

DIVERSIFYING PHYSICS EDUCATION FOR DIVERSE PHYSICISTS

by Amy C. Rowat

Following the path of scientific curiosity involves intuition and creative problem solving. The way physics has traditionally been taught does not convey the dynamic and imaginative aspects of being a physicist. Early undergraduate students may thus have a limited impression of physics that can discourage them from continuing in the field. In this article, I present practical ideas of how we can change perceptions of physics through education. Specifically, I address the importance of teaching styles and assessment techniques, undergraduate research experiences, and the role of mentors in retaining a more diverse group of students, particularly one that includes more women.

INTRODUCTION

Science is a product of human creativity that can be described as elegant and aesthetic. The average person, however, does not perceive physics in this way, nor did I as an undergraduate physics student. When I entered university, physicists I could recognize included Einstein and Bohr. Physics seemed to me a discipline that had succeeded in describing the physical laws of the universe. I had the impression that physicists worked and solved problems in isolation; that ideas, as they are presented in textbooks, are not to be challenged; that women could *do* physics but rarely become physicists.

Delving deeper into the process of scientific research as a summer student and then as a graduate student, I have come to realize that being a physicist may not necessarily involve wearing a white lab coat and solving problems in isolation. Our medium is distinct from that of brush and canvas, but like artists, physicists seek to describe Nature and its beauty. Physics is a vibrant art. When I explain that scientific research is one of my most creative endeavours, it comes as a surprise to those outside of the field. This is not the general public's only false perception of physics. It also comes as a surprise to many people, including younger physics students, that I do not 'look' like a physicist. I am not middle-aged, nor do I display my collection of pens in my pocket. Clearly I do not fit into society's stereotypical image of a white-lab-coated (male) physicist.

As a first-year undergraduate student, I was privileged to experience life in a lab where I discovered the inventive, intuitive elements of physics. Had I not had this opportunity, I would have instead pursued what I perceived to be more creative subjects during my undergraduate education. My departure from the field would have contributed to sta-

tistics of women leaving physics and becoming increasingly under-represented at higher academic levels^[1,2] (Figure 1). This leaky pipeline phenomenon is well-documented^[3,4,5] and represents a loss of talent for the physics community^[2,6]. This applies not only to women but also to other students whose interest in physics is not captured by the way in which the discipline is presented during the formative years of high school and early undergraduate education^[2,7].

In this article, I present ideas of how physics teaching can illustrate the creative and dynamic nature of physics as well as foster intellectual curiosity, intuition, and critical thinking. I also introduce practical solutions for expanding physics culture to change perceptions of physics and diversify the breadth of physics students and physicists, with a focus on retaining more women.

The way physics has traditionally been taught does not convey the dynamic and imaginative aspects of being a physicist. Early undergraduate students may thus have a limited impression of physics that can discourage them from continuing in the field.

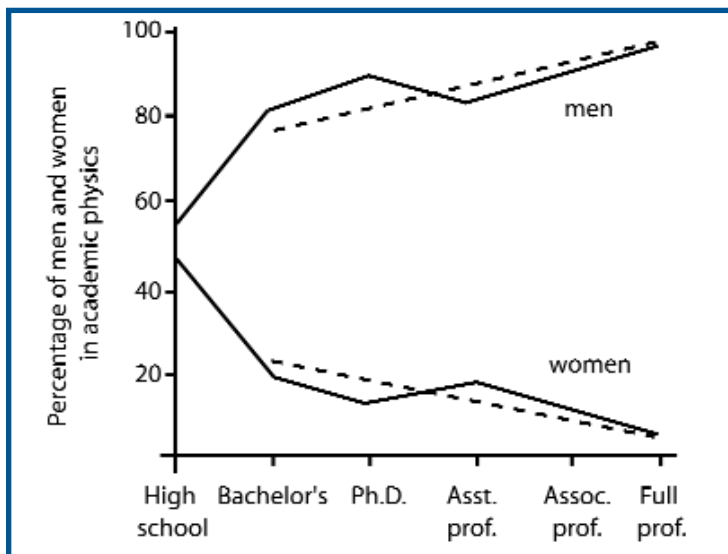


Fig. 1 The leaky pipeline: the proportion of women in academic physics decreases with level of academic position. The solid line denotes statistics from the American Institute of Physics Statistical Research Centre from the late 1990s (adapted from [4]). Canadian statistics from 2001 are represented by the dashed line (from [3]).

Amy C. Rowat <rowat@memphys.sdu.dk>, MEMPHYS - Center for Biomembrane Physics, University of Southern Denmark, Campusvej 55, DK-5230, Odense, Denmark



TOWARDS CREATIVE PHYSICS:**How to better represent the true nature of being a physicist**

The traditional physics classroom is based on a hierarchical structure where the professor lectures to and evaluates students [8,9]. Each course deals with a specific subtopic of physics where professors explain the textbook material. Assignments largely involve plugging numbers into similarly structured problems, essentially 'reproducing' what was presented in the textbook [8]. This routine is intended to equip the physics student with problem solving skills [9]. Students are evaluated in the form of written midterms and final exams. Separate from the classwork, highly choreographed laboratory exercises are designed to teach students how to execute experiments and analyze data [10]. This makes for a decidedly passive classroom experience [7,11]. Students educated in this way may gain a limited and incorrect impression of the nature of physics. The lack of creative experience and intellectual adventure can discourage students from continuing in the field [2,7,12]. I nearly left physics for this reason.

Indeed, poor science teaching has been cited as one of the most common reasons for undergraduates leaving science [2,6]. In addition to providing a strong basic knowledge and understanding of concepts in physics, a physics education should also seek to communicate the artistic, innovative nature of physics and a sense that it is a dynamic field of ideas. Often the advance to more creative levels in physics begins after having mastered an understanding of basic concepts. Higher-level undergraduate physics courses, for example, may involve more imagination and invention. Considering that early undergraduate courses can determine who continues in physics [7,13], early undergraduate physics education should also progress to the level of creative expression. New avenues of physics education are currently providing students with a better understanding of the creative side of physics as well as what being a scientist is like.

Teaching and learning styles

Diverging from the traditional professor-as-authority-who-lectures style, more interactive forms of teaching, such as problem-based and peer-learning methods, are becoming more established in physics education across Canada (see Table 2, Slavin, 2005, *Physics in Canada* (this issue)). The problem-based approach captures the essence of physics' creative and dynamic nature: students are presented with problems which they must solve by applying a variety of methods. This methodology approaches real-life problem solving where lab and course work are integrated together instead of being presented as two separate entities [11,14]. Not only does this highlight how physics is integrated into other fields of science and aspects of life, problem-based learning also encourages interaction and cooperation, important elements that reflect the spirit of science but are often left out of the traditional physics classroom [7]. Some simple ways to simulate problem-based learning in the classroom include:

-PHYSICS IN CONTEXT. The social and historical construction of science is an integral part of understanding the

nature of scientific knowledge [15], so the context and history of physics, as well as biographies of scientists and their work, should be presented in the classroom. Students could also gain a broader perspective of physics by understanding lessons in the context of recent discoveries and contemporary work. Presenting physics in a manner that is rich in interdisciplinary concepts and applications can demonstrate how a knowledge of physics contributes to other fields including medicine, technology, and industry. This is of particular importance for a subject that some deem irrelevant. The connection to everyday experiences, other disciplines, as well as potential job opportunities can enhance student interest in physics education [2,7,8,12].

-INTERPRETATION IN PHYSICS. Providing a list of alternative materials can encourage students to learn from a variety of resources. This could be provided in addition to, or replace, a single textbook and can illustrate the interpretive aspect of physics.

-MORE IS LESS: EMPHASIZE THE CONCEPTS. Instead of racing through one hundred per cent of the material and presenting fifteen different examples, a stronger focus on concepts and slightly fewer examples can leave more opportunities for reflection, questions, and discussion [7].

-TEACHING STUDENTS TO TEACH. Assigning students topics can challenge them to teach a concept to their classmates. As teaching requires one to deepen one's own level of understanding, this can be a valuable pedagogical technique. Other peer-learning methods are described in Williams *et al.*, 2005 (*Physics in Canada*, this issue) [14].

Most of these methods can be implemented with both larger and smaller classes. Evidence shows that alternative teaching methods are more effective for students who do not learn well in a traditional physics classroom [8,11,16], so varying approaches to teaching can help to diversify the type of students that pursue physics [2].

Assessment Techniques

Not only can different teaching and learning methods broaden a physics education, unique methods of evaluation can also convey to students more about how the physics community works. Typically the professor assesses students in the form of written exams and assignments. Since doing physics involves far more than a written test can evaluate, it makes sense to assess the capabilities of physics students using a variety of methods, for example both written and oral exams. Using solely conventional forms of evaluation, abilities and talents that are valued in physicists may otherwise remain latent and underdeveloped in students. Alternative ideas include:

-SCIENTIFIC REFEREE EVALUATION. In addition to the professor's evaluation, 'referee' classmates can evaluate student lab projects and presentations. This method better reflects the reality of the scientific referee process and helps to foster critical thinking and questioning.

-SKILLS FOR SCIENTISTS. *Writing essays* can challenge students to develop scientific writing skills, an indispensable tool of a physicist that is often underrated in more conventional forms of physics education. *Oral presentations* are also an integral component of being a scientist.

-ENCOURAGE STUDENTS TO ASK QUESTIONS.

Evaluation on this basis can help to provide students with the necessary tools of scientific criticism and the ability to question.

All of these activities, both with respect to teaching styles and assessment techniques, aim to develop students' abilities as physicists, not simply as physics students.

Undergraduate research experiences

Undergraduate research experiences can also provide a highly effective way to challenge beliefs that may stem from conventional undergraduate education, namely that physicists work and solve problems in isolation, as well as the perception that physics as presented in textbooks is infallible. The importance of student research experiences in retaining students in physics is well documented^[17,18]. Research can engage students in creative problem solving, and involve them in collaboration and discussion within a team and community of researchers. In many cases, students can also contribute both to asking new questions and defining new directions^[17]. Experiencing the process of exploration and discovery first-hand can demonstrate that physics is a highly creative discipline. Many of these positive aspects of the undergraduate research experience can be recreated in the classroom:

-DESIGNING INDIVIDUAL LAB PROJECTS. This is an important exercise for cultivating intuition and imagination, both important elements of scientific exploration and invention. Independent projects require that students ask questions and invent ways to answer them, as well as design and build instruments and conduct experiments. Individual learning furthermore demands that students consult multiple resources and learn from different perspectives, a critical exercise for understanding the interpretive nature of physics and scientific debate. Communicating the research results in class, at undergraduate physics conferences and/or meetings can demonstrate to students that being a physicist involves interaction with a community that extends beyond both the classroom and the department.

Typically many of these elements are reserved for graduate education. However, integrating a sharper presence of the importance of asking the right questions, testing hypotheses, and analyzing and interpreting results into the undergraduate curriculum could benefit physics education. Instead of reinforcing science as a body of knowledge where theories are often represented as the Truth^[15], a physics education should teach students that results may differ from the information presented in textbooks. Scientific ideas exist to be challenged, to be reformulated, to be built upon. This is the spirit of science.

WHO PHYSICISTS ARE:**Debunking myths of the physicist**

Not only does undergraduate research expose students to the creative nature of physics, it also provides opportunity for scientific interaction between student and professor. Students who interact with faculty have been documented to have a more positive view of science^[2,17,18]. Getting to know my supervisors and professors, largely through undergraduate research projects, made me realize that it is

possible to be a successful physicist and have active interests outside of science. Importantly, one of my summer projects was supervised by a female physicist. I had always believed that women could be physicists but had never before directly interacted with a female physicist. Her example convinced me that women can be physicists. My contact with this professor did not stop when I left her lab. In fact, she continues to provide support and encouragement as I further my career in physics. Student-professor interactions such as this often continue beyond the undergraduate context and have been documented to improve student retention^[2,18]. Especially in the case of retaining women in physics, mentors play a critical role^[12,19]. In fact, an absence of mentoring for women has been cited as an important cause for women to abandon science and math^[19]. Interacting and being able to identify with women in physics has provided support at critical times when I have felt isolated in the physics community; I am not the only one who has felt this way^[4,13]. Such 'mentoring' is important in light of the disproportionate numbers of men who hold higher academic positions^[1].

The hard facts are that women comprise less than 10% of all physics faculty across Canada^[3]. While there is a greater proportion of women at the undergraduate level, the numbers progressively decrease the further one proceeds up the academic ladder: the percentage of women in PhD-granting Canadian physics departments from 1998-2001 included 22% BSc graduates, 15% PhD graduates, and 8% faculty^[3] (Figure 1).

Why there are so few women faculty in physics is an extremely complex issue. Factors on many different levels come into play, from personal intellectual interests, to culture and media^[12]; from peer review and granting agencies^[20], to the structure of the scientific career^[12,19] and the subculture of physics^[4,13,21]. The way in which physics is taught cannot be excluded: indeed some evidence shows that women flourish in teaching environments involving small group discussion and collaborative projects^[8]. This idea may be extended to acknowledge that people learn best in different ways and that some - both men and women - learn less effectively in conventional lecture settings^[16,22]. Diversifying the way in which physics is taught and presented to students can make physics appealing to a broader group of people with varied interests and talents^[2,12].

Changing the way physics is presented to students in the classroom (as discussed above) may influence the variety and composition of physics departments. In addition to diversifying teaching styles and assessment techniques, other simple measures can be taken to deconstruct stereotypes of physicists and encourage more women to continue in the field.

-VISIBLE ROLE MODELS. As I have described, role models - men and women who balance family, friends, and other interests in tandem with an active and fulfilling career - can provide students with positive images of physicists^[1]. With women comprising less than 10% of Canadian physics faculty, there are few women physicists in academia with whom younger women students can identify^[3,6]. The presence of women on faculty can make a difference: there is a strong correlation between the number of women faculty and the number of women graduates who become doctoral

scientists [23]. The support of advisors and teachers is also important for the success of women physicists [1]. Senior students as well as alumni can also provide helpful mentors for younger students [1]. On a more formal level, younger students could be paired with mentors - both men and women - whom they could consult and who are supportive of women in science.

- *A VARIETY OF PHYSICISTS*. Not only should an effort be made to expose physics students to a variety of physicists, both students and faculty of physics departments could benefit from a variety of presenters - senior and junior, men and women - at departmental seminars as well as at workshops and conferences. Attending an undergraduate conference where an energetic and dynamic female physicist was the keynote speaker made a very strong impression upon me as an undergraduate physics student. In fact, I continue to be inspired by women I meet at conferences and workshops who exemplify success in scientific research, teaching, and leadership. Profiles of physicists on exhibit around the department can also help to expose students to who physicists are and what we do.

- *GUEST LECTURERS IN THE CLASSROOM*. In order to counter stereotypes of physicists, a physics education should include exposure to physicists of both genders and a range of levels of experience. This is critical in classes for both first year students and non-physics students, especially for those who will become teachers and communicate their perceptions of physics to younger students [7]. Inviting a female physicist, for example, to give a lecture can be very effective in broadening perspectives and deconstructing stereotypes of physicists.

CONCLUSIONS

In practice, presenting physics in different ways to undergraduate students may seem unrealistic in light of class size, the volume of material, and limited class time. Incorporating elements of physics' creative and dynamic nature into physics education, however, need not involve a revolution but merely a conscious effort of diversifying perceptions of physics in the classroom as well as at the departmental and administrative levels. Furthermore, it is important that good teaching be recognized, appreciated, and rewarded. We can - with relatively little effort - make a difference in the way students and the public perceive both what physics is about and who physicists are.

To summarize, I have presented various ideas of how physics education can be diversified. These include: (i) communicating the imaginative and intuitive side of physics and scientific thought; (ii) focusing on the development of scientific skills in students; (iii) conveying the dynamic, interactive environment of the physics community; and (iv) being aware of how we can change common perceptions of the physicist. In the interest of attracting and retaining diverse students including more women, we should seek to provide students with a stimulating environment where they can gain an understanding of the fundamentals of physics in addition to discovering the joy of curious learning. Such an effort will make our understanding of the world in which we live, and the art of physics, even more rich and colourful.

ACKNOWLEDGEMENTS

The author is grateful to the Natural Sciences and Engineering Research Council (NSERC) of Canada (Targeted Award) and to the National Research Council's (NRC) Women in Engineering and Science (WES) Programme for providing the opportunity to experience life in a research lab as an undergraduate student. Thanks also to Elana Brief, Per Lyngs Hansen, Paul-Jean Letourneau, and Tricia Koenig for critical reading of this manuscript.

REFERENCES

1. B.L. Whitten, S.R. Foster, M.L. Duncombe, "What works for women in undergraduate physics", *Physics Today*, **56**: 46-57 (2003). (<http://www.aip.org/pt/vol-56/iss-9/p46.html>)
2. E. Seymour, N.M. Hewitt, *Talking about leaving: why undergraduates leave the sciences*, Westview Press, 1997.
3. J. McKenna, M. D'Iorio, A.C. McMillan, E.C. Svensson, "Report on the first international conference on women in physics", *Physics in Canada*, **Nov/Dec**: 17-23 (2002).
4. T. Feder, "Women, and some men, ask why women don't flock to physics", *Physics Today*, **55**: 24-25 (2002). (<http://www.physicstoday.org/vol-55/iss-5/p24.html>)
5. ETAN - European Technology Assessment Network on Women in Science, Science policies in the European Union: promoting excellence through mainstreaming gender equality, European Commission Research Directorate-General, 2000.
6. C. Mlot, "Is science talent squandered?", *Science News*, **151**, (1997). (www.sciencenews.org/sn_arc97/5_31_97/bob1.htm)
7. S. Tobias, *They're not dumb, they're different: stalking the second tier*, Research Corporation, 1990.
8. R.M. Felder, "Reaching the second tier: learning and teaching styles in college science education", *J. College Science Teaching*, **23**: 286-290 (1993).
9. T. Kuhn, "The Structure of Scientific Revolutions: Postscript - 1969", in *The Philosophy of Science*, Eds. R. Boyd, P. Gaspar, J.D. Trout, MIT Press, 1991. pp 174-210.
10. S. Traweek, *Beamtimes and lifetimes: the world of high energy physicists*, Harvard University Press, 1988.
11. P.J. Williams, C.S. MacLachy, P.J. Backman, D.S. Retson, "Studio physics at Acadia University", *Physics in Canada*, **Mar/Apr**: 96-101 (1997).
12. A.C. Rowat, *Women in physics: why are there so few?*, Philosophy, Sociology, & Physics Special Topics Thesis, Mount Allison University, 1998. (Reprints available from the author.)
13. B. Hodgson, E. Scanlon, E. Whitelegg, "Barriers and constraints: women physicists' perceptions of career progress", *Phys. Educ.*, **35**: 454-459 (2000).
14. P.J. Williams, P.K. Varma, R.L. Hawkes, "Collaborative modes of undergraduate physics teaching", *Phys. in Can.*, this issue (2005)
15. I. Lanzinger "Toward feminist science teaching", *Canadian Women Studies*, **13**: 95-99 (1993).
16. D.A. Kolb, *Experiential learning*, Prentice Hall, 1984.
17. A.L. Zydney, J.S. Bennett, A. Shahid, K.W. Bauer, "Faculty perspectives regarding the undergraduate research experience in science and engineering", *J. Engineering Education*, **91**: 291-297 (2002).
18. R.S. Hathaway, B.A. Nagda, S.R. Gregerman, "The relationship of undergraduate research participation to graduate and professional education pursuit: an empirical study", *J. College Student Develop.*, **43**: 614-631 (2002).
19. A. Fels, *Necessary dreams: ambition in women's changing lives*, Pantheon Books, 2004. pp122-129.
20. C. Wennerås, A. Wold, "Nepotism and sexism in peer-review", *Nature*, **387**: 341-343 (1997).
21. M.S. Dresselhaus, J.R. Franz, B.C. Clark, "Interventions to increase the participation of women in physics", *Science*, **263**:1392-1393 (1994).
22. P. Wickware, "Along the leaky pipeline", *Nature*, **390**: 202-203 (1997).
23. M.E. Tidball, "Baccalaureate origins of recent natural science doctorates", *J. Higher Education*, **57**: 606-620 (1986).