polymers
CRT Displays	Cyclotron	Dynamic RAM
Eddy Currents / Inductive Heating	Electrets	Electromagnetic Properties of Water
Electric Eels	Electric Safety & The Stun Gun	Electrical Cross-Talk
Electron Beams	Electrophoresis	Electrostatic Precipitator
Giant Electromagnets	Health Effects of Power Lines	High Dielectric Materials
The Human Nervous System	Ignition Systems using E&M Fields	Lightning Rod
Mag-Lev Trains	Magnetic Motor Brake	Magnetic Recording / Hard Drives
Magnetic Resonance Imaging	Magnetic Sensors in Living Systems	Magnetic Speakers
Magnetic Traps	Magnetometers	Mass Spectrometer
Millikan Oil Drop Experiment	Mu Materials	Neuromuscular Transmission
Normal Lightning	Pacemaker	Photocopier
Physical Principles of the LCD	Rail Guns	Scanning Electron Microscope
Sound Pick-ups	Spin Stabilized Magnetic Levitation	Stud Finder
Sun Spots	Tesla Coil	Transformers
Van Allen Belts	Van de Graaff Generator	Van der Waals Force
Wimshurst Machine		

understanding of their topic, thus enhancing the ability to recall the material at a later date. Furthermore the act of publishing the work instills a sense of pride and ownership, and a tendency to do well and show it off. Our experiences confirmed what Bean points out in *Engaging Ideas* [10], namely, that because we were teaching with writing, the writing became a tool with which we could actively engage students. Through their need to select secondary material and the act of writing itself, students acquired discernment strategies that improved their ability to make judgments in qualitative contexts. Furthermore, because all of the students were publishing to the same class web site and sharing their contributions, the students gained experience forming their own knowledge communities. Learning was allowed to become dynamic and student-based and less reliant on a single authority figure.

The student feedback about their experience was overwhelmingly positive. Students reported in anonymous course evaluations that they liked an opportunity to receive credit for non-analytical work, that knowing the "whole world" could read their papers made them more responsible about the presentation of their material. (In fact a major chemical supplier linked one of the student's web page to their site, and at least one other student was contacted for more information on their topic.) Additionally, the need to explain scientific concepts to generalist peer writing tutors required that the students have a very clear understanding of the material. We also suspect that the act of writing, which is a constant challenge in the art of decision-making, gave students practice in the "uncertainty" that is an integral component of "all engineering design" [1]. As writers, the students had to exercise judgment and make decisions in a context very different from the dichotomous right or wrong arena of problem solving. In writing, as in engineering design, "there is no right or wrong. We can speak of design only as good or bad" [1]. Finally, the idea that science was again living, that it spoke a language beyond mathematics helped to encourage students to make connections between the symbols on the page and the phenomena they experienced in their daily lives.

While the use of web publishing was decidedly advantageous (e.g., for monitoring student progress, giving the students a tangible audience, and promoting graphic creativity) it is a medium with a relatively short life span. The students' computer accounts are erased upon graduation. As of this writing, only a handful of the reports remain in their original locations (see Table III). But faculty can turn even this seeming shortcoming into a pedagogical advantage because it teaches students the ephemerality of knowledge on the web. What stands as irrefutable truth today may be impossible to find tomorrow. However, because saving a paper copy of a web page does not fully capture the rhetorical effects of the medium, we recommend maintaining a web server that is not under the direct control of the campus computing center. This may preserve the documents after either the students or faculties leave the institution.

ACKNOWLEDGMENT

This work was conducted while the authors were professors at Worcester Polytechnic Institute. Grover Swartzlander received support from the Research Corporation as a Cottrell Scholar and the National Science Foundation as a Young Investigator.

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TABLE III
SAMPLE REPORTS STILL IN EXISTENCE AT THE TIME OF THIS WRITING

Nikolai Basov	http://www.wpi.edu/~speakie/ph1121.html
Jean Baptiste Biot	http://www.wpi.edu/~hymielor/ph1121.html
Joseph Henry	http://www.wpi.edu/~shade/ph1121.html
Neuromuscular Transmission	http://www.wpi.edu/~apollo/ph1121.html
Mass Spectrometer	http://www.wpi.edu/~dcronin/ph1121.html
Electromagnetic Traps	http://www.wpi.edu/~cdiep/ph1121.html
Amplifier Tubes	http://www.wpi.edu/~elwood/ph1121.html
Magnetic Sensors in Living Systems	http://www.wpi.edu/~ppham/ph1121.html
Tesla Coil	http://www.wpi.edu/~joelt/ph1121/diagrams.html