CONNECTING MATHEMATICS AND THE APPLIED SCIENCE OF ENERGY CONSERVATION

R.E. CARBONE
Dept. of Mathematics, Clarion University of Pennsylvania
Clarion, PA 16214

J.M. PEARCE
Dept. of Mechanical and Materials Engineering, Queen's University
Kingston, Ontario K7l 3N6, Canada

Abstract

To effectively teach science in the elementary classroom, pre-service K-8 teachers need a basic understanding of the underlying concepts of physics, which demand a strong foundation in mathematics. Unfortunately, the depth of mathematics understanding of prospective elementary teachers has been a growing and serious concern for several decades. To overcome this challenge, a two-pronged attack was used in this study. First, students in mathematics courses were coupled with physical science courses by linking registration to ensure co-requisites were taken. This alone improved passing rates. Secondly, an energy conservation project was introduced in both classes that intimately tied the theoretical mathematics base knowledge to problems in physical science, energy efficiency, and household economics. These connections made the mathematics highly relevant to the students and improved both their theoretical understanding and their grades. Together, the two approaches of tying mathematics to physical science and applying mathematical skills to solving energy efficiency problems have shown to be extremely effective at improving student performance. This five-year study not only exhibited record improvements in student performance, but also can be easily replicated at other institutions experiencing similar challenges in training pre-service elementary school teachers.

Introduction

To involve pre-service elementary education majors in applying mathematics to the sciences, two professors linked their mathematics and physical science classes. In these linked classes, the students completed a project that was based on energy efficiency retrofits that saved students hundreds of dollars, while also preventing tons of pollution. The results of this project show that the real-life applications of mathematics to physics and energy conservation improved the students' understanding of and the relevance of the mathematics they learned in order to prepare them to effectively teach their future students.

In order for future K-8 teachers to be effective in teaching science in the classroom, pre-service teachers need a basic understanding of the underlying concepts of physics. Unfortunately,

The Journal of Mathematics and Science: Collaborative Explorations Volume 11 (2009) 233 - 243

the depth of mathematics understanding of prospective elementary teachers has been a serious concern in the research of mathematics education for at least three decades [1-12]. The inadequate mathematics preparation for elementary education majors to enter a standard introductory physics course normally results in physics courses designed specifically for them. For students to be successful in these types of physics courses, the pre-service teachers need to perceive physics as an inquiry process in which they and their future students should be actively involved. They also need to realize that simply memorizing information is insufficient for effective teaching [13-15]. Past research has shown that connections of mathematical topics deepen student understanding [12, 16]. In order to build on this previous work, an initiative began at Clarion University of Pennsylvania to create a learning setting that connects mathematics to physics for future elementary teachers. This article reports on that initiative as realized through an innovative educational project on energy efficient compact fluorescent light (CFL) bulbs that spanned both the mathematics and physics classrooms. This project not only showed improvement in student grades, but also resulted in a significant reduction in the environmental impact of the families of the students that participated.

Linking Mathematics and Physics

In order to ensure that students are receiving identical course material across multiple courses, Clarion University has been experimenting with linked classes. In creating linked classes, the same group of elementary education majors who schedule one of the classes must also schedule the other class. This automatic scheduling connection assures that the class rosters of both classes are identical. One of the first experiments was linking a physical science course and a basic mathematics course in 2004. With the same professors, this initiative proved successful in raising student grades with 94% of the students in the linked class obtaining grades of C or better, compared with only 71% of the students in an equivalent, non-linked mathematics class. For this study, this linking was repeated utilizing the Making Connections Program at Clarion University of Pennsylvania. Two classes, *PHSC 112 Basic Physical Science: Physics and Astronomy* and *MATH 211 Fundamental Topics in K-8 Mathematics*, were connected as linked classes. The *MATH 211* class was scheduled on Tuesdays and Thursdays for one hour and 15 minutes, with the *PHSC 112* class immediately following it for the same length of time.

Efficient Light Bulb Project

Previous work has shown that students are more motivated to learn material if they see a connection to their own lives and have some self direction over the project [17, 18]. Thus, the students were assigned to collect data that was relevant to their lives so that they could see the usefulness of the mathematics they were learning in connection to the physics concepts. The project that students were actively engaged in was a cost-benefit analysis for their families that compared standard incandescent lighting with more energy efficient compact fluorescent lights (CFL). The CFL bulbs use one quarter the energy to produce the same amount of light as a standard incandescent light bulb, fit in the average light socket, last longer, and cost less over their life cycle than incandescent bulbs. Thus, a light socket using a CFL produces only 25% of the greenhouse gas emissions as an identical socket using incandescent light bulbs. It is therefore possible to be fiscally responsible while reducing pollution, greenhouse gas emissions, and the concomitant climate destablization as a result of retrofitting incandescent light fixtures with CFL's. However, despite widespread availability and ease of implementation, CFL's have not infiltrated the residential market in large numbers as quickly as economics would suggest was optimal [19]. Ten years after the original Energy Information Association study, most students in the linked classes were unfamiliar with CFL's [19].

Past work showed that advanced university classes can form interdisciplinary alliances on environmental education projects, such as CFL campaigns, and thus effectively address the gap between complex environmental problems in the real world and disciplinary curricula in a university [20]. This project built on this previous work and utilized the same methods and answered CFL frequently asked questions (FAQ) to improve the mathematics and physics understanding of less advanced students [21]. Being that the *MATH 211* course first studied a unit on "Data Analysis" and the *PHSC 112* course began with "Electricity," it was appropriate to begin both courses with the linked project, "Lighting Inventory of a Dwelling—or the Efficient Light Bulb Project." To prove to the students that the hi-tech bulbs were worthwhile and functional, the linked classes had funds from Clarion University's Making Connections Program to donate one bulb to each student in the linked classes. It should be noted that, as the penetration of CFL's increases in the lighting market, an investment in demonstrating the basic technology for the students is not as necessary as for those students who have never had firsthand experience with a CFL.

Data Collection

The first step in the student's cost-benefit analysis for their families' residences was a lighting survey. Students were presented with the chart shown in Figure 1, which they used to gather their data.

Room	Type of Lighting	No. of Fixtures, Wattage	Can it be replaced by a CFL? If "no," why not?	Average Hours/Day Lit
e.g., Living room	Incandescent lamps	4 each 100 W	Yes	6 each

Figure 1. Data collection worksheet.

Students were encouraged to be both precise and accurate by being awarded five points for both linked classes for gathering the data and presenting it correctly in the rubric of the assignment. In order to maintain a control on the experiment, a similar section of *MATH 211* that was not linked to the science class was used; these students took part in the project and also were awarded the same number of points for the assignment.

The students completed another related project for the *MATH 211* class for their Data Analysis unit using the data gathered about lighting from their homes. Students found the average number of watts used per room, and compared the mean, median, and mode of this data set. They also were required to create a stem and leaf plot, and a box and whisker plot of the wattages of each bulb in their house that could be replaced. In addition, they calculated the variance and standard deviation of the wattages. They then found the average (mean, median, and mode) of the watts used for the replacement CFL's and also created a box and whisker plot with that data. Finally, students were required to write at least one sentence in which they discussed the meaning of each of the required calculations and summarize their work by making conclusions that connected their calculations to the "Light Bulb Project."

Cost Benefit Analysis

Next, in *PHSC 112*, students learned about the concepts of electrical energy and electrical power. Using the data they had collected for the mathematics course, the students calculated the average energy that each of the light bulbs used. This was done by multiplying the power of the bulb by the number of hours used per day to establish an energy and then converting the watt-hours/day to watt-hours/year, and then finally kilowatt-hours/year (kw-hrs/year). As electricity is billed by the kw-hr, the students could then convert the energy used in each bulb into dollars. The average electricity cost in the Clarion area at the time this activity was conducted was $0.063

per kw-hr. Since the CFL that provides an equivalent amount of light to an incandescent uses one-fourth of the electricity, the cost of each existing light bulb was multiplied by 0.25 to calculate the cost of using CFL's. The students used the same calculations to compare the cost of 40W, 60W, and 100W light incandescent bulbs with CFL's. By summing the savings from each fixture that could be retrofitted, students were able to obtain a total potential savings on a yearly basis.

In addition, students were exposed to the entire life cycle calculation by determining the number of incandescent light bulbs that would need to be replaced in order to provide light over the much longer lifetimes for the CFL's, and then calculating the total amount of energy consumed by both technologies over the entire lifetime. This can be conveniently presented in a chart format where students can input the total number of fixtures of each wattage. The most common power draw of 100W for incandescent light bulbs is shown in Figure 2 with the life cycle calculation computed for a single fixture. This table is not generalized, so other costs of bulbs, lifetimes, and price of electricity need to be corrected for a given location.

	100W equivalent CFL	**100 W Incandescent**
Number per package (**#**)	1	4
Price per package (**Pt**)	$6.00	$1.37
Price per bulb (**Pt / #**)	$6.00	$0.34
Lifetime (**L**) of the bulb	8,000 hrs	750 hrs
Number of bulbs needed to fill 8,000 hrs of illumination **N** = (8,000 hrs/**L**)	1	10.7
Price of bulbs for 8,000 hrs = **N** * (**Pt**/ **#**)	*$6.00*	*$3.64*
Wattage (**W**)	25	100
kw-hrs used = (**W***8,000hrs)/1000	200 kw-hrs	800 kw-hrs
Cost of 8,000 hrs of illumination at a rate of $0.0615 per kw-hr (This rate is location specific)	$12.30	$49.20
Total cost over 8,000 hrs of light	*$18.30*	*$52.84*

Figure 2. Life cycle calculation computed for a single fixture.

In addition, the cash flow for the energy efficient retrofit can be plotted versus time as seen in Figure 3, which is an example cash flow for a single light fixture that is used eight hours per day over its entire lifetime. The retrofit pays for itself in under six months as can be seen where the line crosses the x-axis. From creating similar graphs for their data, students determined that they would always save the same amount of money over the life cycle, but that the payback time was inversely proportional to the number of hours that the bulb was used per day.

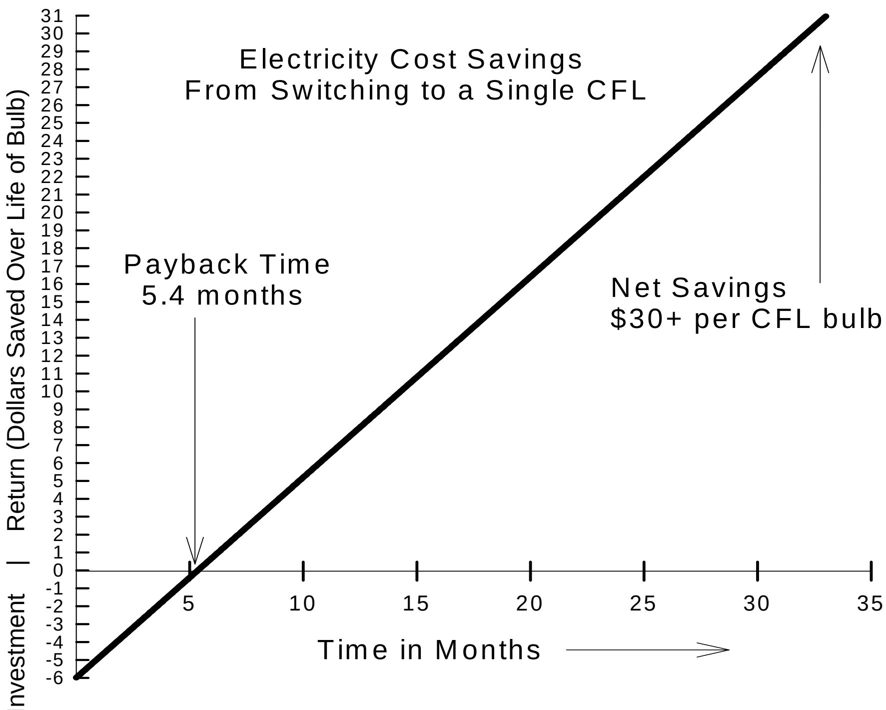

Figure 3. Life cycle electricity cost savings for a single CFL retrofit assuming the light is used for eight hours per day.

Results and Discussion

As a part of service learning, energy efficiency campaigns run in the past while full life cycle calculations were used based on the lifetime of the CFL [20]. These programs, although successful, were limited by cash flow arguments and lacked information on usage. In this study, the actual usage for each fixture was determined from the data collection section of the project.

In the linked class of thirty-one students, the average dwelling used 763 kw-hr/year for incandescent light bulbs, which at local rates would cost $48.14/year. The range was fairly extreme, as one home used 2,474 kw-hrs or more which is more than a factor of three and costing $155.91. As a whole, the families of the class members used 23,681 kw-hrs, costing $1,492.26/year. They calculated that if they collectively switched to CFL's, they would save $1,112.36 and 17,524 kw-hrs/year, respectively. Data was also collected from a non-linked physical science class for control and the results were found to be similar. This energy saving information also lends itself to environmental physics lessons concerning environmental stewardship and the burgeoning field of greenhouse gas mitigation. If this electricity saved from the CFL retrofits in the class was produced by a typical 500 megawatt coal plant, the class has the potential of saving 7.16 tons (14,300 pounds) of coal, 18.5 tons (37,100 pounds) of carbon dioxide, 0.626 tons (1,250 pounds) of ash, and 11,000 gallons of water every year [22]. It should be noted that this is the pollution offset if all of the energy came from the average coal plant, which is a reasonable assumption for the area. Actual emissions vary by the efficiency of the facility and quality of the coal. The larger correction in this figure is that roughly a third of Pennsylvania electricity is supplied by nuclear power plants. Although it is tempting for students to simplify the calculation and reduce the carbon dioxide emissions by 36%, it should be noted that nuclear power is actually responsible for considerable emissions over its life cycle and cannot be treated as an emissions-free source of energy [23]. This type of question enables students to begin to understand the more complex life cycle analysis which is needed to solve modern day energy problems.

At the end of the semester, students completed an anonymous survey in which they evaluated the linking of the two classes. All students responded that they would definitely schedule the link again if it were offered rather than take the courses separately. Responses by the students to the question, "What advice would you give a sophomore elementary education major about whether they should take these same courses linked with the same instructors?" were also overwhelmingly positive:

- "I would tell them that the link was very beneficial to me. Being with the same group of people every day allowed us to get to know each other better. Also, the profs worked great together."
- "I would tell them to do it. It's a more memorable experience and I think I learned more because of it."
- "I learned so much more than I probably would have by taking them separately. It's a great opportunity. Take advantage of it."

Students also responded to the question, "Do you think being in the linked class helped or hurt your understanding of the content and concepts in either *MATH 211* or *PHSC 112*? Why?" The salient themes that emerged from this question are summarized by the following student comments:

- "I think I understood more because we were linking ideas and concepts together and the professors were more willing to help us make the connections and understand."
- "Helped. Conversions esp! [sic] Doing conversions in *PHSC* allowed me to have a better grip on them when they came up in *MATH*."
- "It helped because I saw the connection."
- "It helped because the math part helped with the physics class and vice versa. It helped because there is a lot of math in both classes."

Many students indicated that the hands-on activities made learning more meaningful. Students were asked which concept or content they would remember in a few years and why.

- "The light bulbs, because they are [used] more every day."
- "I will remember the hands-on because actually doing it helps me relate and remember things better outside the classroom."

Not only did the students appear to appreciate both the linking and the energy conservation project subjectively, these two methods also improved their performance in both the mathematics and physical science classrooms. Of the students that passed the class, the grades improved significantly with the linking: 80% of the linked class received A's, while only 32% received A's in the non-linked section. However, both the linked and non-linked *MATH 211* classes completed the CFL project and this appeared to improve pass rates, and overshadow the effect of linking on providing students with enough intellectual growth to average over 60%. Although in the first linked class experiment grades improved, this linking showed no statistical difference in passing rates. For the *MATH 211* classes, 92% of the students in the non-linked course were successful in passing the class with grades of C or above, while only 88% of the students were successful in passing the linked class. For the class sizes observed, this small percentage is within error.

To determine if the CFL project actually improved mathematics knowledge, the next semester the CFL project was removed. The success rate for two *MATH 211* sections decreased to 79% and 64%, respectively, in the following spring semesters with the same professor. The connection to the physical science class and the CFL project was the only difference in the *MATH 211* curriculum; however, the class size increased due to the increased demand for the class. The connections in the linked experience and the CFL project had the highest success rates in the *MATH 211* classes in the past five years.

These improvements observed in student learning and the success rate can be explained by both the motivation that the energy efficiency project brought to the classroom, but also the connection of abstract mathematics to physical realities of everyday decisions. Tying physics and mathematics to money in the energy efficiency project seemed to help solidify many of the course concepts for the students. One very useful method to get student attention is to give a CFL bulb to each student after completing the calculations which shows them that CFL's will save them over an average of $35. As CFL's continue to scale in production, their prices continue to drop as CFL's can now be acquired from many vendors for less than $3/bulb, whereas the bulbs we based this project on were $6/bulb. If this cost is prohibitive for the number of students, CFL giveaways are not necessary, but a class demonstration of CFL's should be considered so that students can see for themselves that the quality of the light (color temperature) is high and the intensity of light is adequate.

Conclusion

This study has shown that the mathematics understanding of prospective elementary teachers can be improved by connecting mathematics education to physical problems. Here, a two-pronged attack was used. First, students in mathematics courses were coupled to physical science courses by linking registration to ensure co-requisites were taken. This alone improved passing rates. Secondly, an energy conservation project was introduced that intimately tied the theoretical mathematics base knowledge to problems in physical science, energy efficiency, and household economics. These connections made the mathematics highly relevant to the students and improved both their theoretical understanding and their grades. Coupled together, these two approaches—tying mathematics to physical science and applying mathematical skills to solving energy efficiency problems—showed to be extremely effective at improving student performance. This five-year study not only showed record improvements in student performance, but also can be easily replicated at other institutions experiencing similar challenges in preparing pre-service elementary teachers.

Acknowledgments

The authors would like to thank the Making Connections Program at Clarion University of Pennsylvania for the funding of demonstration CFL's for student participants. The authors would also like to acknowledge Paul Ashcraft's work on this project.

References

[1] M.M. Wheeler and I. Feghali, "Much Ado about Nothing: Pre-Service Elementary School Teachers' Concept of Zero," *Journal for Research in Mathematics Education*, **14**(3) (1983) 147-155.

[2] A.R. Mevarech, "A Deep Structure Model of Students' Statistical Misconceptions," *Educational Studies in Mathematics*, **14** (1983) 415-429.

[3 A. Graeber, D. Torosh, and R. Glover, "Pre-Service Teachers' Beliefs and Performance on Measurement and Partitite Division Problems," in G. Lappan and R. Even (eds.), *Proceedings of the Eighth Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, Michigan State University, East Lansing, MI, 1986.

[4] A. Graeber, D. Torosh, and R. Glover, "Pre-Service Teachers' Misconceptions in Solving Verbal Problems in Multiplication and Division," *Journal for Research in Mathematics Education,* **14**(3) (1989) 95-102.

[5] D.L. Ball, "Prospective Elementary and Secondary Teachers' Understanding of Division," *Journal for Research in Mathematics Education*, **21** (1990) 132-144.

[6] D.L. Ball, "Crossing Boundaries to Examine Mathematics Entailed in Elementary Teaching," in T. Lam (ed.), *Contemporary Mathematics*, American Mathematical Society, Providence, RI, 1999.

[7] T.R. Post, G. Harel, M.J. Behr, and R. Lesh, "Intermediate Teachers' Knowledge of Rational Number Concepts," in E. Fennema, T.P. Carpenter, and S.J. Lamon (eds.), *Integrating Research on Teaching and Learning Mathematics*, SUNY Press, Albany, NY, 1991.

[8] M.A. Simon, "Prospective Elementary Teachers' Knowledge of Division," *Journal for Research in Mathematics Education,* **24** (1993) 233-254.

[9] H.S. Lee and P. Sztain, "Focusing on Units to Support Prospective Elementary Teachers' Understanding of Division in Fractional Contexts," *School Science & Mathematics*, **108**(1) (2008) 20-27.

[10] L. Ma, *Knowing and Teaching Elementary Mathematics: Teachers' Understanding of Fundamental Mathematics in China and the United States*, Lawrence Erlbaum Associates, Mahwah, NJ, 1999.

[11] *The Mathematical Education of Teachers*, Conference Board of the Mathematical Sciences, The American Mathematical Society, Providence, RI, 2001.

[12] R. Lesh, T. Post, and M. Behr, "Representations and Translations among Representations in Mathematics Learning and Problem Solving," in C. Janvier (ed.), *Problems of Representation in the Teaching and Learning of Mathematics*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1987.

[13] D.B. Harlow and V.K. Otero, "Beyond Concepts: Transfer from Inquiry-Based Physics to Elementary Classrooms," *AIP Conference Proceedings*, **883**(1) (2007) 73-76.

[14] L.C. McDermott, "A Perspective on Teacher Preparation in Physics and Other Sciences: The Need for Special Science Courses for Teachers," *American Journal of Physics*, **58**(8) (1990) 734-742.

[15] L. McDermott and L. DeWalter, "The Need for Special Science Courses for Teachers: Two Perspectives," in J. Minstrell and E. Van Zee (eds.), *Inquiring into Inquiry Learning and Teaching in Science*, American Association for the Advancement of Science, Washington, DC, 2000.

[16] J. Hiebert, D. Wearne, and S. Taber, "Fourth Graders' Gradual Construction of Decimal Fractions during Instruction Using Different Physical Representations," *The Elementary School Journal*, **91** (1991) 321-341.

[17] J. Pearce, "The Use of Self-Directed Learning to Promote Active Citizenship in Science, Technology, and Society Classes," *Bulletin of Science, Technology, and Society*, **21**(4) (2001) 312-321.

[18] J.M. Pearce, "Teaching Physics Using Appropriate Technology Projects," *The Physics Teacher*, **45** (2007)164-167.

[19] *Residential Lighting: Use and Potential Savings*, Office of Energy Markets and End Use, Energy Information Association, US Department of Energy (DOE/EIA-0555(96)/2),Washington, DC, 1996; Internet: http://tonto.eia.doe.gov/FTPROOT/consumption/0555962.pdf.

[20] J. Pearce and C. Russill, "Interdisciplinary Environmental Education: Communicating and Applying Energy Efficiency for Sustainability," *Applied Environmental Education and Communication*, **4**(1) (2005) 65-7.

[21] "Frequently Asked Questions about CFL's," Appropedia; Internet: http://www.appropedia.org/CFL.

[22] "Pollution Saved by Offsetting Coal Fired Plant Production," Union of Concerned Scientists; Internet: http://www.ucsusa.org/clean_energy/fossil_fuels/offmen-how-coal-works.html.

[23] J.M. Pearce, "Thermodynamic Limitations to Nuclear Energy Deployment as a Greenhouse Gas Mitigation Technology," *International Journal of Nuclear Governance, Economy, and Ecology*, **2**(1) (2008) 113-130.